TRANSACTIONS

OF

The Institution of Engineers and Shipbuilders

IN SCOTLAND.

(INCORPORATED.)

VOLUME XXIII.

TWENTY-THIRD SESSION, 1879-80.

EDITED BY THE SECRETARY

GLASGOW:
PRINTED FOR THE INSTITUTION BY
WILLIAM MUNRO, 80 GORDON STREET.
1880.

OFFICE-BEARERS.

TWENTY-THIRD SESSION, 1879-80.

President.

ROBERT MANSEL.

Vice-Presidents.

ALEXANDER C. KIRK. | JOHN THOMSON.

GEORGE RUSSELL.

Councillors.

J. L. K. JAMIESON.
RALPH MOORE.
JAMES HOWDEN.
JOHN INGLIS, Jun.
D. J. DUNLOP.
JAMES REID.
R. BRUCE BELL, C.E.
JOHN ROBERTSON.
JOHN HENDERSON, Jun.
DAVID ROWAN.

Treasurer.

JAMES M. GALE, C.E., 23 Miller Street.

Secretary and Editor of Transactions.

W. J. MILLAR, C.E., 100 Wellington Street.

Librarian.

JOHN INGLIS, Jun.

Sub-Librarian.

THOMAS NAPIER, Institution Rooms, 207 Bath Street,

CONTENTS.

TWENTY-THIRD SESSION, 1879-80.

PLATES—*continued.*

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

TWENTY-THIRD SESSION—1879-80.

Introductory Address. By Mr ROBERT MANSEL, President.

Read 28th October, 1879.

GENTLEMEN,

About the time of the opening meeting of last session, the community were beginning to form an estimate of the hideous commercial disaster which, in an intensified degree, had fallen on our neighbourhood, and that the failure of the City of Glasgow Bank had brought ruin to several, and, in a direct or indirect way, was certain to bring heavy losses to many more. This, added to the general depression of all trade, the limited demand for labour and consequent distress amongst the working classes, coupled with a long period of weather of unprecedented severity, rendering all agricultural operations precarious and unprofitable; all this would lead us to expect to meet this year under less happy auspices.

It is true, we have had neither war, famine, nor pestilence in our land; through the dark clouds of adversity some gleams of encouragement for the future have latterly been apparent, and I can refer with pleasure to the visit which, according to our invitation, was paid to our city and district by the Institution of Mechanical Engineers. This large and influential body, having its head-quarters in London, but making periodical visits to the chief seats of industry in the provinces has on two previous occasions held its meetings in

Glasgow, and both are memorable to us: the first, from the fact that the large number of our local engineers who attended that meeting formed the nucleus from which our own Institution originated; and the second (some fourteen years ago) from its having been presided over by the late Robert Napier.

The recent meeting, you are aware, took place in the Corporation Halls, kindly granted by the Lord Provost and Town Council of Glasgow, who also co-operated in other ways in the accommodation and entertainment of our guests. Your Council would express their deep sense of their kindness and courtesy, and also of the kind and disinterested way in which many of our prominent members, and even parties outside of our Institution, put themselves to much trouble and expense to do honour to our guests.

At these meetings, under the able presidency of Mr John Robinson, a large number of valuable practical papers were read and discussed, many visits made to the most interesting of our industries, and a social meeting and excursion to Inveraray took place: all of which were carried out in a most efficient and agreeable manner, leaving, it is to be hoped, no source of regret to any one of the participators therein.

But I have now to approach a painful duty, and make brief mention of the many members who, since the opening of last session, have been removed from our ranks by death.

I first notice the loss sustained by the Institution in the death of our late treasurer, Martin R. Costelloe, a gentleman with whom those of us immediately connected with shipbuilding had much to do during his twenty-three years' occupancy, in this district, of the office of tonnage measurement surveyor under the Board of Trade. By all of us he was held in the highest esteem, as a faithful, hard-working official, conducting his duties with great ability and discretion, and in a uniformly courteous and obliging spirit. He was an original member of the Shipbuilders' Association, and our meetings were often enlivened with his large store of general information and calm good sense.

Next, from the list of honorary members, after having graced it but for a too short time, lapses the name of William Froude, a man of world-wide reputation and honours, who for years had disinterestedly devoted his time and talents to unravelling the difficulties in the theory of an important industry; to whom, from his ability and eminence, this department of science had learned to look, and with reasonable expectation of further guidance, for many years to come!

In the death of Charles Randolph, in his 70th year, we have lost our most prominent member; a man of culture and distinguished as a mechanician, "who going forth bearing precious seed," returned in the evening with sheaves for which he had worthily laboured, and with a heart and head to make them useful to future generations through the medium of our old University, to which, his predeceased junior partner in the firm of Randolph, Elder, & Co., had also been a generous friend.

Then, in Robert Curle, of the old firm of Barclay, Curle, & Co., we have lost one of the most able and experienced of our Clyde shipbuilders, and an upright, practical man, always ready to assist with wise action in any good cause. Born in Troon some 68 years ago, and winning his way to management of a shipbuilding yard in that neighbourhood, and afterwards of one in Glasgow, in 1845 he joined the late Robert Barclay in the oldest shipbuilding firm in Glasgow. Mr Curle took an active interest in the formation of the Shipbuilders' Association, of which his partner, the late Robert Barclay, was the first president.

Mr Menzies, principal of the oldest shipbuilding firm in Leith; Mr Morton, senior of the old engineering firm of S. & H. Morton of Leith, well known in connection with slip machinery, and latterly also in iron shipbuilding; these, and Mr William Waddel of Polmont, eminent as a railway contractor, swell our obituary.

Mr John M'Nab also disappears from our list of members. A skilful engineer, after many years' residence and labour in the West Indies, he returned to his native country, ending his days here, not prosperously!

Lastly, from where it has stood some 22 years in the list of members, disappears the name of Alexander Whitelaw. In the meridian of his energy, with the cares of a gigantic business on his shoulders, parliamentary representation of a powerful political party of our city, and administration of a large trust fund for religious purposes, at the age of 54 his useful life has been cut short: the dread shadow which "keeps the keys of all the creeds" beckoning him away!

On the sunny shores of Greece, in long gone days, which the poetic mind is so apt to paint in golden word pictures, but which to the actors in them doubtless presented troubles enough, we may read of the existence of an old custom. When a man had evidently drawn near to the close of a long, useful, and honourable life, his neighbours held high festival, and in token of their esteem presented him with a wreath or crown of *wild olive;* regarding which, the cynical old pagan playwright, with a depth of meaning which would take much thought to fathom, has made this remark—

> "And indeed it ought to have been gold, only, Jupiter was so poor!'

With some kindred feeling, some three years ago, we might have read, how, on the comparatively sunless shores of Greenock, her townsmen had been presenting one of their oldest and most honoured with "his portrait." Surely as wise and graceful an act as lay within their power, for which let the men of Greenock have all honour. And now "the silver cord has been loosed, . . . and the wheel broken at the cistern," and at the ripe age of 88 years, Robert Steele, shipbuilder of Greenock, has gone to his rest. We may well reflect on the changes which have occurred on the shores of his native Clyde during that long and useful life, and on the active and influential part which, in his silent, unobtrusive way, he took in the improvement of his own loved craft; and in which his fine taste, and thorough integrity, by very name—*noblesse oblige*, true as steel—has so much contributed to make Clyde shipbuilding what it is!

Early prominent actors in effecting these changes—John Wood, the brothers Steele, and cousins David and Robert Napier—all passed away, and at ages much beyond the allotted span, and, except the esteem of their countrymen, no fount of honour open to them. Probably it is as well it is so; flunkeyism might have given them strange companions, and unadorned they stood adorned the most. True it is, we find by some accident another native of Greenock, James Watt by name, honoured with the symbols of our local learned association, which professes to acknowledge merit in "laws and languages." The men I speak of may have read Nature's laws in their own fashion; their acts showed this was in a way that pedants might never rival. Admittedly they knew little or no Latin or Greek, and, on the whole, were decidedly averse to talking and talkers, and therefore could not be associated with, or have much sympathy from those eminent men to whom decent composition of sermons seems, very nearly, to be the only road to recognition.

I will lastly mention the death, in his ninety-first year, of another wise and venerable old man—Robert Hart. A man of fine scientific instinct, although his walk in life lay otherwise than in mechanics. By far, I think, he was the oldest living member of our associated friends, the Philosophical Society; and also notable in this link with the past: in early life Mr Hart, and a brother long predeceased, were known to, and esteemed by, our illustrious countryman, James Watt!

On consideration, my address of last year seems to have been very much of the nature of a sermon, having appropriate text, and subject "Mutual Admiration," with illustrations of its effects on its participators, in blinding them as to their real relation to each other, and to the facts of the universe! Decidedly a *lay* sermon; having its origin in certain *cackle* over the relaying of a very old and somewhat addled philosophical nest egg, and capable of being amplified to a greater extent than you would care to listen to.

There are, however, a few points which might have been more fully explained, with inferences and deductions which, to some, may be interesting, if only managed to be made intelligible. Allow me therefore to add some touches to the first sketch, so that you may have some better idea of the points *supposed* to be at issue, their history and present position, so far as I understand the same.

Of living men, the wisest intellect known to me, has somewhere enunciated his belief that Nature does not carry her secret in her face, but veils it resolutely from the vain and the foolish; and quite as emphatically these other truths: "From the wisest thought of a man to the actual truth of a thing as it lies in Nature, there is, one would suppose, a sufficient interval;" "The faithfullest, most glowing word of man is but an imperfect image of the thought, such as it is, that dwells within him; his best word will never but with error convey his thought to other minds: and then, between *his* poor thought and Nature's fact, which is the Thought of the Eternal, there may be supposed to lie some discrepancies, some shortcomings;" "Fail by any sin, or any misfortune, to discover what the truth of the fact is, you are lost so far as the fact goes! You will vainly try to work upon the fact. The fact will not obey you, the fact will silently resist you, and ever with silent invincibility will go on resisting you, till you get to image it truly instead of falsely;" "Needless to vote a false image true: vote it, revote it by overwhelming majorities, by jubilant unanimities, . . . it helps not a whit: the thing is not so, the thing is otherwise than so; and Adam's whole posterity voting daily on it till the world finish will not alter it a jot."

"*Nubem pellente mathesi.*" Clouds are dispelled by mathematics, wrote Dr Halley some two hundred years ago; and the Laureate's faith that "through all ages an increasing purpose runs," so far as mathematical pretensions are concerned, is well exemplified by Dr Spottiswoode's declaration to the British Association: "Conterminous with space and coeval with time is the kingdom of mathematics: within this range her dominion is supreme, otherwise than according to her order nothing can exist, in contradiction to her laws nothing takes place;" and he appealed to the common consent which speaks of the mathematical as the pattern form of reasoning and model of a precise style, also "that we take precision and exactness as the characteristics which distinguish the mathematical phase of a subject."

It seems to me, Newton's simile between such knowledge as *he* had arrived at, and the few shells picked up by a child on the shore of a boundless and unexplored ocean, is in a very minor key indeed as compared with the foregoing trumpet blast. In the long interval mathematical science has undoubtedly made much progress, but in the able and excellent account of its recent achievements given by Dr Spottiswoode, it would seem that these are situated outside of the specified boundaries; and sailing on the opposite tack, in a caustic, but not unkindly vein, might we express some regret that mathematicians did not occupy their "dominions" more solidly before allowing their imaginations to go on filibustering expeditions into the unknown! Conquests, incapable of verification, are certain to lead to loose habits of thought, and some slender wits will assuredly get wandered!

Thus, imaginary algebra, in which we may have time different from present, but neither past nor future; measurements made one way, which reversed, instead of taking us back to the original position, carries us farther away; and speculations in something corresponding to, but having less or more dimensions than the only space we know of, which has its dimensions—length, breadth, and depth—strictly limited to three; all this possesses both novelty and charm, and it is interesting to learn that in space having four dimensions "it would be impossible to tie a knot," and that a closed surface could be turned inside out "without tearing"!

Whether speculations in a knotless universe will assist to unloose the hard knots so plentiful in this of ours, is a question which we will not discuss. Not feeling equal to it we give it up, accept the assurance that it is so quite trustfully; and wonder whether a study of the evolutions of an ironclad in space of four dimensions would enable us to understand and mollify the disagreeable consequences which so frequently accompany their gambols in space of three, seeing these are of a nature to make unlucky participators fervently wish that our universe had been favoured with one dimension less, and that the third one—depth—had been left out!

I fear, however, an "ancient mariner" would indignantly repudiate being schooled by a "fourth dimension" lubber. He would think, No knots! the service had at last got to the place where he had so frequently declared it was fast hastening; the "old man" would step sorrowfully ashore and send in his papers, begging an immediate appointment on the retired list!

Then, again, we have non-Euclidean Geometry! Nemesis, at last, has overtaken that verbose and incomprehensible old sinner! For great geometers are now busy with imagining conditions which would render his deductions all wrong. Hence, he will not be allowed to dictate to them, in their flights of fancy, until he alters the confident tone of his assertions; and, instead of his "therefores" and "wherefores," substitutes, possibly, circumstances permitting, and like evasive phrases. The schoolboy of the future will also have much greater latitude for his reasoning powers. Only, the schoolmaster will require to take care—a proferred absurdity might have its origin either in natural stupidity or supernatural geometry! He will require to judge from the symptoms which of these two has actuated the perpetrator, and prescribe a blister or emollient accordingly. It has also been found out that Euclid has been drawing straight lines without a proper demonstration of his capability of doing so; and his method of drawing two parallel straight lines (not at all satisfactory) has only been retained, provisionally, because no one, hitherto, has succeeded in producing a better!

The decided condemnation bestowed by mathematicians on each other's plans of effecting this important problem, is, however, about to be changed to complete agreement by the happy idea of imagining themselves in a dome or saddle-shaped universe of such a nature that it would be quite impossible to draw parallel straight lines; and an irreverent critic has expressed an aspiration to "goodness" that they might be kept there. Dr Spottiswoode, however, recommends another suggestion, and politely remarks that mathematicians had possibly gone rather far; after such mental triumphs, they should rest on their oars for a time, and, by way of relaxation, lend a helping hand to physics and mechanics.

Of these propositions, the first will meet with general approval, and the second by an equally general affectionate entreaty, not in the least to hurry themselves; and, possibly, on their way back from *wherever they are,* they might call in at Shanghai, since, according to accounts, there seems to be a little matter going wrong in that part of their dominion.

A few weeks ago. you might have read in the *Times* notice of the following "Imperial Edict" addressed to the Governor of Shanghai: "The censorate has memoralised us to the effect that Tung Yu-chi, an expectant subprefect . . . proposes to construct a steam boat to be impelled by steam generated without the use of fire, which shall transplant the one using fire. Its construction is already well nigh completed, and it is calculated that 3000 taels will suffice to finish it. A diagram with illustration of the invention has been presented to the memorialists for their inspection. Should the steamer invented by the officer in question be found capable of quick motion and adapted to practical use, it will of course be proper to adopt it. We, therefore, command Shên Pao Chên to devise means for providing the 3000 taels required to carry the invention to execution. He is further commanded, in conjunction with Li Hung-chang and Ting Jih-chang, to examine the diagram and the illustrations and to give the matter his most careful consideration. . . . . To put it to the test of experiment and to report as to whether it is adapted for practical uses."

This machine, according to the account, consists of a train of wheelwork with "Signs of the Zodiac" implicated in the wheels or diagrams in some mysterious sort of way, subprefect-expectant having evidently muddled himself with mixed mathematics; and, in charity, a hint should be given to the poor man to clear out for America as fast as possible, certainly before that machine comes to be tried. As a rule, Chinese governors are not merciful; and on an irate governor, minus 3000 taels, plus a train of wheelwork without signs of go in them, the "Signs of the Zodiac" with the "sweet influences of the Pleiades" thrown in, would fail to exercise any soothing effect; and our subprefect-expectant's cherished pigtail would be an extremely unsatisfactory form for liquidated damages to assume.

It would not, however, be advisable for our mathematical friends to try and convert this "Heathen Chinee." In all likelihood he has got hold of the views expressed by some of our great authorities in their writings, and it would look rather foolish to get "hoisted by one's own petard."

Suppose he were to argue, "Force expended produces Energy," the thing I want, and your learned men assert, admit, or dare not deny that "Force is a mere name, not a thing," so that expending a mere name and *no* thing produces *the* thing; my machine, by blessing of benign celestial influences of the zodiac, will do the same. Of course the proper answer, and one not well suited to either the mathematicians or the Chinee, would be: Force expended no more produces Energy than cart expended would produce the horse. Force expended never produced anything but the grossest confusion. When Energy is being expended we have the phenomena named Force which, in mathematical language, is the *differential co-efficient* of the Energy, a sort of cart which mathematicians invariably and improperly place before the horse. Our poor Chinee would not likely be treated with this view of the matter, and by positive or tacit deductions from numerous learned treatises would probably proceed, logically, to prove himself right, which "argufying" might result in his loss of passage to America, and ultimately to his loss of pigtail, every hair of which would be at your doors, ye mathematicians; so please waive discussion and try to terrify or coax the poor man to be off at once!

In New York, our Chinee would probably be very much less muddled in mathematical matters than many of our ingenious cousins. With some taels, mechanical proclivities, and "smile childlike and bland" he, commercially speaking, might do very well; and, like his celebrated countryman, "not knowing the game," might even risk an investment in the "Keeley Motor" (a recent American invention) and come out, right side up! This "Keeley Motor" is described as an arrangement of strong metal vessels, with bewildering arrangement of pipes, cocks, guages, &c., which being duly manipulated by the inventor, developes mysterious gases under enormous pressure in its internal economy. Ostensibly a most efficient motor, but, according to later accounts, the gases when analysed, seemed to consist of damp air; surmised to have been surreptitiously introduced under great pressure, and on being allowed to expand into the vessels, the reduced pressure is then fearfully exaggerated by gauges made to show results which are unreliable! Clearly a most mendacious motor, designed to develop dollars from the boundlessly silly, and with its inventor, would be more complete with the adjunct of one of our old-fashioned "Glasgow Keellie Motors" to "run them in" to Sing-Sing or some other of these extensive hydropathic establishments where unprincipled machines get regulated, and where problems in the theory of exchange are wrought out by those who, in an imprudent manner, follow out the system of giving nothing, or as little as they can help, in exchange for all they can get at!

It is in shady transactions of this sort that members of "the force" are found to answer much better than mathematicians, and these latter philosophers might be expected to give some explanation as to how it has come to pass that in the alleged fundamental fact of mechanics, as taught by them, we should have a state of things which only the previous year warranted Professor Tait in stating, as the latest scientific achievement, the knowledge of the fact that the result of all teaching, books and lectures included, was this, "there can be but few persons in this country who have an accurate knowledge of the proper scientific meaning of the little word Force."

Or, again, referring to the recent work on mental science, "Problems of Life and Mind," by the late G. H. Lewes, in the summation, we may say, of the knowledge obtained in a long life of earnest and acute research in mental philosophy; we find this author has begun the section on "Force and Cause" in the following terms:—

"The word Force is a symbol which has many meanings. It varies in different works and often in different passages of the same work. Sometimes it stands for the unknowable whose manifestations are the objective universe; sometimes it is the common measure by which all phenomena are rendered intelligible; sometimes it is an imaginary entity supposed to take up its habitation in substances, passing freely from one to the other; sometimes a peculiar kind of matter, very subtle and endowed with qualities very unlike those of ordinary matter; sometimes it is the simple synonym of cause, sometimes of strength, sometimes of motion; now confounded with, and now distinguished from Energy."

In this quotation we are called upon to contemplate an amount of "precision and exactness," which to some must suggest a prior inquiry as to whether this little word ever had any "proper scientific meaning" and a kindred reflection to that proverbially expressed by the hopeless nature of an attempt to deprive a Highlander of his breeches!

Mathematicians "cloud dispelling" outside the universe and within, leaving the rudiments of their knowledge enveloped in a dense fog; leading lights into port invisible, and only guidance a distracting booh ing of numerous fog horns! Surely a good breeze, even with clouds, were preferable? Dense though these may be, through rifts, pole, and other heavenly bodies occasionally seen, lunar distances approximately estimated, we may form some notion of our latitude and longitude, and, most desirable result, get fog and fog horns considerably abated!

Lewes' work, to which I have referred, contains many gems of thought collected from many sources; but, in effect, he seems to have attempted the hopeless task of glozing over some inherent contradictions; the setting of these gems is consequently ineffective and inaccurate, and might have been much condensed had these fallacies and sundry imitation gems been properly eliminated.

I give, first, the following quoted, very excellent, concise, and modest statement regarding Force: "A mathematician is contented with defining it 'the differential co-efficient of the quantity of movement,' and the formula $F = M \frac{dv}{dt}$ answers all his purposes." In this, a constant mass, its velocity, and the time in which this has been communicated, are represented by the symbols M, v, and t respectively.

It is correctly stated that Dr Young first applied the term Energy to express the quantity of work a body is capable of. Along with this, however, it ought to have been concisely stated that Newton by *actio agentis*, Leibnitz by *vis viva*, and Smeaton by *power*, had long before expressed the very same idea.

Again. We have a statement, "Physicists now, in England at least, refuse to apply the term Force to the phenomena of Energy." This should be amplified by the fact that Newton by implication, in his first statement regarding *actio agentis*, Leibnitz, Smeaton, and a whole host of mechanicians for two hundred years back, have protested against the confusion of Force, as strictly given by the foregoing statement, with the definite existence to which other names besides Energy has been applied.

Again. Lewes states, "Energy is the indwelling capacity of doing work possessed by any agent—1st, in virtue of its position; and 2nd, in virtue of its change of position," which amounts to this: Energy is the capability of doing work possessed by an agent, and which has also been correctly defined as its "power," is equal to the sum of the parts into which, for our convenience, we may suppose it divided.

Then, in terms of Energy, Lewes has quoted this other definition of Force: "The measure of the tendency of Energy to transform itself from the negative condition of position to the positive condition of motion;" another piece of fine writing of the circumlocutory type, which, in precise language exactly parallel to the former definition of Force, is as follows: A mechanician is contented with defining it as the differential co-efficient of Energy, and the formula $F = \frac{\delta E}{\delta s}$ answers all *his* purposes.

We thus have Force defined by the mathematician as the differential co-efficient of the quantity of movement, and by the mechanician as the differential co-efficient of energy.

Both are strictly accurate, and hence, since things equal to the same are equal to one another, then, differential co-efficient of quantity of movement is equal to differential co-efficient of energy; and many deluded persons have, from some such point of view, come to the conclusion: therefore, quantity of movement is equal to energy, equal to power, equal to *vis viva*, or whatever name they applied to the existence underlying both these phenomena. Observe, we have not two things, only different phenomena under which the same thing, the definite underlying existence, is viewed under two aspects. Which of these best; or, do they equally express this underlying existence, the fact of the universe with which we have to deal; and what is the meaning of Force, their common differential co-efficient?

This was the real subject of the war of "the measure of force," which raged so long and so furiously, and only suspended from the exhaustion and death of the combatants, rather than from any definite settlement. There has been a hollow truce, and glozing over difficulties, with the result of utter confusion as to first principles, and a "mathematical phase of subject" without either "precision or exactness."

As in other wars, many of the combatants had very hazy notions as to what they were fighting about, and its historians, in general, biassed, and not over acute; so that it is improperly represented as a mere wrangle arising from misunderstanding terms, and, at bottom, that both parties were equally right.

Consideration of a simple case is better than long verbal statements. Suppose two pairs of equal masses of matter; to the first pair, let velocities of 6 and 12 be communicated respectively; and to the second pair, let each receive the velocity 9. The quantity of movement in the first pair is as 6 plus 12, or 18; and in the second, twice 9, or 18, as before, and obviously equal. Now, compare the Energy or quantity of work which these moving masses could perform before being brought to rest, which is as the squares of their velocities. In thefirst pair this will be as 36 plus 144, and sum 180; and in the second twice 81, or 162, in this case differing 10 per cent. from the greater, obviously very unequal.

Now, mechanical and physical facts demonstrate that the existence underlying the phenomena is not quantitatively equal in each pair of cases, whereas quantity of movement is; therefore, quantity of movement cannot be a true measure of that existence. On the other hand, so far as the mechanical effects are concerned, this existence is quantitatively exactly proportional to the unequal numbers last obtained; and hence, these phenomena, named indifferently power, *vis viva*, or energy, are proportional to, and are now accepted as, the definite quantitative measure of the underlying existence.

Then, in regard to existence, we have this attribute, which ancient piety recognised in the following form: "Whatsoever God doeth, it shall be for ever: nothing can be put to it, nor anything taken from it; . . . that which hath been is now; and that which is to be hath already been."

Across all apparent contradictions, this explicit fact, formulate its origin and cause as we may, which we name conservation, is the attribute which thoughtful men have applied to existence; neither experience nor analogy having established any fact which would lead us to infer that we had witnessed either the creation or annihilation of an existence. The perfectly indestructible nature of that which we name matter is freely admitted; no one pretends to create or annihilate matter, and it is this fact which makes chemistry a possible science. In the same way, from its first and rude conception, the same thing has been contended for in regard to the existence underlying mechanical phenomena; and under the terms, conservation of *vis viva*, conservation of work, conservation of energy, fallacy of any of these delusive schemes proposed as perpetual motions, or machines which would develope power without the exhaustion of some source: in all these, the mechanician has made this attribute the basis of all certainty in his reasoning, without which no science of mechanics would be possible; and, from the mechanician's point of view, you will see the reasons why John Smeaton refused to admit quantity of movement as a true fundamenal standard, and why he asserted, no mechanical effect could be produced except by the expenditure of power.

The theoretical points involved in the mathematical view of the question may be illustrated as follows; and, in regard to the meaning of the term differential co-efficient, we may borrow a rough illustration from that painful subject the income tax.

Her Majesty's Ministers in fact, and her faithful Commons in theory, having committed her Government to certain expenditure, the latter body, as in duty bound, assign to their Sovereign Lady from the profits of her lieges, a sum to meet this expenditure. Those profits are approximately estimated, and a proportion levied from the respective contributories according to a definite rate—say, to fix ideas, one-fortieth. Here the object is gross profits, a large sum of money; next, the proportion of it assigned to Her Majesty, a smaller sum of money, corresponding to the differential of the object; and, lastly, the ratio, one-fortieth, which is not money, but a mere numerical abstraction, and corresponds to a differential co-efficient. Now, take a strict example: we have here a small cube of granite, of which we suppose the length of one edge to be x units. Let us now consider the question of the variation in the number of units of granite in the cube, supposing the length of the edge to be increased by a very small quantity δx. Obviously, when the edge length is x, the quantity is y granite units $= x^3$ granite units.

Now, suppose the cube increased by laying a very thin layer, δx in thickness, of granite, on each of the three cube faces which meet in one corner. Obviously the increase of quantity of granite, δy granite units $= 3x^2 \, \delta x$ granite units; and if we divide these equals by δx granite units, we have

$$\frac{\delta y \text{ granite units}}{\delta x \text{ granite units}} = 3\,x^2.$$

It will be seen, this is only very approximately true if δx has a sensible value, but the smaller δx becomes, the nearer it approaches to truth, and at the limit when no granite is added to the cube, and the added film has consequently no thickness; that is to say, when $\frac{\delta y \text{ granite units}}{\delta x \text{ granite units}} = \frac{0}{0} = 3\,x^2$, the tendent ratio is strictly true, and $\frac{0}{0}$ has the definite value $3\,x^2$, which is the differential co-efficient of our granite cube, in this way shown to be mere abstract extension in the form of three squares of side x, and does not contain a particle of granite, the intrinsic object of consideration. This differential co-efficient is perfectly definite and consistent as to itself, but in regard to the smallest atom of granite has no meaning whatever. We cannot put the sign of equality between the smallest atom of this latter and any multiple whatever of the former; mathematically speaking, it is a quantity of unlike dimension, and no mathematician is true to the principles of his science, who commits, or allows to pass without protest, the prevalent absurdity of equating the differential co-efficient of an existence, to the existence differentiated; which, in their definitions of force, is the usual starting-point of all our treatises on mechanics!

Space and time require no definition—no form of words could convey the meaning of either to a mind where no conception of them existed; phrase-making regarding them is of little use, and we may also say much the same in regard to the conception of a material point. Granting we are conscious of such a point changing its position in space, this change of position, viewed in regard to the time occupied in accomplishing it, gives us the conception of velocity, defined as the ratio of the small space described, to the small time in which it is described; and, strictly speaking, velocity is the differential co-efficient of space to time, or—

$$\frac{\delta s}{\delta t} = v. \qquad (1)$$

Next, matter is put into motion, and the ratio of the conjoint phenomena of the product of mass moved, and velocity generated, to the small time in which this quantity of movement is generated, is the differential co-efficient of this quantity of movement in regard to time, and is also the mathematical mode of stating the value of force, as follows—

$$\frac{\delta\,(mv)}{\delta t} = F. \qquad (2)$$

Hence, when it is asserted that force is the cause and measure of motion, we assert that the differential co-efficient of an existence is the cause and measure of the existence, which is radically and mathematically false! We might as well declare that $3\,x^2$ was the cause and measure of the granite of our little cube!

But, again, according to the *vis viva* school of mechanics, another form of this equation is—

$$\frac{\delta\,\frac{1}{2}\,(mv^2)}{\delta s} = F. \qquad (3)$$

That is to say, force is the differential co-efficient of the *vis viva* in respect to space.

And, again, according to the modern mechanical and physical school, this is written as the differential co-efficient of energy, in regard to space, or—

$$\frac{\delta E}{\delta s} = F. \qquad (4)$$

Professor Tait in a note to his "Recent Advances in Physical Science" remarking on the confusion introduced by ambiguous use of the word Force, justly remarks, "Even a mere want of precision in the use of terms of such fundamental importance is altogether incompatible with the existence of a true scientific method." Let us therefore consider the following quotation regarding Force. "Force is wholly expended in the *action* it produces, and after the force ceases to act, retains by its inertia the direction of motion and the velocity which were given it;" and, again, "The measure of a Force is the quantity of motion which it produces in a unit of time;" also the following from Lewes, "The *force* is that which is said to be expended in the production of energy, hence its definition—'that which generates velocity and is measured by momentum.'" In the two first and last of these statements, force the differential co-efficient of quantity of motion is assumed to be the antecedent and measure of the quantity of motion; in the third, force the differential co-efficient of energy is assumed as the antecedent and measure of energy. Quotations like these are to be found in every treatise on mechanics; as they stand they are radically erroneous, and only by an ellipsis and strained conventional meaning do they express the fact, and having been admitted without protest or explanation, have been the source of all confusion on these subjects.

The true explanation is this: all mechanical effects are due to the *actio agentis*, *vis viva*, power or energy of the agent, in virtue of which it can perform work, and being expended in producing an effect, we have the indefinite phenomenon named force directly and apparently definitely evident to our senses, and hence improperly credited as the antecedent or cause of the effect noted.

Professor Tait indicates this in a slightly different way as follows: —"In every case in which force is said to act, what is really observed, . . . is either a transference, or a tendency to transference of what is called energy from one portion of matter to another . . . and the so-called force in any direction is really the rate of transference of energy per unit of length," or these other, which to many seemed very extraordinary propositions, "that which is termed living force which has absolutely no right to be called force, is something as real as matter itself. . . . Force is a mere name . . . it is not to be regarded as a thing. Force is the rate at which an agent does work per unit of length," all of which are but simple variations of the mathematically stated mechanical principle: Force is the differential co-efficient of energy in regard to space. And, again, that which is differentiated in regard to space in order to get the differential co-efficient, George Green named the potential or power function. Hence the word Power, so commonly in use, and written so slightingly of by mathematicians, has a better origin and a far more correct meaning than many of the terms with which they have confused the simple truth.

Lewes has written as follows:—"The word Power is also open to objection, being already used in mechanics in three different senses, namely, the power of an engine (the rate at which it performs work), the pressure which drives the engine and the 'mechanical powers,' *i.e.*, certain elementary machines."

Many meanings to a word are certainly objectionable, but there are many instances of this without the slightest confusion resulting. and, strictly speaking, neither of the three meanings for power given above are correct.

If the power of an engine be the rate at which it performs work, what is meant here is power of performing work in a given time. Space being taken instead of time, this, according to Professor Tait, is force, and agrees with the second meaning, "the pressure which drives the engine." Neither of these have the slightest connection with John Smeaton's definition of power, and are simply absurd. As to the third: a blockhead or any number of blockheads, naming pieces of matter "powers" is no reason why they should be left in improper possession of a good word: they ought to be taught to call things by their right names. When a missionary finds poor heathens calling stocks and stones gods, does he run to his Greek lexicon and coin a new name for the Deity, leaving God to the heathens? It is also strange how many very able men have managed to confuse themselves and others over a very simple convention in regard to power. In some countries ask a peasant the distance to some adjacent place, he may answer, it is distant a quarter of an hour, meaning of course, at the usual rate of walking, the intervening space will be gone over in quarter of an hour; no mortal is so muddled as to imagine the intervening distance thereby becomes a rate!

Now, question an engineer as to the power of his engine and in effect, he answers that it can develop power equal to so much work in a minute, but this power is no more affected by the rate at which it is developed than the distance of our example is affected by the rate at which it is walked! Power is the capability of doing work and is quite independant of the time of doing it. The conditions of the structure of an animal or machine only allowing it to develop a certain power in a given time, is a quite different question, which is often quite improperly mixed up with the consideration of the power which it developes as an existence, in which time can form no element.

Leaving the mathematical phase of the subject, and turning to the physical, let us consider a simple case. I raise this little granite cube, and in the act, some virtue leaves my arm in the exact ratio in which it is raised vertically through space, and by suitable mechanism when the granite had returned to its original level and left there without velocity the whole of this virtue, call it what you will, could be transferred, say, to fix ideas, to a quantity of water, with the effect of slightly raising its temperature; or, again, the granite cube in descending might move a loop of wire in the vicinity of a permanent magnet and then the effect would be represented in the wire by a current of the mysterious entity which we name electricity, which under known conditions might be made to carry my thought, my act, nay my very speech to the uttermost ends of the earth, or, in the form of light, might radiate immeasurably into space!

This mysterious existence then, power or energy, always associated in our experience with matter, but capable of changing from one portion of it to another, and under some phase exhibiting equivalence, and consequently definite quantitative existence, apart from the associated existence we name matter: by some philosophers has been viewed as only an affection of matter, which one piece of matter can develope in another, and not as an independent existence.

For example, the following quotation: "If the material particles capable of electric condition had never existed there would have been no electricity . . . electricity would never have existed without these particles." On the other hand other estimable and able philosophers seem to try to explain everything by movements seemingly of nothing!—a still more mysterious conception, leaving us, on the whole, with only this certainty, beyond vague assertion: we, individually and collectively, know very little, and that our best attitude is one of anxious expectancy for "more light."

As to the fundamental facts of mechanics, no such dubiety ought to exist: physical science has furnished facts which show the utter untenability of the usual mathematical statements as to force. The late Dr Nichol in his "Cyclopedia" has defined "Power, a term equivalent to *force*, or rather to the origin of force;" the first statement is inconsistent with fact and incorrect, the second is true and must be rigidly maintained. In the whole of this and my former address I have only more fully explained the grounds upon which, some eighteen years ago, I scandalised some of my shipbuilding friends by the statement that no amount of force could be equal to the smallest conceivable iota of power. And to conclude, Power or Energy is the definite antecedent of mechanical effect, and force an indefinite phenomena thereof whose amount is dependent upon circumstances and may have any value; and it seems to me, the science of mechanics ought to be developed from its true definite basis, and not by abstract reasoning founded on a superficial phantom which, however useful and valuable as affording a ready means for the application of mathematical analysis, ought not to be confounded with, and invested with the attributes of the deeper lying existence.

On a New and Perfect Compound Action Piston Packing

By Mr John Turnbull, Jun.

(SEE PLATE I.)

Received and Read, 28th October, 1879.

I desire to bring before your notice to-night a new and perfect compound, or double-action piston packing, but before doing so I would like, with your permission, to glance very briefly at the progress of the piston, so far as its connection with the steam engine is concerned.

The word piston we take directly from the French, who adopted it from the Latin word, *pistillum*, which again was derived from the Greek verb, πτισσω *(ptiso)*, meaning "to pound, or bruise," and it was employed originally in this sense in the word pestle, the well-known instrument for pounding in a mortar.

The first time anything in the form of a piston was used in the mechanical arts was about 120 B.C., when Ctesebes, a mathematician of Alexandria, employed one made of wood, but covered with leather to keep it air and water-tight, in his invention of the force pump. It seems to have remained in this form through many centuries, for in 1650 Otto Guericke, who

> "Bade with quick stroke the sliding piston bear
> The viewless columns of incumbent air,"

used a similar one in connection with his pneumatic air pump. It is impossible to say whether the Marquis of Worcester contemplated the use of a piston in his mysterious enunciation of the application of the force of steam to the useful arts, but it is without doubt that

Savary's successful, although not economical, mode of raising water by the condensation and force of steam alternately was quite independent of the use of a piston.

Savary's patent is dated July, 1698, and although Papin ultimately adopted Savary's principle he must be credited with having been the first who pointed out the principle of raising a piston by steam, which was published in his "Acta Eruditorum," in 1690, and printed in the "Philosophical Transactions" of 1697, a year prior to Savary's patent. As I have already said, however, Papin's whole contrivance was so imperfect that he abandoned his scheme with a piston, for Savary's scheme, which required no piston.

But Newcomen, in 1705, used a piston raised by steam in an open-mouthed cylinder, transmitting its effect to the pump rods through the medium of a working, or walking beam, as it is now called. Newcomen condensed the steam under the piston by the influence of a jacket of cold water surrounding his cylinder, and kept it air and steam-tight by means of hemp packing round its periphery, as well as having a layer of cold water lying on the top of the piston. A defect in this piston, permitting, unexpectedly, the water lying on the top to pass rapidly to the underside, caused such a quick return stroke that Newcomen changed his mode of condensing by introducing the cold condensing water into the inside of the cylinder, instead of surrounding it as formerly. The whole effect has thus been poetically described by Darwin :—

> "He bade with cold streams the quick expansion stop,
> And sunk the immense of vapours to a drop.
> Pressed by the ponderous air the piston falls
> Resistless, sliding through its iron walls.
> Quick moves the balanced beam of giant-birth,
> Wields his large limbs, and nodding shakes the earth."

I will now pass on to Watt, who, in his first patent of 1769, amongst other more important matters, secured the right to use "oils, wax, resinous bodies, fat of animals, quicksilver, and other metals in their fluid state, to render the piston or other parts of the engine air and steam-tight."

In his patent of 1782, wherein he proposes to put a cover on the cylinder and admit the steam on the top of the piston, he refers to a "solid piston accurately fitted into the cylinder, so that it may slide easily up and down, and yet suffer no steam to pass by it." A year previous to this, however, Hornblower, of compound engine fame, embodied in his specification of that engine the "use of a piston so constructed as to admit steam round its periphery and in contact with the sides of the steam vessel, thereby to prevent the external air from passing in between the piston and the sides of the steam vessel." In 1788 Watt used "a piston accurately fitted into the cylinder and surrounded by a packing of hemp rammed hard into a groove round the edge of the piston, and retained therein by a ring or cover which is fitted into the groove over the hemp, and strongly pressed down upon the hemp by screws," or in other words by a junk ring, now so called.

With this historic *resumé* I will now direct your attention to the more immediate cause of this paper—viz., the use of metallic packing for pistons, which was first adopted by Edmund Cartwright in his patent of 1797, wherein it is thus described: "The base of the piston being somewhat less than the bore of the cylinder, and its surface being made as true and smooth as may be, a flat metal ring equally true and smooth is laid upon it, divided into segments (whose ends are also accurately fitted to each other), which ring completely fits the cylinder. Within the ring lies a spring pressing it outwards. The whole is kept from rising off the base by another flat ring, accurately fitted and held down by an adequate pressure, but not so great as to impede the segments from gliding freely upon the base." Herein we have the germ of the major number of metallic piston rings now in use. It is deficient, however, in one very important point, which also applies in a greater or less degree to all others, in not having suitable means for keeping the piston faces, as well as its periphery, steam-tight. This has been attempted in several ways but never very successfully, the general plan being still that adopted by Goodfellow in 1838, of two packing rings having the inside faces bevelled which, being acted upon by the compressed force of an inner spring ring or rings, is supposed to keep the packing rings up to the surfaces as well as against the sides. Rings made upon this principle require a considerable degree of strength and compression on the spring ring so as its various increments of extension may act efficiently on the inner inclined planes of the packing rings, to press them both outwards and apart by the one action. When the spring ring is made of cast-iron it is generally of an eccentric form on plan, to give it power, and is of considerable weight. In 1866 Messrs Buckley & Smith patented a helical or coiled spring ring, which was brought before the members of this Institution by Mr Prior in 1875, having an improved section, and only about one-half the weight of cast-iron. To form the spring ring (although defective by not being one continuous ring) of steel was undoubtedly a step in the right direction; but as it only pressed in an outward direction it still required the packing rings to have inside inclined planes, so as to enable the outward effort of the spring ring to push them apart, and here arose a new difficulty, the pressure against the flat surfaces not being altogether able to prevent the steam passing into the inside of the piston, the tallow and impurities passing into the cylinder with the steam also found their way inside the piston, and gradually filled up the inner core of the spring ring so as to render it inoperative, which, in several cases within my own knowledge, has been the cause of much annoyance.

The form of spring ring which I now desire to bring before your notice is the invention of Mr Lockwood, and designed so as to have two distinct actions, one to press the packing rings outwards against the walls of the cylinder, and the other to press the rings apart against the flat faces, each action being entirely independent of the other; and at the same time should impurities by any means find their way into the inside of the piston there is no receptacle to retain them, and therefore they cannot interfere with the action of the spring ring. This spring ring is entirely original in form and well suited for the purposes in view. In plan it represents a series of contiguous segments of a circle, and in section a single segment of a circle. It is made from round steel wire equal in section all through and in one piece for any diameter of cylinder, thus rendering it equally elastic at all points. The ends are secured together by means of a gun metal double-ended bolt having a solid washer between. This bolt is made long enough at both ends to enable additional washers to be put on at any time after the ordinary tear and wear of the cylinder and packing rings require increased tension on the spring ring. I may also point out that this spring ring, from the nature of it, is only one-seventh part of the weight of the ordinary cast-iron spring ring, and one-third of the weight of the helical coiled steel spring ring for equal diameters.

It at the same time possesses the maximum of strength and elasticity, with the minimum of weight, and ensures the maximum of steam tightness with the minimum of friction.

In the packing rings which I employ I prefer to have a continuous cavity round their outer circumference, not so much to reduce the friction as to form a receptacle to retain the lubrication and moisture from the walls of the cylinder. This is especially suited for those engines having separate exhaust ports, and whose cylinders are horizontal. The inner edge of each packing ring is made parallel for some distance towards the faces, so as to permit the spring ring to enter easily and without any compression, but, by the gradual screwing up of the junk ring, the packing rings are brought closer together and permitted just to touch each other with their inner edges, so as not to press unduly. During the operation of screwing up, the packing rings are gradually distended by the points of the spring ring acting upon an inclined plane until it comes in contact with the projecting flanges, when compression downwards begins. After the junk ring is screwed firmly up, a hoop iron gland may then be applied round the packing rings, to draw them into the diameter of the cylinder, so as to enable them to enter. The section of the packing rings is such as to render them very elastic, and to compensate for their apparent lightness they are cast from a superior mixture of iron principally composed of hematite re-cast. They are thus strong, hard, and tough, and from their small amount of friction on the cylinder cause little wear, at the same time being so elastic that they work with equal efficiency although the cylinder is tapered oval or circular.

I have prepared a short table to show a few of the proportions which I consider most suited to meet the ends in view, and as the rule, which my experience proves to be the best one to employ in determining the depth of packing rings, varies with the square root of the diameter of the cylinder, I will only refer to those diameters whose square root is a prime number so as to avoid fractions.

Diameter of Cylinder.	Depth Occupied by Two Packing Rings.	Width of Face of each Packing Ring.	Width of Gap on each Packing Ring.	Section of Wire to form Spring Ring.
4	$1\frac{3}{8}$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{1}{4}$
9	$2\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{5}{16}$
16	$2\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{11}{32}$
25	$3\frac{1}{2}$	1	$\frac{5}{16}$	$\frac{3}{8}$
36	$4\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{8}$	$\frac{13}{32}$
49	5	$1\frac{1}{4}$	$\frac{7}{16}$	$\frac{7}{16}$
64	$5\frac{5}{8}$	$1\frac{3}{8}$	$\frac{1}{2}$	$\frac{15}{32}$
81	$6\frac{3}{8}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{1}{2}$
100	7	$1\frac{5}{8}$	$\frac{5}{8}$	$\frac{17}{32}$
121	$7\frac{3}{4}$	$1\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$

The gluts or tongue pieces are made the whole width of the face so as they cannot get out by any possible means, and they partake of every movement of the packing rings, being so thoroughly identified with them.

In conclusion, I would say that with this double-action spring ring you have thorough steam tightness at all points with the smallest amount of friction possible, a ring not liable to break or lose its action, one that is simply and easily adjusted, in conjunction with a system of packing rings which are at once strong, elastic, durable, and, I may say, self-lubricating, and a simple and thoroughly efficient tongue piece.

In the after discussion,

Mr HOWDEN said this was a piston of which he had some experience. More than eighteen months ago a gentleman from Sheffield called one day at his office and showed him one 7 or 8 inches diameter. As he had at the time been thinking over the matter of a double-action piston spring, but without being able to satisfy himself, when he examined the model he saw it was the very thing he had been seeking. He gave an order shortly after for two balance pistons, for the P. and O. Co.'s steamer "Indus," which had made two runs to India and China, and the pistons had done exceedingly well. He had since then put them into a cylinder as large as 62 inches diameter, and he had no doubt they had done well there, and he had now ordered others, one being for a cylinder as large as 94 inches diameter. He was of opinion that this arrangement of spring for piston packing was the best yet tried. He believed the packing rings would wear well, owing to the proper double action of the springs. It was also much lighter than other springs described in the paper, which he thought an important feature, especially for large pistons, as some of the other kinds were very heavy in pistons of large diameter. He did not think the exact proportion of depth of much consequence, as this could be varied without injuring the effect of the spring. For marine engines it was possible that it was preferable to have no grooving in the packing rings. Altogether, he thought this was a most admirable piston, and one which would do its work well.

Mr WM. CLAPPERTON said there seemed to be a similarity between this arrangement and that which had been so much in vogue for the last two and a half years made by Messrs Lees, Anderson, & Co. He could not give in entirely to the high eulogiums which Mr Howden had indulged in regarding this piston packing brought under their notice by Mr Turnbull. He would like to know what were the differences between the rings of the two pistons referred to. In all springs for pistons the essential necessity is to keep the packing close to the sides of the cylinder, and in this respect he did not think the arrangement exhibited was superior to the other. Indeed, if the models exhibited conveyed a just representation of this apparatus, he was of opinion that that made by Lees, Anderson, & Co. was the best.

Mr W. R. M. THOMSON thought the cheapness of these springs shown by Mr Turnbull would commend themselves to all. They only undulated in the one direction and their elasticity must be greater than the Buckley spring, on which he thought it was a decided advance.

Mr JAMES REID asked how an advantage was gained by having a junk ring in connection with this spring. Mr Turnbull claimed some good from this spring pressing up and down and outwards, now the junk ring would have no influence on that when screwed down. In locomotives they dispensed with all junk rings, and adopted as light rings as possible. He thought that the same system would be found to act well in marine engines, and save expense in the way of junk rings and other springs. It was known that through time all springs lost their temper by the heat of the steam. Could Mr Turnbull explain the operation of this spring after the junk ring had got screwed tight down and had ceased to act?

Mr TURNBULL, in answer to Mr Howden, said that the second last column in his table pointed out the gap as very little, but this was not claimed as a novelty. Mr Clapperton had said that the tightness of packing was got by pressing against the sides, but it was equally as essential that they should be pushed apart against the faces. Now, Buckley's spring ring was not compressible in this direction, and consequently when the junk ring was screwed down it was only lessened in diameter; the effect aimed at with the double-action spring ring was to keep the others perfectly steam-tight at all points.

Mr CLAPPERTON said that Mr Turnbull was quite right with regard to Goodfellow's piston, but the eccentric spring was made to press up against the junk ring. That was a very successful piston, so far as up to 50 inches was concerned, taking very little trouble to keep it in order.

Mr TURNBULL said Goodfellow's packing ring was certainly the original of all those that had inner inclined faces to enable the outward pressure of the confined spring ring by friction to push them apart, but the double-action spring ring does this without friction. With regard to Mr Clapperton's remark of the similarity between this spring of Lockwood's and Buckley's, it ought to be remembered that this one was only half of a circle in section, and as he had already said in his paper, Mr Lockwood's had a much wider pitch, and therefore here they had only a third of the weight. Mr Reid had said of locomotives' pistons that they did very well, but he was under the impression, although he had no data in proof, that they required very frequent renewing. If so they would not answer well for marine engines making long voyages.

Mr REID said it would be found that the number of miles run, or the number of revolutions made by a locomotive without renewal of its piston rings was quite sufficient to enable a marine engine to cross the Atlantic. He could not say accurately how long these rings lasted, but he believed it was much longer than those in use in marine engines.

Mr HOWDEN said that pistons with springs and rings of this kind, instead of requiring to be renewed after a voyage across the Atlantic, would work many years with very little adjustment. A spring like this could be adjusted whenever it was found desirable. He thought that the age of these Lockwood springs should be a good number of years. He did not know that they had yet been long enough in existence for any to have worn out. Buckley's had been longer in use, and had stood well. With regard to Ramsbottom's springs, they had been often tried in marine practice, but had not done well. They got quite fast in the body of the piston, and then did not keep it steam-tight.

Mr TURNBULL mentioned a case of a 24 inch Corliss engine, the piston of which was fitted with Ramsbottom's rings, and they had got worn down a good deal, when the thin part of one got under the piston and burst the cylinder.

Mr REID thought there was confusion between the Ramsbottom ring and the one now most used in practice. The Ramsbottom ring was a very small ring of wrought-iron, and the one now in use was cast-iron nearly the whole depth of the piston. It is sometimes in one and sometimes in two breadths.

Mr WEIR having had experience of Buckley's springs, and being one of the first to adopt them, would like to make a remark. The one that had been longest in use is in the "Princess Royal," a steamer plying between Glasgow and Liverpool, the piston of which travels 600 feet a minute. These rings were giving every satisfaction. They had only had them out three times to examine and they had never seen anything wrong with them They had found some oil and dirt round them, but that had no effect upon their use. They had also over 100 of these pistons running and never had found in one instance anything wrong, never having had to put in a liner. He believed that if they had failed it was by people lining them up when they didn't require it. One great feature that was only in Buckley's original patent was this—any spring, no matter how made, might break. What was the result? Buckley's ring could only go together the distance between the coils and it could not get out of position. He would be afraid a spring like that of Mr Turnbull's would collapse altogether.

Mr TURNBULL could assure the meeting that of the 150 of these pistons now in use nothing detrimental had ever happened. He maintained that such a thing as Mr Weir dreaded need not be contemplated, as it would not occur.

Mr ANDERSON said that if the tallow got into the space round about the spring it would block up its action. It had been found by trial that such springs would not stand any hard work.

Mr W. R. M. THOMSON showed by a drawing on the black board the difference existing between the springs referred to, which only undulated in one plane, while the simple curving of the undulations segmentally gave the double elastic action.

Mr TURNBULL said that the breaking of any spring would be serious enough, but care was taken to make these strong enough for their work. As already pointed out in the paper, it was impossible for tallow to get into the space round about the springs, and as to such springs being found after trial not to stand any hard work, it was the first time he had ever heard such a thing hinted, let alone asserted, and desired the speaker to give the instances referred to.

The further discussion of the paper was then adjourned till next meeting.

The discussion on this paper was resumed on November 25th, 1879, when

Mr JOHN TURNBULL, Jun., said that since the printed transactions of the last meeting had been placed in his hands, he had gone over the discussion that followed his paper on the double-action piston spring ring, and had jotted down a few further remarks thereon, which he would state, in order that they might provoke a wider discussion, as it was a matter of the greatest interest to every engineer to know which was the most efficient packing. There were two classes of people who left this world better than they found it, viz., those who from study and experience produced a good thing, and those who knew and adopted a good thing when they found it. Mr Howden in criticising his paper explained the impression made upon his mind when he first saw this spring ring. He adopted them, has had them in use for fully eighteen months, and was going on ordering more, and that upon the merits of the ring alone. The Buckley ring, about which so much was said at last meeting, absolutely failed with him. When he appealed to its representatives to get him out of his difficulty they said that tallow did not do with these rings, it clogged them up. Still Mr Clapperton, who had never used any, Mr Weir, who had used many, and Mr Anderson, who was the representative for them, all recommended them and asked engineers to remain perfectly content with the Buckley ring as it was impossible, they said, to produce anything better; but engineering in this country was not carried on upon these principles, and as his experience was all in favour of the Lockwood spring he considered it his

5

duty to bring it before the members of this Institution. Mr Clapperton said "this ring was almost similar to Buckley's." Such, however, was not the case, and the simplest expression he could use to enable them to comprehend the difference of the two would be to compare this ring to a hollow rubber ball, which was light and elastic, and Buckley's to a solid rubber ball, which was heavy and rigid. Mr Weir said that any spring, no matter how made, might break, but he was sure that gentleman knew well that the greater the quality of elasticity the less was the liability to break. This ring, containing the very essence of elasticity, was the least likely of all others to break. Mr Weir further said that he would be afraid such a spring as this would collapse. This is a circumstance that may happen to Buckley's, but cannot possibly with this, as it was provided against in two ways: first, by splitting the packing ring in the form of a diamond point, and secondly, by sinking both piston flanges slightly and boring out the packing rings inside to fit, thus priming, reversing, or any sudden shock could in no way push them inwards. Mr Weir further said that on examining the Buckley rings under his charge he had only found a little oil or dirt round them. This, however, was not the experience of others. The S.S. "City of Agra," after her first run, had her pistons examined, and, much to the dismay of the engineers, the spring rings could not be seen; however, after a careful search they found them safely embedded in a layer of salt and tallow, lying peacefully at rest, evidently under the impression that they had been superannuated! He might also refer to the S.S. "Khios," in which the tongue-piece of one of the Buckley rings had got out, and shortly after the spring ring itself broke, after being only six months in use. Mr Anderson said that if tallow got into the space round about this spring it would block up its action. He had here two of the rings to show them that there was no place for the tallow to settle in should it get inside, but the peculiar and direct action of this ring in constantly keeping the faces steam-tight, prevented the tallow or salt from getting inside. Mr Anderson also said it had been found by trial that such springs would not stand any hard work; and when he asked him to state the instances he said "he (Mr Turnbull) had misunderstood him—that he meant rings of similar construction." His answer to that was, that there were no rings of similar construction, these were entirely novel in their form, which any one could see on comparison. In many cases Buckley's rings had been taken out and these substituted with advantage. As for their not being able to stand hard work, he knew not of a single failure, and their capabilities might be best illustrated when he said that Messrs Wilson, Cammell, & Co., Bessemer Steel Works, Dronfield, had fifteen at work, whereas the Steel Company of Scotland had been obliged to have the whole of their Buckley rings taken out. In conclusion, he might say that Mr Lockwood was present and would be glad to answer any questions in reference to them should his explanations have failed to make plain their superior advantages.

The PRESIDENT said this form of packing spring looked a very simple and efficient contrivance, and although it had not been so long in use as others with which it had been compared, that ought not to be considered a serious objection to it.

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

On the Reaction of the Screw Propeller.

By Mr James Howden.

The adjourned discussion of this paper, which was read on the 29th April, 1879, was resumed on the 25th November, 1879.

Mr Howden, being called upon by the President, said—I would have liked had the subject of the paper been more fully discussed by the members generally. The President has really been the only member who has in the discussion contributed to our general knowledge of the screw propeller. I do not intend to add to what I have already brought before you in my paper; but there are several points arising out of the discussion on which I would like to make a few remarks.

I had occasion in my paper to refer, as you may remember, to the views in regard to slip of one of our most esteemed honorary members, the late Mr Froude. Since my remarks were made, we have learned—I am sure with the deepest regret—of the death of Mr Froude in South Africa, where he had gone on a voyage in the hope of recruiting his health. You have, Mr President, in your opening address last month, referred in fit terms to the loss which science, in all that pertains to naval matters, has sustained by the death of this distinguished man, which will be appreciated by all who know anything of the great discoveries and original investigations made by Mr Froude in connection with the laws which govern the rolling and other motions of ships at sea, fluid resistance, and kindred subjects. At the discussion of this paper in May last, I made a remark on what appeared to me to be a misuse of mathematics, or at any rate a tendency to expect, from their use, what they are not designed to give — viz, the knowledge or verification of facts. It is worthy of notice that the late Mr Froude, while having, as his writings show, a high mathematical culture, did not as a rule work out his greatest discoveries, and add so largely as he did to our knowledge, from a mathematical basis, but rather followed a strictly inductive method of investigation, by first submitting the various phenomena which led up to his conclusions to the actual test of experiment. The conclusions which Mr Froude formed, however, in regard to slip, as given in his paper "On the Elementary Relation between Pitch, Slip, and Propulsive Efficiency," to which I took exception, were not arrived at in his usual way, and verified by experiment. In this case, as he informs us in that paper, his deductions were based on a law of resistance to the advance of a screw blade, rigorously determined by an eminent mathematician of the day, on stream line principles. The deduction which Mr Froude formed from the mathematical formula thus determined was: "Instead of its being correct to regard a large amount of slip as a proof of waste of power, the opposite conclusion is the true one. To assert that a screw works with unusually little slip, is to give a proof that it is working with a large waste of power." Experience shows this conclusion to be incorrect, and I think theoretical considerations also lead us to the same point. This law, therefore, leading to erroneous conclusions, however rigorously it may have been determined mathematically, justifies the remark I made at the discussion of last session, that conclusions may be arrived at quite correct mathematically, but quite wrong in point of fact. I believe that had Mr Froude investigated the subject in his usual method, he would have come to a conclusion very nearly the opposite of that to which he was guided by this mathematical formula. I would look, therefore, for further advances to our knowledge, both theoretical and practical, in matters of this kind, not to any merely mathematical origin, but to patient study and elucidation of facts, combined with correct application of natural laws.

I would be wanting in courtesy to my friend Mr Inglis if I did not, at some length, notice his remarks at the discussions of my paper last session, for though Mr Inglis did not attempt to add to our knowledge of the action of the screw propeller, he was evidently desirous to keep me right in any statements I advanced. With every desire to profit by Mr Inglis' corrections, I must confess I have been unable to do so, for in the many and grievous errors he supposed he had discovered in my paper—I speak now of my first paper—I fail to find he has in any one case justified his contention. The explanation, it appears to me, is not difficult to find, for his remarks bear evidence that he has not sufficiently acquainted himself with the points on which he undertook to correct and instruct me, either in my own paper or in that of Dr Rankine's, to which I had called attention. I have not been able to discover any special reason for Mr Inglis' vigorous criticism on my paper, not being conscious of its containing any "red rag" provocative of attack. My impression is, that on reading so much as to find that I differed fundamentally from Dr Rankine, Mr Inglis concluded I must necessarily be wrong, and falling on some apparently, to him, dubious statements, the exact meaning of which he did not take time to understand, he thereupon resolved to correct me.

Referring now more particularly to Mr Inglis' remarks at the discussion of this paper in May last, as these are now printed and in my hands, I would like to add somewhat to what I then said in reply, as it is impossible for one to reply fully on the spot in subjects of this kind, more especially if some parts have been imperfectly heard, and the memory fails to retain a good deal of what has been said.

I must confess to being somewhat disappointed generally at the character of Mr Inglis' remarks at this discussion. He had announced in forcible terms the discovery of remarkable errors in my first paper, and in regard to my objections to Dr Rankine's theory, his desire and intention was, as he says, "to show that if Dr Rankine's theory failed, it did not fail for the reasons I had brought forward." Being thus deliberately challenged, I submitted this present paper in order to give fuller and more definite proof that the reasons I had given in my former paper for objecting to Dr Rankine's theory were correct, and that Mr Inglis had been mistaken in his imputations of error on my part. Under these circumstances, it will be conceded that Mr Inglis is in honour bound either to give a definite proof of error in the statements I have adduced, or to acknowledge his own mistake. I regret to say Mr Inglis does neither. He does not controvert one of my statements, nor does he acknowledge himself to have been in error; but, on the contrary, he leaves it to be inferred that he is still in the right, and with, I must say, considerable ingenuity, by several general phrases and observations of no direct bearing on the subject at issue, gives the impression of very superior knowledge of the subject on his part, and of the opposite on mine. But, as I have said, I am not satisfied with this style of criticism, and I must regard Mr Inglis' remarks as unsatisfactory until he has either given definite proof of the errors he ascribes to my paper, or acknowledges that he himself has been in error.

Regarding the late Mr Froude's statement as to the relation between the thrust of the propeller and the augmentation of resistance to the vessel's progress from the action of the propeller, which Mr Inglis has given—viz., "that the augmentation is zero when the thrust is zero, and is as near as may be in direct proportion to the thrust"—I have already given reasons for supposing that this augmentation is not wholly due to the thrust, but to the thrust or slip, and displacement combined; and that in a well-proportioned screw in ordinary circumstances, the latter may be the greater factor of the two. With the greatest deference to the opinion of Mr Froude as here expressed, I would venture to submit a further reason for supposing that this augment to the resistance cannot be wholly due to the thrust. Mr Froude refers to this augmentation as caused by the volume of water sent astern by the thrust of the propeller, therefore we must conclude that with the greater thrust the greater amount of water must be sent astern if the augment from this cause is in direct proportion to the thrust, We find, however, that the volume and velocity of the water sent astern does not necessarily bear any direct proportion to the thrust. By using a propeller of different proportions or shape, we may make a much greater slip without increasing the thrust, and with the same propeller, a head wind, or other causes, may increase the slip from say 5, to 30 per cent. In the latter case, with the engines working at less power, we would have nearly six times the volume of water sent astern at a greater velocity, without the thrust being appreciably increased, if increased at all. We can scarcely imagine, therefore, that this greatly increased displacement of the water under the stern of the vessel would have no influence on the augment of resistance if it is caused, as Mr Froude believed, by the volume of water sent astern by the propeller. On the contrary, I humbly think we have good reason to believe that the augment in question is in some ratio proportional to the quantity and velocity of the water displaced under the stern of the vessel by the propeller—which, as I say, does not bear any direct proportion to the thrust—whether caused by the slip, or displacement by the body of the propeller.

The whole of Mr Inglis' remarks on my present paper are contained in three short paragraphs, which, as you may not remember them, I will read. They are as follows:—"Coming now to Mr Howden's new paper, I find an important error on page 184. The words 'momentum' and 'thrust force' are there used as if synonymous, and in the equations (1) and (2), momentum is set down as equivalent to a certain thrust. I believe it is generally understood that momentum is equivalent to the product of the force producing it and the time during which that force acts. The time being unity in equation (1), the value of the thrust is unaltered by a proper stating of the equation, but in equation (2) the thrust would be ten times greater than Mr Howden makes it, because the momentum is produced in one-tenth of a second. The two thrusts then bear the same relation to each other as the two energies in the succeeding two equations, and the argument founded on the supposed difference fails."

I have here to call attention to the fact that the examples I gave in my paper of the different amounts of energy which would be expended in producing the slip motions in each of the two ways which could be supposed possible by Dr Rankine's theory,—though important enough in itself, had no proper connection with the question at issue in the paper, and could have been left out without in any way affecting the general argument. Dr Rankine in his paper makes no reference to the energy expended in making slip. Mr Inglis is, therefore, too hasty in concluding, even if I had made the "important error" he supposes, that my argument is at all affected. The fact is that if the "thrusts" in the examples given actually varied in the same ratio as the "energies," as Mr Inglis says they do, my argument against Dr Rankine's theory would be ten times stronger than my calculations make it.

It may, however, be useful to examine the points as brought forward by Mr Inglis more fully so as to ascertain what are the facts and who is actually in error. Mr Inglis objects to my using the words "momentum" and "thrust force" as synonymous. I intended that they should be so understood in the cases referred to—the velocities being measured by the standard unit of one second—and gave the usual expression for momentum as measured by the standard of gravity, $\frac{Wv}{g}$, otherwise written Mv where $M = \frac{W}{g}$. Mr Inglis says further that he believed "it is generally understood that momentum is equivalent to the product of the force producing it and the time during which that force acts." So far, I think, from this being the generally understood definition of momentum, it is one probably held only by Mr Inglis himself. It is at least obviously incorrect as a definition of either momentum or energy. The product of force into time is not a measurable or definite quantity. We cannot equate, for example, 100 lbs. × 1 second, or 1 hour. Granting that some motion of the 100 lbs. is supposed, in Mr Inglis' definition, this motion may be either great or small in the given period, consequently the definition would express, as I have said, no definite quantity. Time in these calculations is not a direct factor at all, its function being simply to measure the *velocity* of the mass or the space passed through in a given period.

It is, indeed, difficult to discover what Mr Inglis means to express as the conclusion at which he arrives at the end of the paragraph does not follow from the definition given.

It is probable Mr Inglis intends to give here a definition of energy, or what is now called kinetic energy, which is different from momentum, and is expressed by the symbol given in my paper $\frac{Wv^2}{2g}$ otherwise $\frac{Mv^2}{2}$, where $M = \frac{W}{g}$, as in the symbol expressing momentum, and $\frac{v^2}{2g}$ represents the height through which a body would fall in space by the action of gravity, to acquire the velocity v. Momentum is in the cases referred to simply equal to the units of force which produce the given velocities in the bodies which are free to move in space. It thus becomes equivalent to thrust, and it varies directly as the mass and velocity. Energy in the same case is equivalent to the foot pounds of work imparted by the units of force in moving the masses at the given velocities through a given space. It is otherwise = force × space and instead of varying like momentum as the mass and velocity, it varies as the mass and square of the velocity. The cases I have given in my paper are therefore quite correctly worked out, and I am, besides, strictly following Dr Rankine's own formula in regard to finding the thrust, so that in equation (2) of my paper the thrust is exactly as Dr Rankine would make it, and not ten times greater as Mr Inglis says it should be. I am sure, if Mr Inglis would study this subject further, he would discover this and find how far astray in regard to it he is at present himself.

I may mention also that the elucidation of this very point, which Mr Inglis terms an "important error," formed the substance of a paper on the "Propulsion of Vessels," read by our Secretary, Mr Millar, at the Glasgow meeting of the Institution of Naval Architects in 1877.

Mr Millar, in that paper founding on Dr Rankine's rule for calculating the thrust, shows that for the same quantity of water sent astern the thrust varies as the velocity, and the energy expended as the square of the velocity, and I am indebted to that paper for directing my attention to the differences which there might be in the expenditure of energy in obtaining equal thrusts. I may take this opportunity also of mentioning that, knowing Mr Millar's intimate acquaintance with Dr Rankine's works, I have taken advantage of this to make sure I have not misunderstood Dr Rankine's meaning in regard to the subjects on which I have called his views in question in these papers on the screw propeller.

I trust I have made it evident that the "important error," which my friend, Mr Inglis, has here so confidently announced, is one of the same category as the "curious and extraordinary misconceptions" he discovered in my paper of 1878, and which, apparently, have been the product of a too eager disposition on the part of Mr Inglis to put me right and a considerable lack of knowledge of the subject on which he undertook to correct me. I believe, however, that the result of this prolonged discussion—chiefly due to Mr Inglis—will be very beneficial, by directing attention to important matters which otherwise might have been lost sight of.

Before leaving the subject I would call your attention here more particularly to a conclusion which, I think, must necessarily follow if I have in these papers given a correct explanation of the action of the screw propeller. Not only have I called in question the quantity of water assumed to be acted on by Dr Rankine and others, and the extent of motion given to it in any case with an ascertained diameter, pitch, and slip of propeller, but I think I have made evident that the principle on which they calculate the thrust reaction is incompetent to meet the conditions involved.

Over and above the fact which I have shown that the motion given to the water by the propeller is uniform and not accelerated. I have also to point out that the measure or standard of gravity is inapplicable for finding the thrust from the momentum of the water in motion. In the formula $\frac{Wv}{g}$ the factor W, or weight of water acted on, cannot be ascertained, and g=32·2 feet or the velocity imparted by the force of gravity in one second to a body free to fall in space, could not measure the effect of a force giving motion to a portion of fluid among other portions not previously in motion. If we suppose the screw to work in a denser or less fluid medium than water, say grease in a semi-fluid state, we could not tell, except from actual experiment, what velocity of motion would be given to a certain section in a mass of indefinite extent of the grease, by the impact of an ascertained force upon that section. Water also, though exceedingly mobile, if sufficient time is given to allow the action of any force to set up motion in its particles, resists motion almost like fixed solid matter, if struck quickly by a flat body and the force as quickly removed. This, as I have endeavoured to show in my first paper, is very like the action of the screw blades on the water when propelling in ordinary circumstances.

I hold, therefore, that the theory of Dr Rankine is not only erroneous in its basis, but that the principle on which he calculated the thrust reaction is inapplicable. The reaction or thrust of a propeller, in any actual case, can be ascertained within the vessel itself; also, the power being expended in driving the propeller. Of this gross power it has been shown that a large proportion is expended in producing various other effects than that of giving thrust or propelling the vessel. The different elements of loss, and their several amounts, I believe can be ascertained by experiment.

The PRESIDENT said, there has been some discussion of abstract matters about which an unfortunate amount of confusion prevails and it may be useful to consider some experimental facts which tend to throw some light upon the subject of Mr Howden's more practical considerations on the displacing action of the screw blade, and the real valuation of slip.

In *The Engineer* of 29th August last, you may have noticed an article and sheet of diagrams exhibiting the results of an admirable series of experiments on the effect of propeller alterations, as influencing the speed of one of the remarkable little vessels designed and built by Messrs F. Yarrow & Co. of London, for the purposes of torpedo warfare.

In these vessels, only 86 feet long, 11 feet beam, about 3 feet mean draft and corresponding displacement of 27 tons, a maximum of about 550 indicated horse power has been developed; circumstances from which we might reasonably expect a high rate of speed to be obtained, and, from the evident care and ability with which the experiments have been carried out, most valuable information as to the effect of propeller variations. Unfortunately, data necessary for an approximately complete discussion of the experiments (notably the revolutions of the propeller) were not published; which, however, through the kind offices of the editor, Messrs Yarrow & Co. willingly offered to supply, had I been able to avail myself of their courtesy. Meanwhile, in *Engineering* of 17th October, there has been published the actual diagrams and fuller particulars of one complete set of ten experiments with the same screw; which serves to illustrate some interesting points discussed in a letter to that journal (published in the issue of 28th November), and we may briefly consider some deductions from both sources of information.

In Fig. 1 (see Plate II.), accompanying these remarks, is laid down, similar to the published diagrams referred to, a set of squares, each of which taken horizontally, represents one nautical mile of speed, and vertically 50 indicated horse-power. Then, as a standard of comparison, is drawn, a full curve line which represents the powers at different speeds, supposing they followed the law that the power varied as one twentieth of the cube of the speed. Or, again, since the displacement is 27 tons; we may take this curve as representing the well-known displacement formula, $E = \frac{D^{\frac{2}{3}}V^3}{180}$, in which the coefficient 180 being found satisfied, would be accepted as a very excellent result with such a small vessel for the particular speeds at which it held good.

Next, there has been transferred to this diagram, the values given in *The Engineer* for the screws No. 1 A and B, and also those for No. 8. It will be seen the result for No. 1 A, and for No. 8, are very much inferior to the assumed standard, while No. 1 B (which differs from No. 1 A in having thinner propeller blades) is better than the standard by about 20 horse for the consecutive speeds between the first and fifth; in the sixth or highest it is only a little inferior. The lower speeds would indicate a displacement co-efficient of 200 very nearly, and the highest, one of 177, while all the other experiments similarly treated would give co-efficients ranging between 131 and 202, which to some extent serve to fix ideas, but must not be considered as absolute measures of comparative efficiency Immediately under these curves is represented the comparative value of the logarithm of the ratio $\frac{E}{V}$, drawn as an ordinate to the corresponding speed. It has been shown that progressive trials, made under similar circumstances, ought to give these values ranging in a straight line. This is seen to be very approximately true for the values of No. 1 B, is only approximately true with the high speeds of No. 8, while No. 1 A at 14 knots, starting with the same power as required for the thin bladed screw, gives points in a curve, which, if the experiments be even approximately correct, would join the straight line of the No. 1 B experiments at a speed of, about, 21 knots. So that from the obvious inference of this curve line cutting a straight line, we have the curious result: under 14 knots the thick bladed propeller would seem to be the best, between 14 and 21 knots the thin bladed is much the best, and above this, supposing higher speeds could be carried out, the thick bladed screw would again be the most efficient! Again, about 12 knots No. 8 screw seems to be about the same in efficiency as No. 1 B, and at 18 knots equal in inefficiency to the thick bladed screw No. 1 A!

Next, proceeding to Fig. 2, where is laid down in a similar way the data published in *Engineering*, we have definite and equally remarkable results. First, an example of the dual character of the phenomena of screw propulsion which I have several times adverted to, it will be seen that one-half of the experiments lie in one well-defined curve, while the other half are situated in another, with a well-marked discontinuity between the two! Referring to my letter in *Engineering* of 28th November, you will see reasons for my opinion that the power for the highest speed has been understated by about 15 horse, and that the true position of this observation spot is on the same curve as the preceding four.

The first speed power also falls beneath the lower curve, but in all the various sets of experiments, besides the two noted, there is concurrent testimony as to the existence of a third definite relation at lower speeds, which would be distinguished by a negative value of the exponential constant in the revolution formula, and a definite change in the same direction as formerly of the constants in the power formula. In the letter referred to I have given the formula for the curves and corresponding straight lines drawn at the bottom of the sheet as noted upon them. The explanation of these changes seems to be an alteration in the manner in which the sternward flow of the displaced water is affected by the action of the propeller upon it, and upon the following current, this latter being principally due to the surface friction of the hull. It is probable, careful observation would show these variations of the constants in the laws of the power and revolutions are accompanied by simultaneous differences of trim, configuration of the displaced water, and its movements. At all events, these experiments, those upon the "Iris," and others which might be adduced, lead to a more hopeful view of the possibility of attaining high speeds in marine practice, and ultimately to truer views on the nature of its accompanying phenomena. That a thick-bladed propeller, as in the case of No. 1 A, and a badly proportioned, one like No. 8, will produce irregular action and inferior propelling effects, is a fact forced upon us in ordinary practice. Only, when they occur, they are generally altered as fast, and as little said about them, as possible. It, also, seems to me an altogether mistaken notion, that every screw produces a very large and permanent increase of the ship's resistance! No experiment with a model, ever so carefully conducted, could establish this. it might be true for the model and not hold good for a slightly enlarged copy and other speeds. Also, we have only to look at the sudden and definite increase of the ratio $\frac{N}{V}$ exhibited by the lines at the bottom of Fig. 2, to see how unlikely deductions as to thrust, founded on the amount of slip, are likely to yield definite and accurate results. We have in these direct evidence that it is not the action of the propeller itself, but a suddenly acting extraneous cause, which at peculiar epochs, entirely modifies the phenomena of apparent slip!

In answer to Mr G. L. Watson, the PRESIDENT said that these vessels had been tried in deep water and the observations had been gone into very carefully.

Mr JOSIAH M'GREGOR said he thought most probably the results arrived at were quite what one would have expected from high speeds. They altered their positions in the water entirely, the vessels sometimes running almost horizontally and at very different speeds. It would have been interesting to have had the particulars. Difference of position did not indicate difference of draught.

The PRESIDENT said that Mr Scott Russell had made observations on the positions of flotation of vessels when in motion 40 years ago.

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

On the Introduction of the Compound Engine, and the Economical Advantage of High Pressure Steam; with a Description of the System introduced by the late Mr J. M. Rowan.

By Mr FREDERICK J. ROWAN, C.E.

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

Received 10th November; read 25th November, 1879.

The present almost general adoption of the compound engine for marine work, and of comparatively high pressures of steam, has been reached by gradual measures. It would perhaps be impossible to enumerate all the trials, and even failures, which have contributed to this result, or had their influence upon the progress of its development. It seems clear, however, that progress has been accompanied by, if it has not followed, the adoption of the dynamical theory of heat, and its application to the action of the steam engine.

The late John Elder is accounted one of the most distinguished pioneers of the march of improvement in steam engine practice, and his name is deservedly connected with the introduction of the compound engine. The facts which I have the privilege of laying before you in this paper show, however, that he was not alone in the work of improvement, and that there were others who, with him, governed their practice by the true theory of the steam engine, and who, at a very early date, perhaps pushed the application of that theory to a more complete result than he did, even in later years.

Mr Holt has recorded* that in 1852 the existing marine engines

* "On the Progress of Steam Shipping," &c. Proc. Inst. C.E., Vol. LI., Part I.

in screw steamers had jet condensers; carried 15 to 20 lbs. steam pressure, with slow piston speed; and had a consumption of coal of from 4 to 5½ lbs. per I.H.P. per hour. In remarking upon the improvement which took place within the next ten years, he has not given us the dates at which pressures were increased, superheating resorted to, or surface condensers occasionally introduced. We do not learn to what point the pressures were increased; but he has told us that with the engine of that day at its best, in 1864 and 1865, "the consumption of fuel in good specimens was perhaps just under 4 lbs. of coal per I.H.P. per hour."

From the late Professor Rankine,* and from Mr John L. K. Jamieson,† we learn that Messrs Randolph & Elder applied, on 15th March, 1856, for a patent for compound engines, and that the first steamers fitted under it were the "Inca" and "Valparaiso," started respectively in May and July, 1856. The pressure of steam was 25 lbs. per square inch in both these instances, and the consumption of fuel 2½ lbs. and 3 lbs. per I.H.P. in them respectively. The "Callao" followed in October, 1858, with a consumption of 2·7 lbs. per I.H.P.; but it was not until 1860 that surface condensers were adopted, or the steam pressure was raised above 40 lbs.; or that the consumption of coal was reduced below 2½ lbs. to 2¼ lbs per I.H.P.

During the years 1858 and 1859, experiments on a practical scale were made by the author's father, the late John Martin Rowan, of the Atlas Works, Glasgow, and his manager, Thomas R. Horton, with the cordial co-operation of Mr John Scott of Greenock, in which the advantages of the use of really high pressure steam worked expansively, and with surface condensation, were demonstrated.

The use of high pressure steam had been a favourite subject of his study for some years, and he became much interested in the

---

* "Memoir of John Elder," by Prof. Rankine.

† Discussion on Mr Bramwell's Paper "On the Progress effected in Economy of Fuel in Steam Navigation," &c., Proc. Inst. M.E., Liverpool Meeting, 1872, Part I. See also obituary notice of the late Charles Randolph, *Engineering*, 22nd November, 1878.

ideas advanced by Mr Thomas Craddock in 1848 and subsequently; so that in 1856 Mr Craddock came as manager to the Atlas Works, in order that a definite trial of his plans, as applied to marine work, should be carried out. The boiler was proved on 6th April, 1857, to 240 lbs. per square inch, before the Board of Trade surveyor. Trials with the engines and boilers showed, however, that there were grave defects inherent in their design, and the engines and boilers were subjected to substantial alterations.

This bore fruit in the shape of a patent, taken out in the joint names of J. M. Rowan and T. R. Horton, on 19th April, 1858, for compound engines, surface condensers, and subdivided boilers, and in the various experiments of 1858 and 1859, carried out in the S.S. "Thetis," of which two are recorded in the annexed reports by the late Professor Macquorn Rankine :—

REPORT by Professor W. J. Macquorn Rankine of Experiments on an Engine made by Messrs Rowan & Co., on 6th November, 1858.

1.—*Circumstances under which the experiments were made.*

These circumstances were very unfavourable to the full development of the economy of the engine, the boiler having contained too much water at the commencement, which occasioned priming, and a consequent irregularity in the pressure of the steam and the speed and power of the engine, as the following statements will show. It is to be desired that further experiments should be made.

2.—*Rapidity with which steam was raised.*

So soon as the fires were spread, the pressure of steam began to rise rapidly, and increased from 10 lbs. up to 85 lbs. above the atmosphere in about 35 minutes.

3.—*Consumption of Coal.*

The steam having been raised, the registration of the weight of coal burned was commenced, and continued during three hours, in the course of which *nine cwts.* of coal were burned, being at the average rate of 336 lbs. per hour.

But this time was divided into two periods—the first of 1 hour 35 minutes, in which 560 lbs. were burned, being at the rate of

354 lbs. per hour;

the second of 1 hour and 25 minutes, in which 448 lbs. were burned, being at the rate of 316 lbs. per hour.

It was during this *second period* that all the complete sets of indicator diagrams were taken; and therefore, in calculating the coal burned per indicated horse power, the consumption during the second period is to be taken.

4.—*Indicated power.*

Owing partly to the cause already mentioned, and partly to the novelty of the engine, which made the management of experiments on it at first difficult, the power fluctuated much, and ranged at different times from 204 to 146 indicated horse power. The nearest approximation which I can make to the *mean power* during the 1 hour and 25 minutes in which *316 lbs. per hour* of coal were burned, is 168 indicated horse power. In any future experiments, it is probable that 200 I.H.P. may be kept up, and perhaps exceeded.

5.—*Coal burned per I.H.P.*

Taking the approximate mean power already mentioned, the coal burned per indicated horse power per hour was

$$\frac{316}{168} = 1{\cdot}88 \text{ lbs.}$$

This, although the result (as stated at the outset) of experiments under very unfavourable circumstances, is *two-thirds of the least quantity of coal burned in any previous marine engine,* and about *one-third* of the ordinary consumption.

6.—*Condensation.*

The surface condenser acted perfectly, maintaining a steady vacuum of 13 lbs. on the inch during the whole time of trial. It is the most satisfactory example of surface condensation that I have ever seen.

W. J. MACQUORN RANKINE.

59 St. Vincent Street,
Glasgow, 8th November, 1858.

Appendix to Report.

A.—*Pressure in Boiler.*

This varied from 65 to 120 lbs. on the inch.

B.—*Calculation of Power.*

Areas of pistons: H.P. 345 sq. ins.; L.P. 1380 sq. ins.

Stroke $2\frac{1}{2}$ feet; therefore,

$$\text{I.H.P.} = 1380 \times 5 \times \text{revol. p. min.} \times \left\{ \left(\begin{matrix}\text{mean effective pres-}\\\text{sure in large cylinder}\end{matrix}\right) + \frac{\begin{matrix}\text{mean effective pres-}\\\text{sure in small cylinder}\end{matrix}}{4} \right\}$$

Abstract of diagrams employed.

No.	Boiler Pressure.	Revo-lutions.	Mean Pressure. L.P.	Mean Pressure. H.P.	I.H.P.
I.	102	50	6·7	51·1	204
II.	65	46	5·5	41·5	153
III.	65	48	5·4	41·0	157
IV.	85	44	5·75	42·2	150
V.	85	44	5·34	40·2	142

Power with 102 lbs. boiler-pressure as by Diagrams set I.,				204
„	65	„	„ mean of II. & III.,	155
„	85	„	„ mean of IV. & V.,	146
			Mean of all,	168

There were other diagrams taken, but the sets are imperfect.

C.—*Water evaporated.*

Evaporation by the mean of the diagrams, 2480 lbs. water per hour, or 8 lbs. water per lb. coal.

D.—*Speed of the Vessel and Screw.*

Screw, 9 to 10 knots; ship, between $7\frac{1}{2}$ and 8.

W. J. M. R.

---

59 St. Vincent Street,
Glasgow, 9th November, 1858.

My dear Sir,

I send you annexed another Appendix, showing a comparison between the pressures in the boiler and in the H.P.

cylinder during admission. In Cornish engines it is not uncommon to find the pressure in the boiler *double* or even *two and a half* times the greatest pressure in the cylinder. In those engines the steam passages are certainly too small; but their smallness is insufficient to account for that great difference of pressure, which in my opinion has never yet been completely explained. In your engine, considering that only *three cubic feet of steam per single stroke* have to be admitted, it seems difficult to conceive that smallness of the steam pipe can be the only cause of difference.

I attach much importance to your statement that the time of admission had been increased. The H.P. cylinder now cuts off at half-stroke exactly; were it altered to cut off at $\frac{4}{10}$, so as to expand in all 10 times instead of 8 times, I have no doubt the result would be better.

I shall be ready to go on Saturday as you propose.

Yours very faithfully,

W. J. MACQUORN RANKINE.

J. M. Rowan, Esq.

Appendix to Report.

E.—*Comparison of Pressure of Steam in Boiler and Pressure of Admission.*

No. of Diagram.	Boiler Pressure, lbs. per inch.	Cylinder, lbs. per inch.
I.	102	68
II.	65	49
III.	65	48
IV.	85	52
V.	85	48
VI. incomplete set of diagrams	65	51

Remarks.—The pressure of admission not only falls very far short of that in the boiler, but the relation between them is quite irregular, as is shown especially by comparing V. with III.

W. J. M. R.

REPORT of an Experiment made with Messrs Rowan & Co.'s Marine Steam Engine, on the 20th November, 1858, by Professor Rankine.

1.—*Circumstances of the Experiment.*

At 10 h. 25 m. the steamer started from the quay at Greenock with the pressure in the boiler at 80 lbs. per square inch above the atmosphere, and soon attained her full speed. The pressure continued steadily to rise, and at 11·20 had reached 101 lbs. per square inch. At 11·30, the pressure being about 115 lbs. per square inch, the condition of the fires was carefully observed, the stoke-hole cleared of coal, the coal bunkers closed, and 448 lbs. of coal, which had previously been carefully weighed on deck, was sent down in sacks for the supply of the fires during the experiment on the consumption of fuel, which was held to commence at 11·30. During that experiment, and for a considerable time after its termination, the pressure (except during an interval when the dampers were closed, to be afterwards specified) never fell below 112 lbs., nor rose above 125 lbs. on the square inch, and in general remained steady at 115 lbs.

At 12·30 the dampers which regulated the admission of air to the fires were shut, the engine stopped, and the experiment was held to have closed exactly one hour after its commencement; but as the fires were lower than they had been at 11·30, they were again fed at 12·42 (the dampers being then opened and the engine started), so as to bring them into as high a condition as they were in at 11·30; and the coal so used was included in the consumption of the coal burned during the experiment on the combustion.

The coal remaining on the floor of the stoke-hole was then sent on deck and weighed, and found to amount to 218 lbs., so that 230 lbs. had been used during the experiment of one hour in length.

During and for a considerable time before and after the experiment, the speed of the engine never fell below 49, nor rose above 53 revolutions per minute.

A leakage of steam took place from the stuffing-box of the slide-valve rod, but for this it was impossible to make any allowance.

The steadiness both of the pressure and of the speed for a considerable time before and after the experiment, showed that the performance during the experiment was no extraordinary effort, but a fair trial.

2.—Power of the Engine.

The horse power of the engine, as indicated by a series of diagrams (see Plate III.) taken during the experiment, varied from 221 to 231, the mean being 226.

3.—Consumption of Coal.

The coal burned in one hour, ascertained, as already described, with every precaution to make the fires as high at the end as at the beginning of the experiment, was 230 lbs., being at the rate of

$$\frac{230}{226}, \text{ or } 1{\cdot}018 \textit{ lb. per indicated horse power per hour.}$$

4.—Condensation.

The surface condenser acted perfectly, maintaining a steady vacuum of 13 lbs. on the square inch. It is the most satisfactory example of surface condensation that I have ever seen.

5. Speed of the Screw and Ship.

The screw being (as I am informed) of 20 feet pitch, its speed at 51½ revolutions per minute is 10·2 nautical miles per hour. The speed of the ship was taken very roughly at a single measured mile and was somewhere between 8 and 8½ nautical miles per hour, but the trial was very disadvantageous, as the screw, of 12 feet diameter, had nearly 3 feet of its diameter above water, and the ship's bottom was foul and her trim bad. With the screw completely immersed, and the ship clean and properly trimmed, a greater speed would be realised.

W. J. MACQUORN RANKINE.

59 St. Vincent Street,
Glasgow, 23rd November, 1858.

Glasgow, 24th November, 1858.

My dear Sir,

Improved Engine.

I send you enclosed my Report of the experiment of the 20th, and the Appendix to it.

I find that the coal evaporated *eleven* times its weight of water.

I am,

Yours very faithfully,

W. J. MACQUORN RANKINE.

John M. Rowan, Esq.

The boiler had *nine square feet* of heating surface per lb. of coal consumed per hour, and the *theoretical* evaporative power of the coal was about $15\frac{1}{2}$.

W. J. M. R.

ABSTRACT OF RESULTS OF DIAGRAMS.

Area of high pressure piston, ... 345 square inches.

Area of low pressure piston, ... 1380 "

= area of high pressure piston × 4.

Stroke $2\frac{1}{2}$ feet: therefore,

$$\text{I.H.P.} = 5 \times 1380 \times \left(\frac{\text{mean press. in H.P. cyl.}}{4} + \text{mean press. in L.P. cyl.}\right) \times \text{Revolutions per minute} \div 33{,}000.$$

Indicated horse power from Diagrams A. and B. (see Plate III.)		221
" " "	C. and D. ...	231
	Mean, ...	226

Coal burned per indicated horse power per hour,

$$\frac{230}{226} = 1{\cdot}018 \text{ lb.}$$

TABLE OF PRESSURES, &c.

Mark cn Diagrams.	Time	Pressure above Atmosphere		Vacuum.		Mn. Effective Pressure.		Revolutions per minute.	I.H.P.
	H. M.	Boiler.	Admission.	Exhaust.	Condenser	H.P.	L.P.		
A. H.P. bottom } L.P. top }	11·35	115	94	11·3	13	55·5	6·8	49½	221
B. H.P. top } L.P. bottom }	11·40	115	90	11·0	13	56·0	7·0	52	
C. H.P. top } L.P. bottom }	11·53	115	89	11·2	13	55·8	7·1	53	231
D. H.P. bottom } L.P. top }	11·55	112	94	11·4	13	56·2	7·2	52	
Means,		114	92	11·2	13	55·9	7·0	51½	226

After various trials had been made with the machinery of the "Thetis," she was worked as a trading vessel between Glasgow and Liverpool for several months steadily. This was done to show the practicability of the plans for regular work, but as the "Thetis" was merely an interloper in an established trade, she could secure a portion of it only at considerable loss.

Apart from the many interesting details furnished by the records of these trials they are evidence of the broad fact that at that early day steam of 115 lbs. pressure was successfully generated at the rate of 11 lbs. water to 1 lb. coal, and used in a compound engine with a surface condenser, and this on a consumption of 1 lb. to 1¾ lbs. of coal per I.H.P. per hour in regular working.

The patent referred to was for boilers of the kind composed of leaves and cells formed by double angle-irons and plates, with vertical or horizontal tubes filling the spaces inside of these; the varieties of arrangement being intended to secure "internal and external heating surface" and alternate air and water spaces. The hot gases were made to travel downwards before ascending to the funnel, or to and fro horizontally, and the whole was enclosed in a sheet-iron casing. These boilers were worked exclusively with fresh water obtained by surface condensation, the waste from leakage being made up from a supply of fresh water or by a distilling apparatus.

A form of surface condenser composed of groups of vertical tubes arranged inside a cylindrical casing, with a special kind of stuffing-box joint in the tube plates, is another part of the patent, and the means proposed for the agitation of the condensing water formed a leading feature of this condenser. It was considered by the inventors an important matter to have the condenser equal to the task of condensing all the exhaust steam and so supplying feed water steadily.

The third head of the patent comprises various arrangements of compound engines having one high pressure cylinder combined with two low pressure cylinders, and having three piston rods connected to the same crosshead, so that the motion of the three pistons is simultaneous and the strains on the crosshead are nearly equal.

This form of engine (see Plate IV.) has proved to be a steady and durable worker as a vertical engine, and also as arranged diagonally and horizontally. An arrangement of it in the latter form was devisedby the Newry Foundry Co., in ignorance that it had been already patented, and illustrated by them in *The Engineer* of 18th October, 1872, as having been successfully applied to some stationary engines.

Further patents were secured by Rowan & Horton on 8th Feb., 1860, and 5th September, 1861; in the one case for improvements in their boilers and for compound engines with cylinders arranged in the manner adopted subsequently by other makers, having one cylinder placed at the end above or below the others, the combination of cylinders resulting in forming a single engine. This was merely a modification of the original three-cylinder engine in which the three cylinders acting simultaneously with one crosshead and connecting rod formed a single engine. In the other case (1861) the patent was for an improved form of boiler* and for an improved form of condenser,† which was the first to have the annular chamber or belt at the top of the casing, for the purpose of bringing the point of escape of the condensing water as high as possible.

Of the machinery of the S.S. "Athanasian," the next steamer fitted with these plans, a screw steamer of 25 feet beam and about 160 feet long, built by Mr James R. Napier and engined by Rowan & Co., there are no particulars. Her engines and boilers were of the patent of 1858, but with this important difference, that in the boiler the hot gases were allowed to escape directly upwards to the funnel without having any downward or zig-zag movement given to them. The result of this was to submit to practical test the effect on the hot gases of exposure merely to a large amount of surface, independent of their rate of movement over it or the time in which they were kept in contact with it. It was understood that if the preliminary trials of this arrangement proved unsatisfactory, an opportunity was to be given of altering it and substituting the serpentine movement and retarded escape of the gases. Trials of this boiler showed a large consumption of fuel, a high temperature in the funnel, and an impossibility of keeping the pressure of steam required, so that both in point of power and in that of economy this was a failure. The opportunity of altering the arrangement of boilers was refused on the plea that the delivery of the vessel was behind the contract time, and as the engineers resorted in a short time to the use of salt water in the boilers, the makers washed their hands of any further responsibility connected with them, and soon they were removed.

The next vessel fitted with these engines and boilers was the S.S. "Queen of the Isles," built of Clay's puddled steel, by Messrs John Reid & Co. of Port-Glasgow (to whom I am indebted for the particulars given about her), and engined by Rowan & Co. She had the boiler of the patent of 1860 and the three-cylinder inverted

* Illustrated in *Engineering*, 13th December, 1867.

† Illustrated in the *Mechanics' Magazine*.

engines patented in 1858, and was started on 29th September, 1860. Her working pressure of steam was 120 lbs. per square inch, and on trial with steam of only 95 to 102 lbs., the engines developed a mean of 128½ H.P. on a consumption of coal of 2 cwt. per hour, or 1·74 lbs. per I.H.P. per hour, and a speed of 8½ knots. This was a small vessel built for the trade of the West Highlands of Scotland, where she worked economically and successfully for a number of years, maintaining the results shown on her trial. No diagrams or accurate records of her performance have been preserved, but from the firm who acted as agents for the owner for several years I have learned that her steady work at sea was of a most satisfactory and economical nature. In 1867, having previously passed into other hands, she was chartered to a Dutch company, her original engines and boilers were still at work and in good order, and her daily consumption of coal was 2 tons to 2 tons 10 cwts. Some of the tubes in her boilers had given out but these had been renewed from time to time without difficulty. She was still at work in 1870 but was wrecked on 16th February of that year on Brest rocks near Ayr.

The paddle steamer "Guajara" was the next vessel started, although contracted for after the steamer "Diamantina." She was built by Scott & Co. of Greenock, her machinery by the Greenock Foundry Co., and started on 15th January, 1861. She had the boiler of the patent (see Plate IV.) of 1860 with a pair of three-cylinder engines arranged diagonally working direct to the paddle shaft, and her consumption on trial was 1¼ lbs. per I.H P. per hour.* She was sent out to a station on the coast of South America, but was very soon disabled through her boilers leaking in a serious way. This was repeatedly a great difficulty in the early examples of this machinery, and arose principally from the fact that engineers were at that time practically unacquainted with the class of work required by the high pressure of steam used, and partially from the rigidity of the connections between the leaves in the boilers of 1860, which led to the

* See *Engineer*, 25th Jan., 1861.

improved form of 1861. The engineer in charge of the "Guajara' used sea water in the boilers in the hope of stopping the leaks, but only succeeded in burning and disabling them permanently. They were then replaced by horizontal cylindrical boilers to work at 90 or 100 lbs.

The only engineers who had practical experience of high pressure steam at that date being the makers of locomotive engines, Messrs R. Stephenson & Co., of Newcastle-on-Tyne, on account of their large experience in this branch of engineering as well as because of their eminence in the profession, were induced by the author's father to undertake the manufacture of the Rowan & Horton marine engines and boilers, and during the years 1860 and 1861 constructed seven sets of that machinery of various sizes, under the superintendence of Mr Jacob Wallau (now of Messrs Black, Hawthorn, & Co.), who has supplied the following valuable information concerning these steamers :—

Particulars of Engines and Boilers made by Messrs R. Stephenson & Co., Newcastle-on-Tyne, in 1860—1861 and 1865, from J. Wallau, Esq., 14th December, 1878.

I find that Robert Stephenson & Co, Newcastle, built the machinery for eight steamers, which were contracted for and constructed by Charles Mitchell & Co., shipbuilders, Low Walker-on-Tyne.

The first seven sets of machinery were built in 1860 and 1861 from my designs made in accordance with your father's patent, and the eighth and last engines were built in 1865, and were in all principal points similar to the first seven.

Six of these steamers had paddle engines with feathering wheels and two of them had screw engines.

The ships had the following sizes of engines :—

						Stroke.	Paddle Wheels.
Diamantina,	..	two 11¼″	cyl. and	four 21½″	cyl.	.33″	...12′ 6″ dia. over floats
Progress, ...	...	four 12½″	,,	eight 24½″	,,	...36″	...15′0″ ,, ,,
Ganges Stmr.	No. 1,	four 11½″	,,	eight 21¾″	,,	...33″	...12′3″ ,, ,,
,,	No. 2,	,,	,,	,,	,,	...39″	...13′9″ ,, ,,
,,	No. 3,	,,	,,	,,	,,	,,	,, ,, ,,
Western, ...	...	two 12½″	,,	four 24½″	,,	...25½″...	Screw steamers.
Sicilia, ...	...	,,	,,	,,	,,	,, ...	Screw steamers.
Ballina, ...	...	,,	,,	,,	,,	... 42″	...14′9″ dia. over floats

In all cases there were two low pressure and one high pressure cylinders cast together, and each set of three cylinders worked upon one crosshead, one connecting rod, and one crank; and the two slides (one high and one low pressure one) belonging to these three cylinders were attached to one slide (valve) spindle and one reversing link, this being the same arrangement as adopted by your father in the screw steamers "Athanasian" and "Queen of the Isles.' The principal difference between the screw engines and the paddle engines was that the former were arranged the same as the common overhead or steam hammer engines, and the latter were inclined cylinders, working also upon solid double crank shafts, with entablatures bolted to a strong wrought iron girder underneath the ship's deck.

The reason why the three Ganges steamers and the "Progress," which was also for the Ganges, had each ship twelve cylinders, is this, that it is necessary to drive each of the two paddle wheels quite independent of the other, to enable the ship to go easily round the sharp bends or windings of the river, by entirely stopping one wheel and driving the other full speed; therefore each wheel is driven by a double crank shaft, and as each crank is worked by three cylinders, we have four cranks and twelve cylinders in each ship, as two cranks and six cylinders belong to a complete engine for one wheel.

Although this seems a rather complicated arrangement, it has proved most successful. The three Ganges steamers, owing to their small consumption of fuel and light draft (the hulls being entirely of steel) could advantageously compete with the best of the older steamers, and after more than ten years' running, new boilers were ordered for the same in 1873, which were built on the Clyde; and a few years after this I heard that they were still doing very good work.

Probably part of their remarkable success was due to the circumstance that although they often ran in very muddy water on the Ganges, yet it was comparatively free from salt, and generally less injurious to the boilers than the sea water. As far as I could learn, it was principally the sea water which caused engines and boilers to be taken out of the "Western" and "Sicilia."

The "Diamantina," however, was much more successful, and after she had run four years a second ship was ordered, with the same engines and boilers, to be built for the same trade. The new ship, the "Ballina," had a little larger engines than the "Diamantina," and the boilers had the same description of square boxes, but instead of having four small tubes in each box, they had only one large tube in each box.

Generally the engines were so proportioned that they could easily work up to four times their nominal horse power, and as the screw engines had a higher piston speed, 21 circular inches of piston area was sufficient for them, but for the paddle engines about 27 circular inches were required per nominal horse power.

The grate area was varied from $\frac{2}{5}$ to $\frac{1}{2}$ square feet per nominal horse power, and the heating surface from 25 to 30 square feet, and the cooling surface in condenser about 7 square feet, all per nominal horse power. The consumption under favourable circumstances was as low as $1\frac{1}{2}$ lb. per indicated horse power.

The whole of the steamers were fitted with boilers consisting of boxes about 8 inches square inside, but the arrangement of the tubes varied. In the "Diamantina," "Progress," "Western," and "Sicilia," four tubes 2 in. outside diameter were placed into each of the square boxes, and generally the boilers were arranged in the same way as those used by your father in the "Athanasian" and the "Queen of the Isles," which were built before R. Stephenson & Co. took their engines in hand. In all these boilers the tubes were fire tubes, but in the boilers for the three Ganges steamers the 2-inch tubes were fitted outside and between the 8-inch square boxes, and then the tubes were water tubes. Finally, in the "Ballina," instead of the four 2-inch water tubes in each box, there was only one 5½-inch water tube.

The boiler pressure we used varied from 100 to 150 lbs. pressure, although the general safe pressure to which the safety valves were loaded did not exceed 120 lbs. The strength of one of the square boxes was tested with cold water up to 850 lbs., when one of the plates began to crack between the rivet holes. This was with iron plate ⅜ in. thick, but a box fitted with steel plate $\frac{9}{32}$ in. thick gave way with 620 lbs. cold water pressure.

The condensers consisted of ½-inch tubes about 5 feet long; they were packed with india-rubber, and the steam was condensed inside the tubes.

The weight and the efficiency of the engines (that is, the speed of vessel obtained by the power) were the same as in ordinary good engines.

(Signed) JACOB WALLAU.

This vessel was the "Ballina," built in 1865, the last example constructed by the Newcastle firm.

The steamer "Diamantina" was the first of this fleet, the hull having been built by Messrs C. Mitchell & Co. of Low Walker, and the machinery tried on 22nd January, 1861.* On that occasion a speed of 9 knots was maintained on a consumption of 1·42 lbs. per I.H.P., and a speed of 11 knots on 1·45 lbs. for a short time after the official trial had terminated.

On another trial of the machinery on 30th January, 1861, a consumption of 1·23 lbs. per I.H.P. per hour was recorded.

This steamer worked successfully on her station on the coast of Australia for several years. During that time the report of her performance, which follows, was made by Mr Samuel Madden, of H.M.S. "Pelorus," then stationed at Sydney; and at the end of four

* See *Engineer*, 1st February, 1861.

years her owners ordered a second steamer, with the same engines and boilers, from Messrs Stephenson, for the same trade.

REPORT on the performance of the Australian Steam Navigation Co.'s Steamer "Diamantina," from Sydney to Brisbane and return to Sydney. By Samuel Madden, Esq., R.N., of H.M.S. "Pelorus." Sydney, 13th June, 1862.

From Sydney to Brisbane, 17th to 20th April, ...	69 Hours.
" Brisbane to Sydney, 24th to 26th April, ...	61 "
Total time under steam, ...	130 "
Total quantity of coal used, including laying fires and getting up steam, ...	22 Tons.
Mean draught of water, ...	Forward, 5ft. 10in.; Aft, 6ft. 0in.
Extreme breadth of beam,...	23 Feet.
Area of greatest section,...	132 Square feet.
State of weather at sea, ...	Variable light winds and smooth sea.
Sails used, ...	Fore and aft occasionally—seldom in use.
True distance run,...	950 Knots.
Average revolutions per minute, ...	32.
Mean pressure of steam, ...	105 lbs.
Estimated average horse-power, ...	200.
Temperature of steam,...	340° Fahr.
" Feed water,...	120° "
Vacuum in condenser, ...	25 inches.

Distance 950 knots, with 22 tons coal, = 43·18 knots per ton of coal. (Cost of coal, 20s per ton, A. A. Co., Newcastle.)

Cost of coal per mile for propelling ship and 145 tons cargo, including stoppages, at 7·307 knots average speed, 5½d.

Coal used per hour = 373 lbs. = one-sixth of a ton at 20s. = ¾d, cost per hour.

Consumption $= \frac{200}{373} =$ 1·865 lbs. per I.H.P per hour, or about 1⅞ lbs.

The distance run in knots, and units of work performed with one ton of coal, exceed any other performance that I have heard or read of in steam navigation.

Mechanical difficulty may for a time prevent the practical working of this most economical invention ; I feel sure, however, that a very short time will suffice to introduce generally these very economical results for steam navigation, viz., high-pressure steam, expansive engines, and surface condensation.

(Signed) SAMUEL MADDEN.

The steamer "Progress" followed the "Diamantina," but of her work I have no information. She was a paddle steamer for work in India. (See Table II.)

I can also only record the name and dimensions of the machinery of the "Western," a screw steamer next started by Messrs Stephenson, for service in Australia. (See Table II.)

These were followed from the same works by the inverted direct acting engines of the "Sicilia," a screw steamer of 800 tons, built by Messrs Richardson, Duck, & Co., of Stockton-on-Tees, for the London and Mediterranean Steam Navigation Co., and a sister ship to the S.S. "Italia," built and started in the same year (1861) at Greenock.

After an official trial at West Hartlepool in July, 1861, the "Sicilia" was delivered on the 8th August, and in the following week ran another trial trip on the Thames, showing an average speed of 9½ knots, and a consumption of 1·36 lbs. coal per I.H P. per hour.*

The "Italia" had a most inauspicious beginning, having suffered so severely from choking of the exhaust pipe, and from leaks in her boiler, that these, combined with the timidity of her captain and engineer, were sufficient to cause her on her first voyage to put back from the Bay of Biscay to Plymouth. After receiving some repairs, however, she seems to have done good work on her station.

The boilers of these steamers suffered so severely from corrosion that application was made to Mr Thomas Spencer, a consulting

* See *Illustrated London News*, 24th August, 1861.

chemist, to report upon the case and to suggest a remedy. This he did in a report dated 23rd April, 1862. He attributed the rapid corrosion to the purity of the fresh water used in the boilers, which he thought gave rise to the formation of magnetic oxide, which propagated itself very quickly; and he suggested the use of silicate of soda and potash in the water, but did not give his reasons for its use, admitting that it was "an untried remedy proposed to meet the necessities of a case somewhat novel." I am disposed to believe that the early commencement of corrosion in these boilers was due to the *partial* use of sea water* in them on their first voyages, and that, having once been commenced, the formation of oxide of iron proceeds very rapidly, assisted by the carbonic acid and air contained in fresh water, even where no sea water is used. Where, as in the case of the S.S. "Propontis," a small quantity of sea water is continuously present, in consequence of some leakage, corrosive action is very much more rapid and severe, and is to be met only by coating the boiler surfaces.

About the same period (viz., early in 1861) Messrs Stephenson constructed the engines and boilers for three river steamers of special build. The hulls were built of steel by Messrs C. Mitchell & Co., under the supervision of Mr Douglas Hebson of Liverpool, consulting engineer to the owners, and embraced several novelties. The three steamers were thoroughly successful for a number of years, and their economy in regard both to consumption of fuel, freedom from repairs, and durability, enabled their owners to distance all competitors for the traffic of the Hoogly. They were most carefully and intelligently superintended by Mr B. C. Crawford, and no doubt a great portion of their continued efficiency was due to the thorough and painstaking character of his work. He returned from India at the end of 1867, bringing and being followed by reports of the excellent condition of the fleet.

* *Vide* paper "On Boiler Incrustation and Corrosion," read before Section G, British Association, 1876.

Each steamer had an independent pair of engines for each paddle wheel, consisting of two high pressure cylinders (11½ ins. diameter) and four low pressure cylinders (21¾ ins. diameter) arranged in groups of three cylinders to each crosshead, with a stroke of 33 ins. in one, and 39 ins. in the other two instances. The boiler had 36 square feet of heating surface, and 0·6 square feet of grate surface per nominal horse power. The engines were of 110 nominal horse power, and 450 indicated horse power, and the result of many trials of the machinery at Messrs Stephenson's works was a consumption of Hartley coal of 1·7 lbs. per I.H.P. per hour, with 120 lbs. per square inch pressure of steam, 24·5 inches of vacuum (the condensers being short of water then), 45 revolutions per minute, or 247·5 feet per minute speed of piston, and 430 I.H.P. The engines and hulls having to be sent out in separate pieces and put together in India, it was impossible to try the machinery in the vessels in this country.

In 1872 orders were sent home for new sets of boilers for these steamers (the "Punjaub," "Oude," and "Burmah,") which were made and sent out in 1873, of the design (Plate V.) patented by Rowan & Horton on 11th Nov., 1869, and first carried out in the S.S "Haco" in 1870, this arrangement having a simpler and cheaper form of construction, and one more readily capable of repair.

The same owners also about that time purchased the steamer "Nepaul," compounding her high pressure horizontal engines, and sent out for her boilers of the same design, and subsequently built at Greenock the steamer "Bengal," for which the machinery was made by the Greenock Foundry Co.; the boilers, however, in all these instances, except the "Haco," having been made by Messrs A. & W. Smith of Glasgow.

The S.S. "Actif," a small despatch boat for coasting service in the French navy, was the last vessel on the old plans built at Greenock, and started in 1862; and her construction was due to the investigation into the performance of the "Thetis," which was made on behal of the French Government by M. Forquenot. She suffered severely from indifferent boiler work and from corrosion, and these evils were aggravated by the boilers being considered "too complicated for repair" by the authorities at Toulon. A very concise account of their dealings with her was courteously given to me by Monsieur Sabattier, the present Minister of Marine.

The patent of 1869 was for the form of boiler in which the leaves and cells of former designs, which were found to be liable to leakage and difficult of repair, are discarded, and the top and bottom chambers are connected direct by vertical water tubes of small diameter.

The patent also includes a fresh arrangement of passages for the combination of three cylinders, and the form of condenser and feed water heater, in which the condensed steam from the condenser is the circulating medium in the feed heater, and abstracts the first portion of the heat from the exhaust steam on its entrance from the low pressure cylinders.

A further modification of the boiler (Plate V.), applicable to the requirements of some ships of war, and arranged for forced combustion with mechanical feeding of the fuel, was patented by me on 16th November, 1876. but has not yet been carried out in practice.

As already mentioned, the boiler of 1869 has been introduced in the S.S. "Haco" (now the S.S. "Constantin"); in the renewals of boilers in the steamers "Punjaub," "Oude," and "Burmah;" in the S.S. "Propontis;" and in the steamers "Nepaul" and "Bengal." The "Haco" was built and engined at Greenock early in 1870, and has been fairly successful, carrying 650 tons cargo at an average speed of 8 knots on 4½ tons Newcastle or Scotch coal per day. Her boiler power was rather small, and a mistake was made in having only one furnace, as this caused great fluctuations in steam pressure when the furnace door was opened for firing and fresh coal was added; and also kept so low a temperature in the combustion chamber that a large quantity of soot was deposited on the boiler tubes. Otherwise she has done well, and compares favourably with other steamers of her size, which for the same duty require nearly double the quantity of coal. She was sold to French owners in 1872, who changed her name to "Constantin."

Considerable interest was concentrated upon the steamer "Propontis," from the fact that she was a regular trader from Liverpool, that her machinery was of larger size than that of any of the former examples referred to, and that the engines and boilers were constructed by Messrs John Elder & Co. It was unfortunate, however, that her boilers were constructed without the external steam connection between the steam domes used in all the other examples, and that the makers relied for the equalizing of the internal pressure of the various sections upon an internal steam pipe which was substituted for the external coupling pipe. The internal pipe proved to be insufficient, and variations of pressure in the various parts induced such alterations of water level as exposed parts of the boilers to so high a temperature that they burst at less than 100 lbs. per square inch, while having a bursting strength when cold of 1,200 to 1,500 lbs. per square inch. The accident was much to be regretted as she was accumulating results of great interest to engineers.

Some of those collected by me on her official trial at sea by the Board of Trade, and on her first voyage, are given in Tables of Results and Indicator diagrams on Plates VI. and VII., and she continued to maintain these results until the accident overtook her.

I have only to add, with regard to these performances, that in the account of the official trial given in *Engineering* of April 17, 1874, I find the average power stated at too low a figure—my statement of average pressure of steam, revolutions, &c., being the mean of 63 observations made during the trial.

On the first voyage all the results recorded in *The Engineer* of 14th August, 1874, were obtained with only three boilers at work.

It is to be observed also that during that voyage a much larger quantity of heat escaped by the funnel than was necessary, on account of the state of the cast-iron division strips or baffle plates for controlling the currents of the gases, and that a distilling boiler of insufficient size consumed coal steadily at the rate of 17 cwt. to 1 ton per 24 hours, as ascertained by careful observation.

Particulars of Engines of S.S. "Propontis."

Engines.

Cylinders.	H.P. (1)		Mid (2)	L.P. (3)
Diameter,	23″		41″	62″
Stroke,	3′ 9″			
	Sq. ins.		Sq. ins.	Sq. ins.
Area,	415·476		1320·25	3019·07
Mean cut off,	from $23\frac{1}{4}''$ to $14\frac{3}{4}''$		$23\frac{1}{2}''$	$23\frac{1}{2}''$
	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.
Steam admitted in one stroke,	„ 11·18	„ 7·09	35·90	82·17
	Sq. ft.		Sq. ft.	Sq. ft.
Inside surface of cylinder, bottom, and cover,	31·94		64 84	112·24

Ratio of contents.

H.P. to Mid $= \frac{1}{3\cdot18}$

Mid to L.P. $= \frac{1}{2\cdot28}$

H.P. to L.P. $= \frac{1}{7\cdot27}$

Pumps.

	Diameter.	Stroke.	No.	Contents in 1 stroke.
Air pump,	29″	18″	1	5·32 cub. ft.
Circulating pump,	$12\frac{1}{2}''$	18″	1	2·35 „
Feed „	4″	18″	2	0·262 „

Water trap from mid cylinder jacket (3′ 3″ cub. ft. contents) area of surface 26·4 sq. ins., water accumulation $4\frac{5}{8}''$ vertically in 6 min.

Water trap from L.P. cylinder jacket (3′ 3″ cub. ft. contents) area of surface 26·4 sq. ins. water accumulation 1″ per min.

Boilers.

Heating surface 8,700 sq. ft. Grate surface 121·6 sq. ft.

Ratio of grate to heating surface $\frac{1}{71\cdot54}$.

Water in one boiler about 6 tons = about 1400 gallons.

Throttle Valve.

Double beat valve 6″ diameter inside.

Total travel $2\frac{1}{8}$ ins. Travel expressed in fractions of the whole in tables.

In conclusion, there are a few observations of a general nature which I desire to make.

Whatever difference of opinion may exist as to the merits of this system of generating and using steam, or as to the amount of credit due to those who introduced it, I think it will be conceded that the results collected in this paper are valuable, as demonstrating the practicability of using steam of 150 lbs. pressure in marine work, and also as proving, by tests on a practical scale, that economy arises from its use. Taking for comparison the average consumption of fuel given by Mr Bramwell in his paper* at Liverpool, it will be seen that the general average in Table I. shows that more than 20 per cent. of advance in economy on the result there given was realised years ago, and has been continued almost to this date, so that it does not depend upon an isolated experiment; and thus also shows that the means of fulfilling Mr Holt's anticipation† are already at hand I anticipate, however, that further economy will result from the use of the plan of forced combustion and mechanical feeding which I have proposed.‡

If it be objected that several of the results were obtained at trials of short duration, I do not know of a more satisfactory reply to this than is contained in the view of the value of trials, as compared with voyages, concisely expressed by Mr Bramwell in replying on the discussion of the paper already quoted. To this may be added that the means of arriving at the total quantity of coal used on a voyage are often of a very unsatisfactory nature.

Table III. is added to show that boilers for the high pressures alluded to need not weigh more than those in use for steam of 60 and 70 lbs. The reason for the extra weight of those of the "Propontis" is given in my remarks on Mr Flannery's paper§ on "Steam Boilers for High Pressures."

---

* Proc. Inst. M.E., July, 1872. Part I.

† Proc. Inst. C.E., Vol. LI., Part I.

‡ "On the Design and Use of Boilers," British Association, 1878; *Engineering*, 23rd August and 4th October, 1878.

§ Proc. Inst. C.E., Vol. LIV., Part IV.

In passing judgment on the failures which too often have occurred in the experience of these twenty years, it will be only just to remember that there was no previous experience in the same, or even in a similar direction, which could be referred to for guidance, the amount of innovation introduced by these plans constituting the effort a fresh departure on new lines of working.

The evils of faulty workmanship, insufficient arrangements, boiler corrosion, and the numerous minor difficulties of pistons and piston rod packing, and of lubrication in presence of steam of a high temperature, have not been confined to examples of compound engines and boilers for high pressure steam on these plans; but their novelty, combined with the special features of these plans, such as the degree of pressure and temperature of the steam used, the thinness of the metal of the boilers, &c., caused them to be felt more severely in these instances than in others.

It is by the process of meeting such difficulties, however, that experience is usually obtained, and success is finally achieved.

TABLE I.

NAME.	Cylinders. Diameter. High	Cylinders. Diameter. Low.	Stroke	Revolutions per minute No.	Piston Speed. Feet per minute	I.H.P. High.	I.H.P. Low.	I.H.P. Total.	Steam Pressure. Boiler.	Steam Pressure. Mn. Effective. High.	Steam Pressure. Mn. Effective. Low.	Coal consumed Per 24 hours.	Coal consumed Per I.H.P. per hour.	Heating Surface.	Grate Surface.	Condenser Surface.	Vacuum.	Date of Trial or Voyage.
	Ins.	Ins.	Ft. Ins.	Mean.	Mean.			Mean.	Mean.			T. C	Lbs.	Sqare Feet.	Sq. Ft.		Ins.	
S.S. "Thetis,"	21	42	2 6	46	230			168	80	43	5·7		1·88	1923·15	36	712·7	26	6th November, 1858.
"	"	"	"	51	255			226	115	55·9	7·0		1·01	"	"	"	26	20th " "
"	"	"	"	47·64	238·2	166·13	90·0	256·13	90	66·45	9·02	3 5	1·20	"	"	"	26	12th August, 1859.
"	"	"	"					Estimated. 220				4 6	1·7	"	"	"	"	Mean of 14 voyages from 14th May to 25th Aug., 1859.
S.S. "Q. of the Isles,"	[2] 7⅞	[4] 16	1 8	76	250			128·5	98			2 8	1·74	880	19·44	207·10	28¼	29th September, 1860
S. "Guajara,"	[2] 12	[4] 24	4 0	30·1	240·8	148·68	125·48	274·16	102	90·05	9·5		1·50	275·2	50	"	27	15th January, 1861.
S. "Diamantina,"	[2] 11¼	[4] 21½	2 9	32	176			178·5	111·5				1·42	1650	24		26½	22nd " "
"	"	"	"					200	105				1·86	"	"		25	Coal includes laying fires, 2 runs, 17th to 26th Apr., 1862.
"													1·23	"	"		"	30th January, 1861.
S.S. "Sicilia,"	[2] 12½	[4] 24½	2 1½	85	361			350	120			6 0	1 6					— July, 1861:
"	"	"	"	74	314			411	115				1·36				28¼	15th August, 1861.
S.S. "Italia,"												6 18	1·5	1135·6	48			30th December, 1861.
S. "Punjaub," }	[4] 11½	[8 21¾	2 9											3960·0	66			Mean of 22 trials from 18th June to 30th August, 1861, Condenser short of water.
S. "Oude," }	"	"	3 3	45	247·5			430	120				1·7				24½	
S. "Burmah," }	"	"	"															
S.S. "Actif,"			2 0					420					1·6	3740	62			February, 1862.
"								329	120				2·42					Average from Sal attier's report, Feb., '62, till Dec., '63.
S.S. "Haco,"													1·7	1805·5				
S.S. "Propontis,"	23	Mi 41 Low 62	3 9	60·9	456	265·9	243·0	} 820	131·4	44·7	12·5	14 8	1·6	8700	121·6	1653·67	26	Mean of 63 observations, 7th and 8th April, 1874.
							311·9				7·1							
"	"	"	"										2·24	"	"	"	26½	Average of first voyage out, May, 1874. Boiler and engines not in working order, I.H.P. small.
								980				17 10	1·64	..	..	..	26·3	Average of voyage home, July, 1874. Coal for distil-

Table II.

No.	NAME.	Length.	B'dth	Depth	Draft when loaded. Aft.	Draft when loaded. For'd.	Displacement.	Propeller. Diam.	Propeller. Pitch.	Paddle Wheels. Diam.	Paddle Wheels. Floats. No.	Paddle Wheels. Floats. Size.	Cylinders. No.	Cylinders. Diameter. H.P.	Cylinders. Diameter. L.P.	Cylinders. Stroke.	Boilers. No.	Boilers. Heating Surface.	Boilers. No. of Furnaces.	Pressure of Steam.	N.H.P.	Builders. Ship.	Builders. Engines.
1	S.S. "Thetis,"	197 8	26 6	15 0	11 1	10 0	734 tons	12 0	23 0				2	21	42	30	2	1923·15	4	115	80	Scott & Co.,	Rowan & Co.
2	S.S. "Athanasian,"	160 0	25 0																	120	60	J. R. Napier,	”
3	S.S. "Q. of the Isles,"							7 0	14 0				6	7⅞	16	20	1	880	2	120	40	J. Reid & Co.,	”
4	S. "Guajara,"	146 0	23 0	10 0	5 6	4 8	305			16 0	10	7 0 × 2	6	12	24	48	2	2752	2	120	110	Scott & Co.,	Greenock F'y Co.
5	S. "Diamantina,"	153 0	23 0	8 6	5 2½	4 7	287			12 6	9	7 6 × 2	6	11¼	21½	33	2	1650	2	120		C. Mitchell & Co,	R. Steph'son & Co.
6	S. "Progress,"	252 0	38 0	10 6						15 0			12	12½	24½	36				120		”	”
7	S.S. "Italia,"												6	12	24	24	2	of Tubes 1135·6	2	120	110	Scott & Co.,	Greenock F'y Co.
8	S.S. "Western,"												6	12½	24½	25½				120		C. Mitchell & Co.,	Stephenson.
9	S.S. "Sicilia,"	235 6	28 0	17 9	15 0 mean			13 9	15 6				6	12½	24½	25½				120	110	Richardson, Duck & Co.,	”
10	S. "Punjaub,"	200 0	30 0		3 6 mean					12 3			12	11½	21¾	33	2		6	120	110	Mitchell,	”
16	”																2		6	150			New Boilers A. and W. Smith & Co.
11	S. "Burmah,"	”	”		”					13 9			”	”	”	39	2		6	120	110	”	Stephenson.
18	”	250 0															2	5300	4	150			New Boilers, Smith.
12	S. "Oude,"	”	”							”			”	”	”	39	2		6	120	”	”	Stephenson.
17	”																2	5300	4	150			New Boilers, Smith.
13	S.S. "Actif,"	134 0	22 4	12 3													2	3740	4	120	90	Scott,	Scott.
14	S. "Ballina,"									14 9			6	12½	24½	42				120		Mitchell,	Stephenson.
15	S.S. "Haco,"																1	1821	1	150	60	Scott,	Scott.
19	S.S. "Propontis,"	318 4	36 3	25 9	23 0	22 2			16 0				3	23″ 41″	62	45	4	8702	8	150	250	Smith & Rodger	J. Elder & Co. Boilers,
20	S. "Nepaul,"																2	5300	4	150	120		Smith.
21	S. "Bengal,"	275 0	35 0	10 6													3		6	150	200	Scott,	Scott.

TABLE III.—Showing Comparative Weights per I.H.P. of Engines and Boilers.

	Engines. Cwts.	Boilers. Cwts.	Both. Cwts.
"Paouting,"	2·5	1·1	3·4
"Valparaiso," ...	2·0	1·1	3·4
"Princess Amalia," ...	2·3	1·2	3·4
"Cameroon,"... ...	2·5	1·4	4·0
Rowan & Horton's boiler, usual construction,	—	1·2	without water, but with brick lining for casing
Do. do.	—	1·4	with water and brick lining.
"Haco,"	—	—	—
"Propontis,"	3·2	2·2	5·0

The discussion of this paper was commenced on the 23rd December, 1879, when

Mr F. J. ROWAN said, in answer to the President, that the only thing he could add to the statements made in the paper, would be to indicate shortly the various steps that had been taken in the construction of the boilers referred to in the paper—he meant, the steps by which the present form was arrived at. This, however, he thought it was unnecessary to do, especially as Mr H. R. Robson was present, who was well acquainted with them, and could describe the early forms of the boilers much better than he could do. There was another reason why he was disinclined to enter into these details, which was that they might tend to narrow the subject more than was desirable, for he might remark that the title of his paper had been made, at the suggestion of Mr Millar, the Secretary, more comprehensive than the paper itself, in order that the discussion might not be confined to the special system described. He wished also to leave room for the introduction of further particulars which he did not possess, regarding some of the matters which were treated of. He had no doubt that some of the members were in possession of facts which would render the paper more complete, and he trusted the discussion would be the means of bringing these forward.

Mr H. R. Robson said that being present at the experiments made with the "Thetis," he felt constrained to say something on this matter. All along he had gone with the late Mr Rowan in the construction of the boiler, and when it came to trial he was very anxious to see how it did, as the pressure was very far ahead of anything that had been the custom previously in marine engineering practice. While they all admitted the great advantage of high pressure steam, up to this time these advantages had not been realised as he believed they would yet be, when they got the connections made in such a way as would stand the extraordinary tear and wear of high pressure. With regard to the taking of the diagrams mentioned on page 54, the first experiment given by Dr Rankine was one in which he gave the consumption of fuel as 1·88 lbs. per I. H. P. per hour, the indicated horse-power being set down at 168, while on page 56, in the next experiment the indicated horse-power was got up to 226, and the consumption of fuel was 1·018 per I.H.P. Now, he believed it was himself who showed how that occurred after the experiments. He regretted that two of the gentlemen who conducted these experiments, and who could have given a great amount of information on this subject, had passed away from amongst them—namely, Dr Rankine and Mr J. R. Napier. Upon the occasion referred to, after the experiments were completed, he (Mr Robson) got Mr Napier to take an indicator diagram for him, which he found upon measuring did not give the amount of pressure, as shown by the gauge, by some 20 lbs. He called Mr Rowan's attention to this fact, and suggested to him that it was caused by the connecting pipes between the indicating instrument and the cylinders being too small. In order to test the matter, Mr Rowan had these connections removed, and larger ones fitted, which caused the difference given at page 56, which showed a consumption of 1·018 instead of 1·88, as on the previous occasion; and while it really made no difference in the results, it made a very sensible difference in the apparent consumption per I.H.P. He simply stated these facts, by way of reconciling the discrepancy. Such mistakes were not likely now to happen, as they understood better how to take indicator diagrams. He found the other day a report, dated 1862, on the steamer "Western," while on a voyage to New Zealand and back to Melbourne, which he would place in Mr Rowan's hands, that he might see the difficulties experienced with the connections, &c.; and probably something might be taken out of the report that would be useful for insertion into his paper.

The PRESIDENT explained that some of the documentary matter which accompanied the paper had been kept out of the Transactions, as not being considered necessary.

Mr F. J. ROWAN thanked Mr Robson for the report, as it referred to one of the steamers of which he had no particulars at all, and was therefore of great interest to him. If any facts could be culled from it they might yet form part of the paper.

Mr J. L. K. JAMIESON thought they were all indebted to Mr F. J. Rowan for putting on record those interesting experiments connected with his father's way of carrying out the expansion of high pressure steam. The late Mr Rowan's early connection with locomotives led him to go into higher pressures than other engineers on the Clyde; and although they had not reached his pressures at the present time, he had no doubt that his experiments and the adaptations which he made in various steamships paved the way for them to go on in a much more certain way than they could have done by jumping from 70 or 80 lbs. to 400 or 500 lbs. pressure. He (Mr Jamieson) was connected with the firm of John Elder & Co. at the time, and went along with Mr Rowan in carrying out his ideas in the engines of the "Propontis," and he must say that every effort was made by that firm to do Mr Rowan justice. Personally, he (Mr Jamieson) had the idea that in previous experiments, as they might almost call them, they had not got the work well designed and carefully carried out; but all this was done by his firm to make Mr Rowan's engines a success; and there was not the least doubt that, with the pressure of 130 lbs. steam carried out in the "Propontis," the engines did their duty remarkably well, and they were more economical than with engines which carried less pressure. The difficulties were connected with the boilers, and he regretted the author of the paper said the firm were in error, for he was of opinion that everything was attended to most carefully to carry out his father's ideas as much as possible. There was no doubt that the details of the experiments which Mr Rowan's father had made were very valuable to them, to the Institution, and to the world at large. He had very great pleasure in reading the paper and in seeing the facts therein put upon record, as a valuable addition to the knowledge which they possessed with regard to the expansion of steam by high pressure.

Mr ALEX. C. KIRK said he would pass over the earlier part of the paper without remark, and proceed to the last part of it which treated of the "Propontis," with the construction and design of whose machinery he was intimately connected. Before so doing he desired to add his testimony of how much they were all indebted to the late Mr Rowan for having shown that the use of high pressure steam was very practicable, and for having assisted in convincing engineers and shipowners that advantage attended its use, that the practical difficulties were either mostly prejudice, or due to defective constructions, which could be avoided. He (Mr Kirk) was then connected with the firm who built the engines and boilers of the "Propontis." This machinery was taken in hand because it was thought, judging by previous experience, that the scheme was a feasible one, worthy of farther trial with all the advantages the best workmanship, &c., could give, and that valuable experience would be got in dealing with higher pressures than were then in vogue. He must at once repudiate Mr Robson's ideas that the use of high pressure steam is attended with practical troubles and difficulties, as the experience gained with the "Propontis" showed that the use of 130 lbs. at all events caused no particular difficulty either in the matter of joints or packings or wear of cylinders or slide valves. The particular type of engine adopted, three cylinders and three successive expansions (somewhat against the late Mr Rowan's wishes who advocated the form of engine he had before used), was selected because by this means the range of expansion in a single cylinder was limited to about 2½ times, the range of temperature in each was small, the expansion was done well without depending much on steam jackets, or refinements of valve, gear, &c. Farther, by dividing the expansion into three steps, many practical difficulties were evaded in connection with steam packings, valves, &c., and leakage past pistons and valves reduced to a minimum. This was borne out by experience, and there was no reason to regret the selection made. Now with regard to the boilers, Mr Jamieson's remark was quite correct. When these boilers were made the late Mr Rowan brought the drawings of boilers of the same kind which had been worked with success in India, and to get the power wanted in the "Propontis" two of these were to be simply grouped into one. Mr Rowan had them grouped into one boiler by connecting the large horizontal water pipes behind the furnaces and connecting the steam domes by the usual steam pipe. In that unfortunate upper connection lay all the subsequent troubles and mishaps. But he should be sorry to cast any reflection on the late Mr Rowan, for on a three days' cruise, neither Mr F. Rowan nor he (Mr Kirk), nor an eminent engineering friend, nor three surveyors of the Board of Trade, found that to this cause was due the excessive fluctuations of water in the gauge glasses. Nor was it discovered till after the ship had been to sea for the best part of two years. Perhaps it might not have been so readily found even then but that the same difficulty had been found in the case of some ordinary boilers connected by pipes in the water spaces near the bottom. The result of this unfortunate connection was that when one section of the boiler was harder fired than the other, the resistance of the increased volume of steam, as it passed out, depressed the water level in that boiler and forced the water through the lower connection into the other section. Worried by the accidents this unfortunate malarrangement caused, the owner had the boilers taken out, and it is to be regretted that the boiler was never tried after the cause of trouble was discovered. The structure of the boiler gave no trouble. There were difficulties in the manufacture, but in working there was no trouble from leakage, and unequal expansion did not seem to affect them. The only serious trouble arose from the rapid pitting of the tubes inside which could not be discovered until on the voyage one of these would break out into a small hole, when fires had to be drawn, water blown out, and a gland put on the pipe. How far this pitting was due to the extreme fluctuations in the water level (five feet being not uncommon) or to the use of improper lubricants in the cylinder (for the use of mineral oil was not then established), or to the frequent replenishings of the boiler by sea water, due to the frequent blowings out when tubes pitted, it was difficult, absolutely, to decide, but he (Mr Kirk) had little doubt it was due to all of these causes combined in some uncertain proportion. Though there was no structural trouble with the brick-lined casings, there was no doubt a considerable loss of heat by their great surface. Besides, most of the heating surface was at a considerable distance from the fire, and this combined with the rate of consumption (about 11 lbs. of coal per foot of grate) being very moderate, caused the temperature to which the heating surfaces were exposed to be exceptionally low. Although this was attempted to be compensated by giving an enormous heating surface, he feared the boiler could not be considered a particularly economical generator of steam. If he (Mr Kirk) recollected aright, from comparing the weight of steam and power shown on the diagrams with that shown by the ordinary compound engine diagrams at 60 lbs. and taking the latter at 2 lbs. coal per indicated H.P., the engines of the "Propontis" ought to have done their work on 1½ lbs. This, however, was never attained. Although this attempt to use high pressure steam was far from perfect he was sure they were all indebted to Mr Rowan for placing on record his father's work in this direction, and though he did not think this was the form high pressure boilers of the future would take, the experience of failure is often more instructive than success. He ought to mention that there was a distilling boiler constantly at work discharging its steam into the receiver of the low pressure cylinder to make up loss of fresh water by the steam leakage at safety valves, &c., which is unavoidable, and which boiler as it worked only at about 20 lbs. pressure could be kept right in the old way by blowing out. The frequent blowing out of the main boilers as described above and necessary refilling from the sea neutralised the action of the distilling boiler. He considered the idea of working only with fresh water at sea a mistake. He had no doubt that was a rock on which the Perkins' system would split. The tubes of the "Propontis" boiler were inaccessible for cleaning or inspection inside, and were unsuitable for working salt water.

Mr JOSIAH M'GREGOR thought the paper must be regarded of service in showing the importance of the late Mr Rowan's experiments in pushing forward high pressures at an early date, and therefore most worthy of being recorded. He was in hopes that some particulars would have been given of the "Telegraph," a high pressure river steamer with which the author's father was connected at a very early date, and which gave extraordinary results. She had an unfortunate end, but which, of course, did not affect the good results obtained. He had come in contact with several of the vessels mentioned by Mr Rowan in his paper, such as the steamers "Nepaul," "Progress," "Punjaub," "Oude," and he had also seen the same class of boilers applied to land engines, working extensive factories in Calcutta, and he must say that his impression of the boilers was far from satisfactory. The boilers in these steamers and in the "Bengal" were answering the purpose —but the most that could be said of them was that they were doing nearly as well as others. They were working entirely with fresh river water, and great care was taken with this water before it was introduced into the boilers, being in fact filtered in a tank with the use of alum before being used. Notwithstanding all this care the inside of those boilers had a considerable incrustation upon them. In some of the tubes of the factory boilers this incrustation had accumulated so as to cause their destruction. He observed in the paper that the first boilers which were cellular had a very small heating surface—he thought only 15 square feet to the foot of grate; while those more recently made had 75 feet to the foot of grate. What was the cause of the enormous increase of the heating surface? Was it that the heating surface in the cellular boilers was inadequate? He would also like Mr Rowan to give them some idea of the rate of combustion in these boilers. From what he could ascertain he thought it was very low, and he was of opinion that the heating surface had a very low efficiency. There was an enormous heating surface in the latter boilers, and consequently the gases escaped at a very low temperature, the draft therefore was bad. A considerable heat of waste gases was necessary to insure a good draught, and he thought that the temperature of the gases in the chimney was too low to insure a good draught. There was no doubt the late Mr Rowan was one of the first to introduce the use of high pressure steam in conjunction with the compound engine, and it must be remembered that at that time boiler-making was not what it is now, and Mr Rowan was compelled by circumstances, in order to get high pressures to use small cellular boilers. Boiler-making had made such strides recently that there was now no difficulty in getting high pressures in ordinary boilers. When they saw boilers 16 feet in diameter working with steam of 70 lbs. pressure he thought that there was little use in resorting to diameters of a few inches only in order to obtain pressures of 130 or 150 lbs. He could see no advantage in that class of boilers over the ordinary class. From Table III., page 79, it would appear that the boilers were exceedingly heavy. There were three columns in the Table headed: "engines," "boilers," "both." He did not exactly understand the meaning of these, as the third column did not appear to be the sum of the other two, which he thought it ought to be, if he understood it properly.

In answer to Mr David Rowan, Mr M'Gregor said that some of the boilers he had referred to were working on land, and that a few of the cellular boilers had lasted some 10 or 11 years.

Mr David Rowan said he thought that was a very good life for boilers having such a pressure of steam. The mode in which the heat was made to ascend and descend was the same as the Earl of Dundonald had recommended. It was rather a weak form of boiler but it did its work well. He understood that the leading of the heat up and down, and then passing away immediately at the head of the furnace bars, was a capital plan, but personally he had no experience of these boilers. The rate of combustion, he believed, was very slow.

Mr H. R. Robson was afraid from what Mr M'Gregor had said that the boilers which had been sent to India were of inferior workmanship. Those which he (Mr Robson) had seen were first-rate—a better job he had never seen.

Mr M'Gregor would be sorry to leave such an impression as indicated by Mr Robson on the minds of the members. The cellular boilers were of first-class workmanship.

Mr Robson said that no doubt corrosion had gone on in these boilers to a great extent. In the "Queen of the Isles" the tubes had given way from inner corrosion, and he did not know that the water had anything to do with it. He believed, however, it might be due to some extent to using the water over and over again. Whether that was correct or not he did not know; but that vessel did not run long until some of the tubes had to be renewed, and he thought the tubes of the "Thetis" gave way similarly. He knew, for instance, that the inside of the boilers of some steamers sailing on fresh water lochs, having ordinary engines there was no corrosion whatever with jet condensers. He believed that was due to the water used. The difficulty hitherto experienced was that they could not get a boiler, that would stand such high pressures as Mr Rowan had used, to be made in such a way as it could be examined internally, therefore it could not be known that anything was going wrong with the boiler until leakage took place, and when such occurred the fire had to be drawn and often the boiler emptied before any repair could be effected or even a tube renewed.

Mr M'Gregor said he thought these tubulous boilers were admirably suited for the purpose of getting inside to see them. They could get into the cylinders for inspection, and could put a light a good distance into the tubes to see their condition. The boilers he had alluded to had given way by pitting in the chambers, more particularly the upright back cylinders, which were mostly patched at the top. Then with reference to Mr Kirk's remarks, the outside casing was generally so cold that one could put his hand upon it. There could not be much loss of heat in the instances he had met with.

Mr HOWDEN said—This paper of Mr F. J. Rowan is interesting in itself, and still more so from a historical standpoint. The earlier period to which it refers recalls a time which it would be well to preserve some records of, a time when there was much discussion among engineers on the advantages and disadvantages of high pressure steam, surface condensation, and high and low pressure cylinders in marine engines.

The use of high pressure steam, in a sea-going steamer necessarily involved the use of a surface-condenser, and obviously also, if a high economy was contemplated, the working of the steam through two cylinders, or what we now call the "compound" system.

There was a revival at the period referred to in favour of steam of high pressure among a small section of marine engineers, the pressures contemplated being so much higher than the practice of the day that it was considered necessary to have an almost entire change in design and construction of the principal parts of the machinery.

Among engineers generally, however, at that time a high pressure in a sea-going steamer was considered, if not absolutely unsafe, at least quite impracticable.

Mr Rowan has recorded how his father, first with the assistance of Mr Thomas Craddock, and afterwards with Mr Thomas R. Horton, entered on the construction of the engines and boilers of the "Thetis," "Athanasian," and "Queen of the Isles," in 1857, 1859, and 1860, the working pressure of steam in these steamers being over 100 lbs. per square inch. This was a sudden leap from the then prevailing pressures of 20 and 25 lbs., or even from the 40 lbs. to which Messrs Randolph & Elder had attained in 1860, and the record of the manner in which it was carried out, and of the results obtained, is instructive.

I remember seeing the "Thetis" in 1859. I never was in the engine-room, there being a considerable amount of exclusiveness in these days in regard to new things of this sort; but I had a bird's-eye view of the engines through the skylight, and the boiler was described to me. The engines had two vertical cylinders, which we learn from Mr Rowan's paper were respectively 21 in. and 42 in. diameter, and 30 in. stroke. The cylinders were placed side by side over the cranks, but instead of being inverted, the piston rods worked upwards through the cylinder covers, and were each joined to a crosshead guided in standards. Each connecting rod, from its journal on the crosshead, passed downwards in the form of a bow encircling the cylinder on both sides, and joining again below just above where it contained the crank pin journal. This bow was large enough to clear the cylinder, and allow of the reciprocating movement of the piston combined with the circular movement of the crank. The boiler, I understand, had water tubes 4 or 5 inches in diameter, standing vertically, and surrounding the fire-grate, the whole being contained in a brick and sheet-iron case, more like those in the "Propontis" than the boilers of the steamers that immediately succeeded the "Thetis." It would have been desirable if Mr Rowan had given in his paper descriptive particulars of the machinery of this steamer. I do not quite make out from the paper whether or not the engines and boilers first erected on board on Craddock's plans were entirely removed. The prevalent idea at the time was that the boiler remained substantially the same, but the engines had been fitted with a new valve arrangement and a new surface condenser, in which the steam was condensed by water in contact with the tubes, while in the one on Craddock's system condensation had been attempted by rapidly revolving the tubes containing the steam in air, the tubes being held in a case in which their whole length was exposed to the atmosphere, their extremities only being fixed in close chambers. Mr Rowan will probably be able to correct these particulars where my memory may be at fault, or where I have been misinformed. Owing to the unusual pressure employed, the novelty of the machinery generally, and the high economy attained on the trials as certified by Dr Rankine, this steamer was the subject of much comment in her day.

The next steamer, the "Athanasian," I remember well, and had occasion to become acquainted with her machinery, shortly after she began to run. She was first tried about April or May, 1860, and it was expected that she would be a considerable improvement in all respects on the "Thetis." As Mr Rowan informs us, this expectation was not realised—her performance, in point of economy, having fallen considerably short, for several obvious reasons, of what had been attained in the "Thetis." I had occasion also to become acquainted with the machinery of the "Sicilia," which was after the same design as that of the "Athanasian," and in this way had considerable opportunity of observing the merits and demerits of the engines and boilers made on this system. I think it must be said that the result of the trials in these various steamers mentioned by Mr Rowan was, on the whole, unsatisfactory — that is, none of them continued to work so that they could have been used for regular ocean service, such as ordinary steamers require to maintain.

In regard to the first steamers, it must be remembered, as Mr Rowan has said, that there was no previous experience in working steam of this pressure in marine engines which could be referred to for guidance, but this can scarcely apply to the later steamers, nor does it explain the cause of their non-success.

Having made my first attempt at the construction of marine engines at an early period of my life, beginning as far back as 1859, and with steam of 100 lbs. working pressure surface condensation, and compound engines, and having learned much from noting the defects in the machinery I constructed, and the causes which led to its abandonment after some years' trial, I would offer a few remarks in no unfriendly spirit, on what I conceive to be the weak points of this system of working high pressure steam in marine engines introduced by Mr J. M. Rowan.

Let me refer shortly to the three principal parts of the machinery, —the boiler, the surface condenser, and the cylinders.

The boilers in all these steamers were of the tubulous kind though some of them had fire-tubes inside the square water-tubes, This design of boiler was doubtless selected because of the greater proof strength obtained from its sub-division into numerous small sections or vessels, than an ordinary tubular boiler containing fire, water, and steam spaces in one vessel is capable of. It was therefore supposed that greater safety also would be secured in their use for supplying steam of high pressure. This supposed greater safety of these tubulous boilers is, however, quite a fallacy, and they are, besides, difficult to keep in order even on land and when worked with pure water, and much more are they difficult to keep in order at sea. Influenced by this idea of strength and safety, and apparent simplicity of construction, I tried this class of boiler also about the time referred to, but having experienced their inherent defects, I have avoided ever since using a boiler of this kind for any purpose.

The boilers of this class fitted in the "Athanasian," "Sicilia," and other steamers were necessarily complicated and difficult to repair or to clean even on the outside; and in the event of salt water getting inside. and causing incrustation, it was quite impossible to remove it. Now in all the earlier steamers—possibly the "Thetis" was an exception—salt water did get into the boilers from the surface condensers having leaked considerably. When, therefore, the boilers once got incrusted, as the incrustation could not be removed, those parts of the boiler exposed to the flame burned away, and the thinner parts, such as the tubes, though not exposed, corroded very quickly, and a general leakage and trouble was the result. I have no hesitation in saying that had these steamers been fitted with plain boilers of the locomotive type, at least three-fourths of all the troubles which arose from the use of these tubulous boilers would have been entirely avoided.

The surface condensers, as I knew them in the "Athanasian" and "Sicilia," and as, I suppose, they were also in most of the other steamers, were subdivided into a number of sections, and were altogether too complicated. The several sections were vertical, and could be dealt with separately. They surrounded a central water space, in which a fan or series of blades on an upright spindle, and worked by gear below connected to the engines, agitated the ascending sea-water among the tubes, the steam being condensed inside the tubes. This agitator, I found, was not, however, used by the engineers at sea. Owing to the numerous joints the condenser was very difficult to keep tight, and the tubes used being very small, it was a work of great labour to examine them or rejoint them when necessary.

This condenser, I am sure, had a great deal to do with originating and continuing the troubles in the boilers. It will be noticed that the boilers in those steamers which worked so long on the Ganges never were in salt water, and used filtered fresh water only.

Coming to the cylinders, each single engine had three—one high pressure in the centre and two low pressures on each side, making a total of six cylinders in each pair of engines. The cylinders in each engine were all connected by their piston rods to one crosshead, from which a connecting rod gave motion to the crank in the usual way—the piston rods thus working altogether simultaneously. Whatever might be said in favour of this multiplication of cylinders for very large engines using steam of a high pressure, it does not tend to economy in small engines such as those fitted in the steamers referred to in Mr Rowan's paper. The engines of the "Athanasian," if I remember rightly, had two high pressure cylinders, 9½ in. diameter, and four low-pressure 19 in. diameter. The steam in passing from the end of the high-pressure cylinder, in which it had done its duty, to the opposite ends of the two low pressure cylinders—as is necessary in this arrangement—came in contact with such a large surface of metal in proportion to its own bulk or weight, that a very great loss of pressure ensued, though the passages and spaces in the valve chests were as small as they could well be made. The loss of pressure, I remember, was about 50 lbs. in the "Athanasian." When the terminal pressure in the high pressure cylinder was about 50 lbs. it began in the low pressure cylinder very little above the atmosphere.

I believe the points I have mentioned were the weak points in the machinery introduced by the late Mr Rowan, and the cause of the shortcoming in economy and efficiency which might otherwise have been attained. Both engines and boilers in the steamers I was acquainted with were well constructed, and had the look of being carefully designed, and I believe there was very little to complain of in their working asising from defective workmanship.

I may mention that my acquaintance with these engines of Mr Rowan's arose from having been employed by the owners of the "Athanasian" about the latter part of 1860 to refit her with new boilers, which were to fulfil the conditions of working at 100 lbs. pressure with salt water, if necessary, and to be accessible in every part, outside and inside, for cleaning and repair. As no record appeared to exist of the power developed by the engines, in order to ascertain this before designing the boilers, I met the steamer at Dublin on her voyage home from France, and having there fitted on indicator gear, took a series of diagrams on the passage between Dublin and Glasgow. The new boilers I fitted in the vessel in May, 1861, and the owners were so far satisfied with the results obtained that they purchased the "Sicilia" about the end of 1862, and gave me an order to fit her with the same kind of boilers as I had constructed for the "Athanasian," and which had then been over 18 months regularly at work.

I would have wished to give some account of the engines and boilers I constructed in 1859, to work at sea with 100 lbs. pressure, as it would probably interest a good many here, and I think it could not fail to be instructive at present, when pressures are gradually rising to nearly the same point as in these earlier days. I have not, however, had time to prepare anything, for until yesterday I had not expected to be present to-night. Should the discussion be continued, I will probably have an opportunity of describing the details of that machinery, and of pointing out the causes which led to its being finally abandoned.

I would only say further at present that a grand mistake of that time was these complicated boilers, arising from the idea that such high pressures could not be safely carried in an ordinary tubular boiler. Pressures quite as high as any that have been used in these steamers fitted with Mr Rowan's engines, can be carried quite as safely, indeed, more safely, in an ordinary boiler, and obtained more economically, and the boiler kept in order, without giving one-tenth of the trouble which these tubulous or sectional boilers give. This conviction has been forcibly impressed on my mind from the experience gained in connection with working high pressure steam at sea. It appears to me therefore that, with all the dearly-bought lessons which experience has taught to guide us, the use of tubulous boilers in steamers cannot be too strongly condemned.

I must also express my admiration of the great energy and perseverance exhibited by the late Mr J. M. Rowan, in continuing, amidst good report and bad report, to advocate, and induce others to adopt, his system of working high pressure steam, no doubt being himself convinced of its being the best possible arrangement that could be adopted for the purpose.

Mr ALEX. SMITH said he had had a little experience with these boilers. It was about 1861 or 1862 that three steamers were built for the River Company at Calcutta, which were sent out and put in working order there. They were built at Newcastle, and Mr H. R. Robson spoke of them as being of most excellent workmanship. They worked for fully ten years before they were replaced. He believed his firm made three sets of boilers to replace those referred to about six years ago, and so far as he had heard they had been working satisfactorily. Of course it must be observed that they had fresh water in the river to work with. He thought it was an objectionable mode of working boilers to condense the same water continuously, thus throwing it back regularly into the boilers, particularly in multitubular boilers. The construction of the boilers was such that they could not be examined, and he thought probably that Mr M'Gregor had not been looking carefully into them, for the tube had a considerable bend, so that though one could get into the chamber, yet only a very short length of the tubes could be seen into, therefore no inner examination of them could be of an assuring or satisfactory kind. He thought if boilers like those that had been supplied to the River Company, and used with a continuous supply of fresh water, carefully filtered in an ordinary way, and well looked after, it would be found that they would stand even a very high pressure, and would work as long as many of the ordinary boilers. He believed from what had taken place that was found to be the case. But if they were worked with salt water, or water condensed and recondensed, and thrown back again into the boiler, they could not stand the test of general work: for it was found that when water was condensed and thrown back again into the boiler, its power of corrosion became very rapid; he therefore did not think it was a safe thing to work with condensed water in any ordinary boiler, especially in those with small tubes. At first these River Company boats were not well handled, but when the person in charge took the boiler in hand, they answered the purpose very well, only consuming half the fuel of other vessels of the same sort on the river. That he considered a satisfactory state of matters. It was different now, after being educated to work with high-pressed steam, and he did not think they ought to talk about these boilers with the high-pressure boilers made now. It was different twenty years ago, when marine engineers condemned the use of tubulous high-pressure boilers with salt water. At that time the boilers that were used in the River Steamship Company at Calcutta had done better than any other boilers that had been sent out, and worked very satisfactorily for ten years; and he thought with Mr David Rowan, after looking at the whole circumstances, that they did very well. He did not think much more could be expected of them, although the construction was a little complicated, there was not much trouble in renewing the tubes, provided that it could be done occasionally. But there was a very great amount of trouble, as Mr Robson had explained, where the fire was inside, and the water outside, as the tubes could not be plugged so easily, and it was very difficult to discover the weak ones. These boilers were proved up to 300 lbs., and they had no difficulty in replacing any weak tube. He thought that Mr Rowan's father was entitled to very great credit in endeavouring to bring into practice the use of high-pressure steam in marine engines, and when he found that the usual shape of a boiler at the time that he was dealing with this subject was far too weak to bring up the pressure of steam he required, he was driven to seek some kind of boiler in which there was perfect safety, while being able to use the pressures he required. He thought the boilers that were constructed in this manner accomplished that object; but did not consider Mr Rowan's boiler suited for being worked with salt water. Probably by and bye they might have something of a boiler different from Mr Rowan's, and yet not of the present size and form. The strain upon a boiler of 10, 12, or 16 feet diameter, at 120 lbs. pressure, was very great, and if anything went wrong the whole ship would go to pieces; but the boilers that Mr Rowan had made might give way and not endanger the vessel; and no doubt that led Mr Rowan to adopt the plan which he had done latterly. The boilers that his firm made had a large grate surface, and very slow of combustion, so that the top and other chambers were subject to the heated gases as they rose up, and they did not escape until they came away down below the centre chamber—(Mr Smith here made a sketch on the black-board illustrative of his remarks)—and that was the system Mr Rowan tried to introduce in the working of these boilers. The outer casing was lined with fire-brick, but the amount of heat from the casing was not very great, because all the heated gases had filled the space among the tubes and centre chambers before they escaped to the outer casing. Mr F. J. Rowan proposed a system of working with forced combustion, while in the first trials that his father had made, he had a much more rapid combustion than in the last, and he would like Mr Rowan to explain the difference that he proposed in regard to that. He thought that the late Mr Rowan deserved very great credit for grappling at the time he did with the adoption of the working of marine engines with high-pressure steam.

Mr James Gilchrist said that he had some experience in the manufacture and repairing of haystack boilers, and had never seen pitting in any of them. He had often seen corrosion, but not pitting, as he considered the pitting was seldom if ever found with a common jet condenser, and was caused by the action of the surface condenser. He asked if Mr Robson had seen any appearance of pitting in the "Lord of the Isles?" as that vessel had a surface condenser.

Mr Robson had not seen the boilers of that vessel internally, and therefore was not prepared to say anything about them. With regard to the use of fresh and salt water in boilers, he threw out the idea that fresh water was better than salt. Some twenty or twenty-five years ago several gunboats were built for Her Majesty's navy, fitted with non-condensing engines, and a steam pressure of about 100 lbs. per sq. inch. While these vessels were used on fresh-water rivers, their boilers continued tight and wrought satisfactorily, but so soon as they were run in salt water, at once the tubes began to leak, and became most troublesome. About that time a screw steamer was constructed on the Clyde, having similar engines and boiler to those of the gunboat described. With that boiler there was no end of trouble, with the tubes leaking. The only reason that he (Mr Robson) could condescend upon was the use of salt water in the boiler.

Mr Kirk corroborated that opinion.

The President having proposed that the paper for the evening by Mr M'Gregor being on the subject of boilers, it might be well for Mr M'Gregor to read his paper now, and to adjourn the discussion of Mr Rowan's paper until next General Meeting, when both papers could be more fully discussed. This was agreed to.

Note Received from Mr F. J. Rowan on 30th December, 1879.

From the report of a voyage of the S.S. "Western" to New Zealand and back, which Mr H. R. Robson was kind enough to hand me, it appears that her boilers were fitted with cast-iron connections between the leaves—below for water circulation, and above for steam connection with the steam domes.

This plan was tried as a substitute for the rigid wrought-iron connections of former boilers, which it was almost impossible to make steam-tight.

In the "Western," variations of expansion of the different metals and strains caused by the rolling of the ship, the boilers evidently not having been braced or tied together except by these connections, caused the fracture of many of the connections, with consequent loss of water and steam.

To remedy this the rough and ready plan of removing the boilers was proposed by Messrs R. Stephenson & Co. of Newcastle, and adopted by the owners.

On the Construction and Efficiency of Marine Boilers.

By Mr JOSIAH M'GREGOR, C.E.

Received and read 23rd December, 1879.

(SEE PLATES VIII. AND IX.)

The duty of a steam boiler is to generate steam from water by the combustion of fuel, and the efficiency of a boiler is the measure of the steam produced by the fuel consumed.

The subject of boiler construction may be considered to divide itself into the following considerations:—

1st. The furnace and its adaptation to the efficient combustion of fuel.

2nd. The boiler, as a water holder, and circulator, and steam storer.

3rd. As a structure to resist pressure and wear and tear under the varied temperature and conditions to which it is exposed.

The endeavour being, in the construction of a boiler, to combine the greatest efficiency in each of the above particulars.

The Furnace.—The construction of this essential portion of a boiler is, even at the present day, frequently either imperfectly understood or ignored. Cramped furnaces and combustion chambers, with dense smoke and flaming funnels, are not uncommon. It is open to considerable doubt whether the long, low, circular furnace, now so common in marine boilers, with a separate combustion chamber to a great extent detached from the furnace, is the most efficient form of furnace for the combustion of fuel with the least possible quantity of air. I decidedly believe it is not; it is unlikely the temperature of the fire can rise so high in this detached arrangement as it does when the combustion chamber and furnace are all in one, as in the locomotive form of furnace, or that of a Field tubular vertical boiler; or is it likely the admixture of gases at a high temperature, so essential to complete combustion, can be as thorough. From a structural point of view it has its advantages, but these advantages should not be exclusively considered.

The first consideration in designing a boiler is the draught, or rate of combustion at which it is intended to work the furnaces. A natural draught, or that produced by the chimney only, is almost universal in marine boilers; frequently a steam jet is introduced into the chimney as a sort of supplementary arrangement; but the rate of combustion is seldom thus increased more than 40 per cent., and that at a considerable sacrifice of steam. The rate of combustion in marine boilers is, therefore, seldom more than 20lbs. per foot of grate per hour, in the best furnaces—16lbs. is a much more usual good average working rate.

The first question that arises in a consideration of the subject, such as we are giving, is—is a natural draught the most suitable for marine purposes? I decidedly think not, and that the day is not far distant when we will have all our marine boilers working with forced draughts only.

It takes about a quarter of the available heat of combustion to produce a chimney draught, and which goes to waste up the chimney. With a chimney draught, also to insure complete combustion, the products of combustion should, according to the best authorities, be diluted with as much air again as is necessary for combustion, but which greatly lowers the temperature of the fire. About 2440 degrees is the temperature reached by a fire produced by natural draught, while with forced draught and half the quantity of air for dilution, the temperature is 3200 degrees, and the waste gases need not exceed in temperature that of the external air. Of course, against this saving we have to put the power necessary and cost of extra machinery to produce the forced draught; but which is a small item, as will be seen from the following:—For boilers with say 50 square feet of grate, and burning 56lbs. of fuel per foot of grate per hour, or ·0155 lbs. per second, to produce which the pressure of air under the fire, supposing it is supplied by mechanical means, we may take for illustration at 3 inches of water equal 16 lbs. per square foot (but which will vary with different arrangements) Then the power required in supplying the requisite air—

$$= P \frac{w V_0 \tau}{\tau_0}.$$

$$= 16 \frac{\cdot 0155 \times 225 \times 511}{493 \cdot 2} = 57 \cdot 8 \text{ ft. lbs. per foot of grate.}$$

Or, in total indicated horse power,

$$= \frac{57 \cdot 8 \times 60 \times 50}{33000} \times 2 = 10 \cdot 5 \text{ H.P.}$$

P = lbs. pressure.
w = lbs. fuel per second.
V_0 = Vol. of air at 32 degrees.
τ = Absolute temperature of air.
τ_0 = Ditto of V_0,
c = Co-efficient, say = 2.

Boilers of this size would indicate about 1400 horse power, so that the power required to work the fan is a small item, and does not compare with the expenditure in producing a natural draught.

Then we have the inestimable advantage, as compared with the natural draught slow combustion, of at least halving the grate surface and greatly reducing the size of the boilers required. Again, considering that the rate of conduction through the heating surface is as the square of the difference of temperatures, from the higher temperature of the fire, we have greater efficiency of the heating surface, and as the waste gases may be discharged at a lower temperature, we can, through the use of forced draught, have greater economy. And which, coupled with the very great advantage of nearly halving the number of boilers required, it is perhaps singular it has not already been very generally adopted. Of course until within recent years the general use of salt water in boilers prevented its adoption, and which, even with natural draught temperatures, frequently rendered it a matter of great difficulty and expense keeping boilers in a workable condition. When surface condensers. were introduced, this cause was to a great extent diminished; but the use of a greater or less amount of salt water continues to the present day, and it was not till the study of and experience with the compound engine of the present day had advanced, that now the conditions of the insides of a number of marine boilers are such as to admit of the profitable application of forced draught. The necessity of increased appliances has also stood in the way of its adoption.

I will not stop to consider the numerous appliances for smoke prevention, mechanical stoking, and furnace cleaning, that have from time to time been brought before the public, being principally mechanical appliances to save labour, and only in a minor degree affect the efficiency of a well-designed boiler. Perhaps, however, I should note the various ways of producing a forced draught, and will mention five, it being understood that the boilers are for use, with marine condensing engines, and that the exhaust steam is not available for a blast.

1st. I will mention a steam jet in the funnel differing only from the common arrangement mentioned previously, inasmuch as the funnel is specially adapted to its use.

2nd. The use of blowers, such as Korting's, worked by a jet of steam inducing a current of air, and which is led to the ash-pit, the mouth of the furnace being air-tight.

3rd. The insertion of such a blower in the funnel, inducing a current of air through the fire, as in No. 1, instead of forcing it through, as in No. 2.

4th. Supplying the requisite air to the furnaces by means of a fan or other blowing machine, worked either by gearing from the main engines, or by an engine for the purpose, the exhaust steam from which being returned to the main condenser, and the air supplied as in No. 2 to the ash-pit, the mouth of the furnace being air-tight.

5th. A similar arrangement of blowing machine to No. 4, the air being discharged into an air-tight stoke-hole, the work of which is carried on under pressure of the blast.

The first three arrangements have the advantage of having no working parts, but as they waste a considerable amount of water as steam, they are not nearly so desirable as the other arrangements mentioned.

The 4th and 5th arrangements waste no water, are most economical and probably most efficient. The 4th necessitates the air being carried to the furnaces by means of pipes, and renders stoking and manipulation of the fire somewhat more difficult, as both ash-pit and furnace-mouth have to be kept closed while the blast is on. These difficulties are entirely overcome by the 5th arrangement, all the operations being carried on in the stoke-hole under the blast pressure, and which has been found to have no injurious effects on the men. There is also an advantage with both the 4th and 5th arrangements, and which will likely, with sea-going steamers, be appreciated, *i.e.*, they render unnecessary the large air grating ventilators to the stoke-hole, which no only occupy considerable room, but are frequently a source of great anxiety.

We come then to the second division—the boiler as a water holder and circulator and steam storer. I have said the duty of a steam boiler is to generate steam from water, and, gentlemen, if this duty only were imposed upon our boilers, we would have had fewer difficulties and better results. But the fact is, the water supplied is frequently a dilute solution of innumerable salts; sometimes they are even concentrated, and as frequently mixed with mechanical impurities. Of course the difficulty is to get pure water, but this, with care and attention, can generally be obtained. I know of vessels that can run for several days, continuously at sea without any supplementary feed, and even then a very little supplies the deficiency due to leakage, and which a very small still can easily make good. This, I know, has occasionally been tried, but without satisfactory results. The impression is that it augments the pitting of the inner surface of the boiler so commonly met with, and this I believe, as hitherto tried, it does. It tends to keep the surface of the iron clean, and expose it to the action of the acids generated from the oils and salts mainly returned from the engine, and the remedy that is always resorted to is the use of a greater amount of sea or limey water, so as to get a preservative coating over the surface of the boiler.

I therefore think the direction in which one of the greatest improvements is to be looked for in the working of marine steam boilers, is in the care and attention bestowed on the purity of the water used, and I can foresee no great difficulty in the way of using absolutely pure water, distilled sea water, with the use of such acid absorbents as lime, &c., the greatest care being taken also in the use of lubricants, in fact, as nearly as possible their abandonment in the internal working parts of the engine. In such matters as the joining of doors, cocks, &c., much greater cleanliness is also frequently possible.

Returning, however, to boilers considered as pure or impure water holders and circulators, there are great differences as to the quantities of water different arrangements of boilers contain per unit of surface. I do not think any advantage can be pointed to in having a large quantity of water in a boiler, while on the other hand there are several disadvantages. Weight is the most important, and which in shallow-draught steamers is of the greatest importance. Circulation is the next, and which is not likely to be so brisk, and is much more difficult to start with large holders of water, necessitating the use of hydrokineters, and such like.

I regret that, situated as I am in this country, in a measure away from my books and papers, I am unable to bring forward the numerical data and plans I should like to illustrate my subject, but would refer to Figs. 1 and 2 (see Plates VIII. and IX.), and which illustrate two classes of boilers I have recently had constructed. They are almost exactly of the same power, as will be seen from the following table—

		Fig. No. 1.	Fig. No. 2.
Diameter,	... ...	8 ft. 0 in.	4 ft. 9 in.
Length,	... ...	9 " 5 "	15 " 5 "
Furnace,	... diam.,	2 " 9 "	4 ft. $1\frac{1}{4}$ in. × 6 ft. 0 in.
Thick. Shell, ..	...	$\frac{5}{8}$ in.	$\frac{3}{8}$ in.
Do. Furnace,	...	$\frac{7}{16}$ in.	$\frac{3}{8}$ in.
Grate area,	... ...	55 sq. ft.	50 sq. ft.
Total heating surface,		1445 "	1486 "
Working pressure, ...		80 lbs.	80 lbs.
Water steaming surface,		128 sq. ft.	133 sq. ft.
Weight of boilers,		19 tons 0 cwt. 0 qr.	12 tons 10 cwt. 0 qr.
Do. water in boilers,		11 " 8 " 0 "	9 " 0 " 0 "
Do. of superheater,		1 " 12 " 0 "	1 " 12 " 0 "

They illustrate two important classes of boilers—the cylindrical with circular flues, and the locomotive. The former may be taken as a boiler that contains a large quantity of water, and the latter though containing more than tubulous boilers, a small quantity. In the examples before us the cylindrical boiler contains 11 tons 8 cwt., while the other contains only 9 tons.

Then as to circulation, a well-designed locomotive boiler barrel is probably as well adapted to promote circulation as any other arrangement, but the sides of the fire-box are not so. In the other class of boiler the arrangement, though in some respects good, can hardly be said to be eminently calculated to promote circulation. The common square boiler and haystack boiler are no better. It may therefore be said that on the whole, in the matter of circulation, there is no marked superiority of one class of the usual marine boiler over another, but that probably the locomotive type is, if anything, superior.

I have referred to the matter of circulation, as it leads to and bears to some extent on the important question of priming, and which we will now consider.

Priming.—There are few engineers who have not had in some way to contend with this evil. Priming causes the water of the boiler to come away with the steam. It appears to be a rising into froth of the whole in bad cases, or a considerable part of the surface of the water in less violent cases, and which is not only trying to the machinery, but if unchecked, soon takes the greater portion of the water out of the boiler. The causes of priming, and how to prevent it, are still imperfectly understood. It can be checked by diminishing the ebullition, either by allowing the pressure to increase, or by reducing the rate of evaporation, but which prevents the boiler being worked at its full power. It can also be reduced or stopped for a short time by the old process of injecting oil or tallow, which generally checks it effectually for a few minutes, after which it is worse than ever.

To guard against priming in the designing of a boiler a number of precautions have been taken, which, however, have very often proved of little account. The principal is to supply a large amount of steam room, yet some boilers so arranged with enormous steam room prime badly, while frequently boilers with comparatively little steam room are little troubled with priming. This steam room is applied sometimes by keeping a large portion of the top of the boiler itself as a steam reservoir. Sometimes the boiler contains little steam, and the room is supplied by a large cylindrical reservoir on the top, or annular superheater round the funnel. Few of the attempts, however, to stop priming by this process alone can be said to have proved eminently successful. Steam collecting pipes, where none exist, originally have frequently been applied, with the view, as a number of engineers say, of preventing priming, and generally when applied with care with satisfactory results, but I believe they do not so much prevent true priming as that of violent suction currents from above, and which, in virtue of the current alone will draw up considerable bodies of water like water-spouts, without there being any real priming in the boiler. I do not therefore consider them much of a remedy for true priming, but they are an efficient arrangement for collecting the steam in such a way as to prevent any considerable current in the steam-room or along the surface of the water —a point that should be carefully attended to in the designing of a boiler. Priming is always worse with dirty water, and it is astonishing how little dirt of a certain kind will start priming. In boilers, therefore, that have a tendency to prime the necessity of clean water is most important, in order to keep them working at their maximum power. There is one consideration in the construction of ordinary marine boilers to prevent priming, which, I think, has escaped to a great extent the attention of boiler-makers, but which I have found, if attended to, reduces priming to the smallest limits, where some boilers with great steam room, applied as above, could only be worked at a fraction of this power. This consists not in proportioning the steam room to the size of the boiler (say the grate surface) but that of the steaming surface of the water. I mean by that the surface of water in the boiler, to which the steam generated below rises and enters the steam room. From this it will be seen I attribute one of the greatest causes of priming in a boiler to the contracted nature of the surface of the water to which the steam rises, and through which it all has to pass. When this is so contracted as to render the velocity of the steam through the water, at this point considerable, and the surface agitation excessive, it, as can easily be understood, will have a great tendency to lift the water with it, and which any amount of steam room above can have no influence to prevent. With ample water steaming surface, then, and an efficient arrangement for collecting the steam, the amount of steam room, of course within limits, is not of much importance.

As to the class of boiler that fulfils the conditions I have mentioned above that affects priming most, viz., good circulation and large water steaming surface, we have seen that the locomotive form of boiler is at least not inferior to others in the matter of circulation, while, from its shape, less difficulty is experienced in obtaining a large proportion of steaming surface. In the examples we have before us Fig. 1 has 128 square feet, or 2.33 times the grate; and Fig. 2, 133 square feet, or 2·66 times the grate, and that with the use of smaller tubes. We have also seen in these examples that the weight of water in the locomotive boiler is much less than in the other type, so that in the second division of our subject the locomotive form of boiler for marine purposes appears to be superior to the usually adopted forms.

I will now proceed to consider the third division of our subject —The boiler as a structure to resist pressure and wear and tear under the varied temperatures and conditions to which it is exposed. Until comparatively recently marine boilers were almost universally constructed on the square type, but the increasing demand for high pressures rendered the adoption of this type in some respects inconvenient, and consequently they gave place to forms more easily adaptable to those pressures, though perhaps not always so efficient from other points of view. A square boiler, except as a structure to resist pressure, is a superior boiler to the now almost universally adopted cylindrical forms; but the difficulty of staying flat surfaces, and of keeping clean and in order square boilers so stayed for high pressures has necessitated the adoption of cylindrical forms. 45 or 50 lbs. is probably the greatest pressures that have been attempted in square boilers, while 70 or 80 lbs. is common with cylindrical boilers, and 100 or 110 lbs. is to be met with. Fig. No. 1 represents approximately perhaps the most usual form of cylindrical marine boiler. It is undoubtedly a form well adapted to withstand high pressures. It is comparatively unencumbered with stays, and admits of easy access to almost any part for inspection, cleaning, and repairs.

The haystack boiler, another type of the cylindrical boiler, does not possess to such an extent this immunity from obstructions. In this respect the Field tubular boiler is somewhat better. But all the cylindrical types of boiler that contain furnaces and heating surface within the same external shell necessitate large diameters, and, consequently, great thickness of plates, rendering them heavy and expensive. The locomotive type of boiler, on the other hand, though cylindrical, is arranged with the furnace and heating surface under different portions of the cylinder, thus greatly reducing the diameter required to contain the necessary areas, and consequently reducing the thicknesses of plates. The effect of this is very conspicuous in the examples noted. While the weight of the two boilers in Fig. 1 is 19 tons, the weight of those in Fig. 2 is only 12 tons 10 cwt.

Perhaps the greatest difficulty, and which is not considerable, in adapting the locomotive form of boiler to marine use, is that of staying it, so as to admit of ready access for cleaning and repairs. In the example given an arrangement is indicated that overcomes this difficulty, and there are many others.

From the above considerations I think it will appear that the locomotive form of boiler for marine purposes is worthy of more extensive adoption. Its length, and the necessity of space for cleaning from behind, are the greatest objections to it; but against this they have the advantage of being low, and as in the examples given, half as much boiler power again can be got into the same breadth.

Before closing I will allude briefly to marine tubulous boilers, various kinds of which have from time to time been tried, but none can as yet be said to have given satisfactory results. I believe that most of them are quite as heavy, and more expensive than ordinary marine boilers, and that therefore the only advantage that can be claimed for them is that of the comparative effects in the event of explosion. That they do burst, as hitherto introduced, and with disastrous effects, is unfortunately too well demonstrated. It is this liability that has usually been the cause of their being replaced by others. Nor does it appear, if we except one or two recent trials, that the pressure at which these marine tubulous boilers have been worked are in excess of those obtainable in ordinary boilers. I am not aware of any working with a greater than 115 lbs. pressure, while we have marine boilers, 16 feet diameter, working with 70 lbs., and a little smaller with 90 lbs., and smaller still, with 110 lbs. I see no reason why 150 lbs., or higher pressure, should not be adopted with every safety in existing types of marine boilers if means are taken to ensure pure water only being used. I therefore fail to see any advantage in the tubulous boiler hitherto introduced over the ordinary marine boiler.

On the Introduction of the Compound Engine, and the Economical Advantage of High Pressure Steam; with a description of the System introduced by the late Mr J. M. Rowan.

By Mr FREDERICK J. ROWAN, C.E

On the Construction and Efficiency of Marine Boilers.

By Mr JOSIAH M'GREGOR, C.E.

The discussion on these papers was resumed on 23rd March, 1880.

Mr HOWDEN gave a description of compound engines and boilers made by him in 1859-60, the working pressure of steam being 100 lbs. per square inch. These engines and boilers were fully illustrated by diagrams. He also reviewed the marine engineering of that period in connection with the introduction of the compound engine into marine practice.* In conclusion, Mr Howden said that he thought Mr M'Gregor's paper was an exceedingly good and suggestive one, and that his ideas therein stated were quite in the line that he himself had been advocating, and quite against the tubulous boilers advocated by Mr Rowan.

Mr JOSIAH M'GREGOR said he thought it desirable to make a few remarks on what Mr Alexander Smith had said with reference to Mr Rowan's boilers, as to some extent a wrong impression might be

---

* On account of the extent and scope of these remarks it has been deemed advisable to hold them over, with the attendant illustrations, so as to form an independent paper for next Session, when a more extended discussion of this important subject would, it is believed, prove interesting to the members. —ED.

formed from what had been said. He would take them in the order mentioned. Mr Smith remarked that the boilers in question "worked for fully ten years before they were replaced." This was perhaps only in a measure correct, as they were made up of a number of cellular segments joined together, so that when any of these segments became particularly troublesome through wear and tear, or otherwise, they could be removed and be replaced by others, which procedure could go on for ever, and yet retain what might be called the same boilers. These boilers, he knew, were treated to some extent in this way, which probably added to their longevity. Mr Smith then said that his firm made three sets of boilers six years ago, to replace the others, but he did not say they were quite a different class of boiler. The former were cellular, the latter tubulous boilers. Then he talked of them collectively as working satisfactorily. The satisfaction afforded might be judged of from the fact that the former were not replaced, and that in three of the vessels only they were replaced by the new tubulous boilers, of which great things were expected, and which were also fitted, not long after, to a new and larger vessel, the "Bengal," belonging to the same company. Of the satisfaction these latter boilers had given, he had in a previous remark said that the most that could be said for them was, that they were working nearly as well as other boilers, which was probably the very most that could be affirmed regarding them. He had just heard that the boilers of the "Bengal" were being replaced by ordinary boilers, which had also been supplied to all the newer vessels of the company. Mr Smith thought probably his remarks were not based on careful observation. It had been his lot to examine more carefully into the working of these boilers than the majority of engineers, and he could not say he experienced any great difficulty in these examinations. The tubes themselves also admitted of quite as thorough an examination as those in ordinary boilers. Mr Smith then remarked that when these boilers were properly handled (which must have reference to the cellular boilers), they consumed only half the quantity of fuel of other vessels of the same sort on the river. He would like very much indeed to see the proof of this; on the contrary, he had every reason to believe that they burned more than an average quantity of coal per unit of water evaporated, and that what superior economy might have been shown over that of other vessels was due entirely to the compound engines and surface condensers with which they were fitted, and which none of the other vessels on the river had at that time. To attribute this economy, therefore, to the boilers was absurd. By the time the tubulous boilers were supplied, several other vessels had been fitted with compound engines, but with ordinary boilers, which had given superior results to those with the vessels under notice. From this it will be seen that it was simply nonsense to say that the boilers alluded to had done "better" than any other boilers sent out, and that they had worked "very satisfactorily." Mr Smith said it was a matter of no great difficulty replacing the tubes. This he could not understand: some of the tubes may be easily replaced, but with others it is a matter of the greatest difficulty. Mr Smith further remarked that the strain on a 10, 12, or 16 feet boiler at 120 lbs. pressure was very great, and that if anything went wrong the whole ship would go to pieces. Perhaps Mr Smith would not believe him when he said the strain on a 10, 12, or 16 feet boiler was not very great, and was not, or should not be, greater than on a 3, 4, or 5 feet boiler, which was regulated by the factor of safety that might be considered desirable. It would, perhaps, be of use to the Institution if Mr Smith would state the factor of safety used in the construction of the cylinders and steam receivers of the cellular or tubulous boilers under notice. Then, relative to the whole ship going to pieces, as he had not yet heard of an instance of this with any of the high pressure cylindrical boilers now in use, perhaps Mr Smith could give an example of the cases that render the adoption of tubulous boilers preferable. That terrible accidents have occurred, and do occur, with these high pressure boilers, no one would contradict, but he believed they were pretty well matched in this with the tubulous and the old low pressure boilers.

Mr H. R. Robson said, with regard to the locomotive class of boiler being fitted on board steamers, he might mention that about the year 1858, Messrs Neilson & Co. made three such boilers for a German steam packet company. The entire boilers, with tubes and stays, were made of cast (crucible) steel, and the workmanship was most excellent. They were intended to carry a steam pressure of about 120 lbs. per square inch. He (Mr Robson) had never heard how they had answered, nor was he aware that any repeat of the order had ever been given. His opinion was that the locomotive type of boiler was not suited for marine purposes, except for vessels running on fresh water lakes, or clear fresh water rivers; for, although surface condensation was now so successfully carried out, still, from leakage and accidents of one kind or other, sea water or muddy water was often unavoidably supplied to marine boilers, which soon accumulated in such contracted water spaces as round the fire-box of a locomotive boiler, which was generally only 3 to 4 inches wide; and also the water space at the fire-box tube plate was very contracted. These parts were impossible to see, let alone get at to remove any deposit that might gather upon them. He supposed it was from the same reasons that boilers on Mr Rowan's plan had done best which had been fitted in steamers plying on the fresh water rivers in India. Other vessels so fitted, and employed in sea service, both in this country and Australia, had not, so far as he could learn, done so well; indeed, they nearly all had only been in use a short time until they had to be taken out. With regard to the strength of these boilers for the pressure intended, they had a very large margin of safety. The objections he had to them were that they could not be examined internally, nor could they be properly cleaned. On that point, with regard to the locomotive boiler, he quite agreed with the remarks Mr Howden had made. With regard to the annular water spaced boiler described by Mr Howden, having inspected it from time to time while in progress, and also after being at work in the S.S. "Ailsa Craig," he was aware of the great difficulties experienced with it, not being able to even see into it, let alone to sludge it. It proved to be a very expensive experiment to the owners and, as Mr Howden had informed them, had soon to be replaced with one of another design. Such boilers as these were not, in his opinion, at all to be compared with the high pressure boiler now universally adopted. Their great recommendations were that they could be thoroughly examined, and were accessible for cleaning purposes. Then, with regard to the factor of safety of large diameter boilers, he endorsed the remarks in Mr M'Gregor's paper that it was simply a matter of increasing the thickness of the shell plates, the rivetting of which together was now so easily and satisfactorily accomplished by the rivetting machine.

Mr D. Halley drew attention to the two boilers shown in Plates VIII. and IX., and remarked that both the locomotive and marine were very inaccessible boilers, and he thought that it would be impossible to keep them running for any length of time. The locomotive design had not only the objectionable feature noticed by Mr Robson—the narrow space at the side of the fire-box—but also, from the way in which the tubes were set, they could not be scaled. If they had been set as in the ordinary locomotive principle—that is, zig-zag instead of vertical—it would have been a little better. With regard to the ordinary marine boiler, the same difficulty occurred with regard to scaling them, as there were no means of getting to the tubes, so as to have them scaled horizontally.

The President said that Mr M'Gregor's proposed boilers had 50 square feet of grate, burning 56 lbs. of coal per foot of grate space per hour; that is to say, 2800 lbs. of coal per hour: so that if there was an economical consumpt of 2 lbs. per indicated horse power, then they would have these boilers giving steam for 2800 indicated horse power. Was there any practical data to justify such an opinion?

Mr M'Gregor said there was a lack of experiments on the subject of the pressure necessary to give a certain combustion of fuel. But if they took it inversely as the vacuum necessary to produce a certain combustion in locomotive boilers they would arrive at the same pressure. The only instance that he knew of pressure used in a stokehole was in torpedo boats, and there the pressure had not been definitely ascertained. He had been recently in conversation with Mr Hedley, of a firm which constructed torpedo boats. That gentleman had assured him he had obtained a consumption of 150 lbs. of fuel per foot of grate space per hour. He had also told him that there was 1½ in. of pressure; but he had been unable to ascertain particulars of any experiments on that subject — the pressure necessary in a stokehole to give a certain consumption of fuel per foot of grate space per hour.

The PRESIDENT said it was very curious to observe how invention repeated itself. A worthy member of the Institution, Mr Brownlee, had informed him that the first steamboat he put foot upon in America, he believed about 1834, had compound engines, and combustion carried on under pressure by forcing air into the stokehole! Mr Brownlee was a man whose powers of observation they could trust.

Mr H. R. ROBSON said that with regard to compound engines in steamers he might state that in 1847 he had crossed the Rhine in a paddle steamer that was propelled by such engines. The vessel was then a pretty old one.

Mr F. J. ROWAN said, before entering upon the various points which had arisen in the course of this interesting discussion, he must thank those gentlemen who had helped to render more complete his record of results. And in particular he was obliged to Mr Robson for his remarks upon the power results noted in Dr Rankine's first report, and for the other information concerning the work of early days which he had given. His explanation of the effect upon the recorded pressure of steam caused by the small connection to the indicator gives the probable clue to Dr Rankine's addition of appendix E (p. 56) and the letter which accompanied it to his first report. In proof of the fact that Mr Robson's interest in his father's work dated from its commencement he might mention that he was the Board of Trade engineer who proved with cold water pressure the boiler of the "Thetis" to 240 lbs. per square inch at the Atlas Works on 6th April, 1857, and that he (Mr Rowan) possessed his letter to his father recording the fact. His official position rendered his encouragement of the new ideas most valuable at that time, and he had given proof of how his skill was devoted to furthering the work. He thought he might venture the remark that had the Board of Trade always been represented by men of Mr Robson's spirit and skill it would have acquired the reputation of being the guardian and fosterer of improvement. He was much obliged also to Mr Kirk for the frank admission which he gave about the unfortunately defective part of the "Propontis'" boilers, and he was the more obliged to him because no one else could have completely shown that his remark, on page 73, merely recorded a fact and did not impute any blame, though he was sorry to observe that Mr Jamieson thought it did. Both his late father and he had so much confidence in the quality of Messrs Elder's work and in their desire to give the plans a fair trial, that, after their suggestion to use an internal steam pipe, instead of the outside connection between the domes was agreed to, it was, as Mr Kirk had shown, never credited with the fluctuations of water level, which were frequently observed, until the experiments of Mr Samson and Mr Parker which were founded upon facts noticed by them in connection with the flow of steam. Mr Kirk's remarks as printed, however, read as if he meant that the *existence* of the upper steam connection was a mal-arrangement and caused the trouble spoken of. The contrary was of course the fact, it was the want of that connection in the "Propontis'" boilers which was the secret of trouble. It was a mistake, too, that the design of the "Propontis'" boilers was a development of those of the Indian steamers, the fact being that the "Propontis'" design was the earlier of the two, and was found, with an additional steam dome, in their patent specification of 1869. Mr Howden's remarks as to the design and alterations of the "Thetis'" machinery were, he believed, in the main correct, except that in addition to the alterations on engine valves and condenser, of which he had spoken, a fly-wheel was added and the boiler was also considerably altered. Several statements were made which he could not pass without correction. First, as to the pressure of steam carried. In the "Thetis" this was 115 lbs. per square inch, and in all the other early examples it was 120 lbs., while all boilers made since 1862 have worked at 150 lbs. per square inch, Next as to the consumption of coal; in the "Propontis," 1·5 lb. per I.H.P. was frequently recorded, and the *average* of her first voyage home was not above that quantity if the distilling boiler and galley fires were allowed for. The "Propontis'" boiler was not, and boilers of this type were not, unsuitable for working with sea-water. In fact there was greater difficulty with them than with other boilers in forming a scale on the internal surfaces because of the rapidity of the circulation of the water. If they had small *horizontal* tubes it would be different, as was shown by some specimens obtained from Mr Parker. And it was a fact that on a voyage from Bombay to Liverpool the engineer of the "Propontis" found great difficulty in getting a scale formed in his boilers, though he desired to get one in order to stop pitting and worked for some time with all sea-water. Mr M'Gregor was in error in some of his remarks, because all through he had confounded the factory and the marine boilers. He had announced that his opinion of the boilers in India was unsatisfactory, and this adverse opinion was based upon the fact that some land boilers made under their patent were not successful. It also appeared from the paper which he subsequently read that he did not approve of water-tube boilers in any form, but advocated the locomotive type for use in ships. He might revert to this view again, but must point out that there was a very material difference between the two designs of the boilers alluded to, and that the land boilers were faulty in circulation of water. This difference would be seen at once by reference to the diagrams. (See Plate XVII.) Fig. 1 showed the design of marine boiler used in India and elsewhere, B being horizontal chambers over the fires, and C being horizontal chambers below the fire-grate level, while A were steam chambers connected by vertical tubes D to B and C. F was fire-grate level. Any defect in circulation was felt most at chambers B and the parts exposed more immediately to the fire. Fig. 2 showed the design of the land boilers adopted in Calcutta, from which it was apparent that there were no chambers C below the fire-grate level, though these were necessary for circulation, and all the boiler was above the fire, the horizontal parts of the small tubes D being exposed so directly to the heat that steam was forced out of them in both directions and water was prevented entering. Fig. 3 showed the form of boiler which he advocated both for marine and land work, the chambers B being entirely dispensed with and those C below the fire-grate level retained. The large tube which Mr M'Gregor spoke of as having been patched and afterwards bursting, was a large vertical tube or chamber at the back of the boilers connecting the top and bottom horizontal chambers. This tube is fitted with an internal tube to allow water to descend quietly in it, the exterior one being exposed to sufficient heat to cause ebullition and consequent ascent of the water near the surfaces. The fact that the water which was used in these land boilers was impure enough to deposit quickly an incrustation was sufficient explanation of the burning of that upright tube. The river steamers did not work with all river water (as Mr Howden also erroneously supposed) for all had surface condensers which were constantly in use during each double trip. The boilers were filled afresh with the river water, filtered free from mud, at the commencement of each double trip. It was not the fact that these marine boilers had suffered from *incrustation*, but on the contrary some of the tubes had been *corroded*, showing that they were not protected by any scale. The water used in the factory boilers was extremely bad, so full of mineral matter that even part had to be precipitated before use by the addition of chemicals. It was not the water of the river Hooghly, and the boilers were also quite different, as he had said. As to the river steamers, the past history of the company afforded abundant proof of their excellent results and much of the success of the company had been due to the use of our system of compound engines and boilers for high pressures. Mr Howden's remarks about the early surface condensers were, he thought, open also to correction. The trouble he spoke of was not traceable to leaky condensers but to leaky boilers. In general the condensers worked well, and Dr Rankine twice recorded his approbation of them. The central paddle might have been an unnecessary refinement, but it in no way complicated the condenser design—a stuffing box and a shaft and pair of small bevel wheels were surely not a very complicated arrangement. The different "sections" were only sections of the top plate used in forming the tube joints. He must distinctly challenge also the accuracy of his remark (on p. 90) as to the non-success of the steamers, because several of those which he had mentioned did good service at sea. Notwithstanding also what Mr M'Gregor had stated to-night, he was in a position to say that he had abundant written testimony as to the excellent results which had been obtained with these steamers, both as regarded economy in working the engines and boilers, and also the effect of that upon the commercial success of the company. He did not agree with Mr M'Gregor that that could have been attained with a good engine and condenser and a bad boiler. He was of opinion that the boiler was the vital part of the whole machinery. Apart from these inaccuracies or misunderstandings the bulk of the discussion turned upon the subjects of corrosion, combustion, and strength, upon all of which he would make one or two remarks:—

1. *Corrosion.*—It appeared that some engineers still cling to the idea that corrosion was due to the use of condensed water and that in some mysterious way water was altered by repeated boiling so as to constitute it an active solvent of iron. This view, however, was entirely without foundation. The only substance in pure fresh water that was capable of producing corrosion was the air, or oxygen and carbonic acid gas, which all waters hold in suspension in greater or less degree. The heat of a room was often sufficient to disengage portions of gas, and a glass of water might be observed to be coated with fine bubbles or bells of air as if the water were effervescent. The *magnesia* salts contained in sea water underwent some decomposition when it was boiled under pressure, and this added materially to the corrosive action when a comparatively small proportion of sea-water was used, as in boilers worked with surface condensers. When a large quantity of sea-water was used, as with the jet condenser, the *lime* salts were deposited as a solid incrustation which protected the iron surfaces as long as it was present. It was, however, partially soluble, in consequence of containing chloride of sodium and

other soluble salts, and might be removed by "working fresh," so that it required the constant use of an excess of salt water in order to keep it on. When that or any similar coating was formed there was no internal corrosion—the two conditions could not exist together. The decomposition of lubricants occasionally added to corrosive action in boilers, but such decomposition could take place only in the cylinders or condenser, so that Mr M'Gregor's remark on pp. 103, 104, was incorrect. There was no doubt, however, that the greater part of corrosive action was due to air, which could not be excluded from the boilers where steam was condensed in contact with air as was the case in all marine engines. If, therefore, the boiler surfaces could be properly protected, fresh water might be used and repeatedly distilled without fear of bad results. Such a system of working rendered internal examination unnecessary. All that was wanted was the occasional application of the water pressure test to prove if the thicknesses and strength were kept up.

2. *Combustion.*—Mr Smith's question as to his proposed use of forced combustion induced him to refer to the problem which confronted every engineer in connection with this subject. It was well known that *provided they had efficient circulation of water in the boiler* (and this was a vital point), the more intense the heat produced by combustion the more rapid was the formation of steam. Mr M'Gregor had referred shortly to this in his paper, and he heartily agreed with the aim of that part of his remarks. But with natural or chimney draught, or even with chimney blast, anything like intensity of combustion was attainable only with great loss of heat, both by the rapidity of exit of the products of combustion up the chimney, and by their dilution with a large quantity of air which was necessary to produce draught. The difficulty was to have the greatest heat of combustion combined with a low temperature of escaping gases, so that no heat was uselessly carried away. In our boilers, hitherto, they had attempted to reach these ends by carrying off the gases at a low point so that the colder portions, or those of greatest density, should escape first. But this checked the draught and consequently the intensity of combustion and made the heating

surface less valuable. This led to increased heating surface in order to gain the increased efficiency which had been obtained. Mr D. Rowan gave the true reason of the low temperature of the escaping gases and of the slow draught in our boilers, and with chimney draught these two results could not be obtained apart from one another But chimney draught was not necessary and a high temperature of escaping gases was not necessary. Mr M'Gregor had mentioned three ways in which chimney draught might be dispensed with and yet a high temperature of combustion obtained. To these he added the one which he had illustrated as the mode which, for several reasons, he preferred to all. This one combined with the means of guiding the gases downwards, already used in our boilers, gave, along with increased intensity of combustion, the power of retarding the escape of the gases to any desired extent, thus retaining them in contact with the heating surface until they had imparted all their heat. Mr Smith evidently understood that by "forced combustion" he meant rapid combustion of a large quantity of coal, but this was a mistake. A *high temperature,* or great *intensity of combustion* was quite compatible with the consumption of a *reduced quantity* of fuel, and as applied to marine boilers this meant saving in other ways also. It was quite true as Mr M'Gregor remarked, that very little had been done in the way of experiment with that plan of combustion. It was now, however, attracting some attention, and his friend Mr Flannery had just recently read a paper before the Institution of Naval Architects, giving the results of some special experiments made by him. Although the experiments of Professor Frankland had been on record for about twelve years, and these experiments demonstrated that a great increase of temperature due to increased intensity of combustion was obtained by burning gases under pressure, the subject had been almost entirely neglected.

3. As to *Strength.*—He cordially agreed with Mr Smith's remarks (recorded on p. 96) about the strain upon boilers of even comparatively small diameters with steam of high pressure, and as to the danger to ships from the use of such kinds of boilers having

large rending surfaces. A "factor of safety" for strength was not a security against all risks, because the limit to the thickness at which plates could be used in constructing the shell was soon reached. In these considerations lay the true reason of the necessity, with increase of pressure, for boilers having small areas of fracture; and the cry of "complicated" would not long serve to frighten people away from them. They could not in fairness be considered more complicated than the old square boilers which were so long adhered to, in spite of their many tortuous passages; and yet these were not considered too complicated for use or repair. Smallness of spaces, moreover, was not necessarily complication, although until the eye was accustomed to it, it might seem difficult. The main causes which operated in producing the change in these designs, from cells to cells and tubes, and finally to tubes alone, were the improved appliances which became available in boiler-making (especially tube-expanding apparatus) on the one hand, and the effort to obtain as free and perfect a circulation of water as possible on the other. He did not believe that boilers of the locomotive type, in spite of their apparent simplicity of design, satisfied any of the conditions required in a good marine boiler for high pressures; and what he knew of their use in steamers justified the belief that if used with forced combustion added, as Mr M'Gregor proposed, all their defects would become more apparent, and their dangerous character more fully felt. The conditions of construction, of use, and of inspection, were so totally different in locomotive from marine practice, that no fair comparison could be drawn between them, justifying a deduction as to the value of locomotive boilers if applied to steamers. He might say that the application, or proposed application, of locomotive boilers for use in ships, was mentioned last year, or the year before, on two occasions, before the Institution of Civil Engineers in London. These were in the discussion on Mr Holt's paper "On the Progress of Steam Shipping," and in that on Mr Flannery's paper "On the Construction of High Pressure Steam Boilers." Any one who read the discussions on these papers would find the objections against the proposed practice pretty fully stated.

The steamer "Telegraph," to which Mr M'Gregor referred, was perhaps the earliest attempt to use locomotive machinery afloat, and it had a disastrous ending; as had also the substitution of a locomotive boiler in the "Guajara" for one of our boilers, which was destroyed by careless working with sea water. In both these instances the hull of the steamer was blown to pieces, so that in them was the record sought by Mr M'Gregor in his remarks. One word with regard to Mr Howden's remarks to-night. Mr Howden had said the idea of obtaining economy from high pressure in combination with surface condensation was common in these early days. He was led to doubt the accuracy of that statement, by a remark of the late Mr J. R. Napier, who told him that Randolph, Elder, & Co. had endeavoured at first to obtain economy by lowering the pressure of steam and adding surface condensation. As to the refrigerator which had been described by Mr Howden, he thought that if the quantity of water in the tank was pretty constant, it seemed clear that the water in it would gradually become hotter and hotter, so that when it had reached its highest temperature the refrigerator's power would cease. In conclusion, he could not fail to be gratified, as he had been, by the many kind remarks which had been made during the discussion, expressive of appreciation of his father's labours in this field of engineering.

Mr Howden was afraid Mr Rowan had not understood his description of the refrigerator. The water for condensing did not keep increasing in temperature, but maintained a uniform temperature of from 15° to 20° above sea water. The water discharged by the air pump through the tubes of the refrigerator was met by a stream of sea water running in the opposite direction outside the tubes. Any waste of fresh water was made up from a supply carried on board, just as it would have been if a surface condenser had been used.

Mr F. Rowan said that Mr M'Gregor was in error as to new leaves or segments for the original boilers having been sent out for repairs to India. The boilers worked in their original form for the whole period mentioned by Mr Smith with ordinary repairs. Mr M'Gregor's statement about the boilers of the "Bengal" being replaced conveyed intelligence which was new to him, and he believed it to be erroneous.

Mr M'Gregor said, seeing that the boilers came under his inspection, he could not be mistaken. He knew defective leaves were taken out, and others put in; but whether the latter came from this country or not, he could not say. With reference to what Mr Rowan had said as to the duration of the voyages of the vessels in which these boilers were placed, he might state that instead of from four to five days, the voyages really lasted during twenty days in the up run, and fourteen days coming down; and the vessels were all those days in fresh water, except two and a half or three and a half days at most in brackish water, during which time they were obliged to precipitate the water in tanks, so as to prevent the salts in the water affecting the boiler. As regarded the different classes of boilers in these vessels, he was quite aware of that, as both kinds came under his inspection.

The President proposed a cordial vote of thanks to Mr Rowan for his very valuable paper, which placed on record a number of interesting facts as to marine engineering; and, also, a vote of thanks to Mr M'Gregor for his deductions as to the best form of marine boilers. He was satisfied that they all felt obliged to Mr M'Gregor for his observations in discussions upon matters which, having come under his immediate inspection in the East, he could speak with an amount of certainty which could not attach to opinions possibly founded on incomplete reports.

Both votes were cordially and unanimously agreed to.

Note by Mr F. J. Rowan. Received 5th April, 1880.

Several statements were made by Mr M'Gregor in the course of the discussion on 23rd March, which required reference to documents for their refutation, but must not be allowed wholly to pass.

It is wholly incorrect that the cellular boilers were renewed in the "stock, lock, and barrel" fashion which he indicated had been applied to them. Mr B. C. Crawford, who was superintending engineer in charge of them for over five years, wrote in December, 1867, "The boilers are nearly as good as new. It is difficult to say how long they will last, but working them as I have done and judging from the state I left them in they ought to last fully ten years. *The only thing I renewed was the copper connecting pipe*, as all connections should be wrought-iron."

Mr T. C. Hide, who examined them as Government Surveyor, says, "At the time I speak of, in 1869 and 1870, I should have had no hesitation in saying that the boilers would have been good for another two or three years. The thickness of plates were tested and very little waste had taken place—this was in the square cells. Some few of the covering tubes in fire-place had burnt through, but this was to be expected. . . . The boilers when tested were quite tight and by far the tightest boilers on the Hooghly."

So much for Mr M'Gregor's "repairs for ever."

When new boilers were ordered in 1873 for the whole of the steamers which had worked so successfully with these, the order sent to this country was for *a repetition of the cellular boilers*. This was changed, at the request of my father, to the tubulous design (which had then been introduced into the "Haco") because it was believed that this was an improvement upon the combination of cells and tubes, and the manufacture of the former form had been at that time given up. This was why "the former were not replaced."

Moreover the new tubulous design was fitted to all the vessels then in the river fleet and to two new steamers which were afterwards added. One or two new vessels have lately been added with machinery by other makers, but this is not to be wondered at if the "inspection" is now carried on in the spirit of Mr M'Gregor's remarks.

It is evident that Mr M'Gregor's inspection is of recent date, as in all the correspondence about these Indian steamers, extending over many years, his name does not once occur, while the names of other inspecting engineers are occasionally mentioned.

On the Proposed Bridges for Carrying the North British Railway across the Firth of Forth, with some Remarks on the Structure and Cause of the Fall of the Tay Bridge.

By Mr St. John V. Day, C.E., F.R.S.E., M.Inst.M.E., &c.

Received and Read 27th January, 1880.

(See Plates X., XI., XII., XIII., XIV., and XV.)

Since the necessity first presented itself of carrying a railway across the Menai Straits, now about thirty-six years ago, questions relating to the best principles to apply in the construction of wide span bridges, whereby to so reduce the quantity of material employed, in order to obtain a minimum of "dead load," consistently with a sufficiently high factor of safety for the structure itself at the instant of maximum stress, is one which has grown with an increasing interest, demanding the grave consideration both of the engineer and the mathematician. In a mountainous island like our own, with its river systems descending on all sides to the sea through broad estuaries or firths, thickly populated, with numerous cities, extensive sea-ports, and habitats of industry located on its shores, it has become imperative to the users, both on the score of time of transit as well as distance traversed, that the shortest direct lines of communication for railway traffic, both coastwise and internally, be established. "Through-trunk-lines" at the interior, with branches leading outwards crossing the rivers at points inland where the "river-breaks" are narrow, are no longer sufficient, for such an arrangement involves sometimes more than a doubling of the direct distance to be travelled by resort to an inverted loop line, whilst a long span bridge across a broader part of the river or estuary would provide a straight roadway. Several "through-lines" have become a necessity, and especially to connect by a direct and shortest route the sea-board cities and towns with the metropolitan and other great towns and cities of the interior. Throughout the southern part of our island (England) we have two principal Trunk lines proceeding from the metropolis for the westward and central cities and towns converging to a common point at Carlisle, viz., the London and North-Western, and the Midland Railways, while the eastern portion is traversed by the Great Northern and Great Eastern Lines, these being respectively continued by the Caledonian, Glasgow and South-Western, and North British Railways, which couple the great through railways of the south with those leading to the extreme north. The result of this has been to create the necessity of crossing our rivers at their estuaries in place of further inland, thereby involving the erection of bridges of sufficient height and width of span, or to tunnel beneath their beds so as not to interfere with naval or shipping interests.

To the North British Railway Company in particular the crossing of two such estuaries has presented in some respects greater difficulties than have been met with in other cases, lest it be in that of the Severn from New Passage to Portskewit, where a tunnel is being made, but is now stopped through the flooding of the works by the incursion of the water from the uplands on the Welsh side.

The full development of the eastern traffic of our island, namely, that which naturally proceeds by the North British Railway system, has been seriously hindered through the delay in transit caused by the Forth and Tay estuaries making two broad cuts across that line, and for *many* years the bridging of these gaps has been contemplated. In regard to the former—the Forth—the contracts have recently been made for the erection in steel of a suspension bridge of the longest span ever attempted, and it is with reference to the bridging of this estuary that this paper is more especially concerned.

The procedure, however, in reference to the contracts for this bridge is without a parallel, and therefore demand some notice, the more especially so, as I am informed by the Secretary of the Board of Trade that the working stresses or factors of safety upon which the construction of the Forth Bridge is to be allowed to proceed, are at present "under consideration."

In a report dated Westminster, June 30th, 1873, of which I have the good fortune to possess a copy, Messrs W. H. Barlow, F.R.S., and William Pole, F.R S., point out that "the whole of the calculations" in their report "have been based on the employment of steel of a tensile resistance of 40 tons per inch, with a maximum strain not exceeding 10 tons per inch." This means, in other words, that a factor of safety of 4 was at the above-named date adopted and thought sufficient. The appendix to this report is so significant in view of what I have to direct your attention to, that I quote it here complete:—

"The whole of the calculations in the foregoing paper have been based on the employment of steel of a tensile resistance of 40 tons per inch, with a maximum strain not exceeding 10 tons per inch.

"The extensive series of experiments made on steel by Messrs Barlow, Berkley, and Galton indicate that when steel is made of high strength it diminishes in ductility, and that the greatest ductility was found in bars having an ultimate tensile resistance of from 33 to 36 tons per inch.

"In this material, which is a milder quality of steel, a 10 feet bar, 1½ inch diameter, will extend about 12 inches before breaking, and the fractured area pulls down to less than three-fourths of the original sectional area. The elastic limit is 16 to 17 tons, and the action is remarkably regular. Moreover, it is of quality which can be obtained in large quantities at a moderate price.

"It was, therefore, deemed desirable to ascertain what differences would arise in the strains, and consequently in the weight of material from substituting this quality of steel strained to 8 tons per inch, instead of steel of 40 tons strained to 10 tons per inch.

"The calculations of the bridge were, therefore, gone through again, and the accompanying diagrams show the relative strains which would arise from the employment of these two qualities of material.

"These duplicate results have been obtained by independent calculations, made under the direction of Mr Barlow, by his former pupil and assistant, Mr Charles Bellamy.

"Taking into account the lower price of the steel, it would appear that this more ductile material could be employed without increasing to any appreciable extent the total cost of the bridge."

Now, it will be apparent that until the permanent working stresses or factors of safety for the bridge are adjudicated by the Board of Trade, that neither the weight of the structure, nor the scantlings of the several members thereof, can be fixed, so that in spite of the reports which we have had of the recent progress made in the manufacture of steel for the chains, &c., we, as engineers, can perfectly understand that any numbers of ingots may be got ready for conversion into what are of necessity at present unsettled sections. It is not our business, as an Institution of Engineers viewing the application of the laws of science in structures rather than the numerous commercial questions which arise in connection with a great engineering work, to discuss the latter; yet when fixing our attention on the fact that by the alteration by an unit* (in a girder bridge of say 600 feet long, 37·5 deep, and 14 feet wide) of the factors of safety—namely,

f = tons tensile inch strain of net section,

f' = tons compression inch strain of gross section,

the difference in the weight of material for the structure is, to say the least, striking.

In a single girder bridge for a single line of railway of the above-

---

* On the difference here given I have not had time before printing this paper to give Stoney's calculations the requisite consideration: what I here quote from him must therefore for the present not be considered a permanent statement.

named dimensions, Stoney* gives two cases: (*a*) in which $f = 5$; $f' = 4$; from which L = permanent bridge load, = 9102·0 tons;

(*b*) in which $f = 6$ and $f' = 5$ L = 3799·4 tons

5302·6 tons =

difference by alteration of the factors of safety by unity.† It is important, in the interests of the public, to know whether the contracts for the erection of the Forth Bridge have been concluded on the factor of safety of 4, which was so strongly recommended in the report of 1873, or whether a higher factor of safety which a structure subject, by virtue of its own dimensions, weights, and varying directions of stress, to unprecedented destructive influences, seems to demand. It is further to be hoped that the contracts are taken on a sliding scale, so that the contractors may reap remuneration in proportion to their risk, for otherwise, with the working stresses or factors of safety being yet unsettled by the Board of Trade, it is incomprehensible that a contractor can know the real state of the case on which to base his estimates.

In regard to the latter estuary the Tay—

When towards the end of last month, I promised to read a paper to this Institution, and which was at first intended to be a notice of what had appeared to myself a very excellent proposal for constructing a long span railway bridge, and especially the long contemplated bridge across the Firth of Forth, it is probable that but few of us apprehended the nearness of so dire a catastrophe, the overthrow of the highest part of that other great structure on the same line of railway—the Tay Bridge—and the burying with itself in the waters it spanned, a train freighted with so many human

* "Strains in Girders and similar Structures," 1873. Longmans, pp. 542 *et seq.*

† f = tons tensile inch strain of "net section;" that is, total section minus sectional area of rivet holes, these detracting from the area resisting tension. f' = tons compression inch strain of gross section; that is, total sectional area including rivets, the whole area in this case resisting compression.

lives. That work has been completed, its importance to the nation demonstrated; but being insufficient for the service it had to perform, it has fallen an unprecedented wreck into the estuary over which it had for so short a lifetime raised its attenuated lattice back. The appalling shock of this unparalleled destruction of life and property on our railways is so fresh in our memories that I need not allude to its details; indeed, it can only be matter of deepest regret to every engineer that an occurrence, a failure of a work so vast in dimensions, in one respect exceeding all that has been achieved in bridge structure either in this or other countries should have to be mentioned under a category of circumstances so mournful as that by which it is circumvented. Yet it became impossible for me to adhere to the original plan of this paper, when a failure so gigantic in long-span bridge structure had occurred right at the moment of arranging its details, the details in short dealing with a branch of engineering of which the Tay Bridge was one typical example as a completed work. I have, therefore, felt it to be almost incumbent upon myself occupying your attention as I have undertaken to do this evening, to make some few remarks on what has appeared to me amongst the most probable primary causes of failure of the highest part of the Tay Bridge; and I do this in the hope that although the views I entertain on the matter may possibly be considered ever so erroneous, yet a start will thereby be given to a discussion of the probable cause, or causes, of the catastrophe which cannot but be useful; which, emanating from an Institution comprised of engineers of all classes, cannot fail to shed important light on points to be watched in the structure of bridges of long span and high level of roadway in the future. It is, then, expressly to elicit discussion that I bring these matters before you.

Those who have read the several theories which have been propounded as to the cause of the failure must, on careful consideration, have been surprised at the opinion most generally expressed, namely, that the presence of the train upon the highest portion of the bridge at a moment of intensest severity of the gale, acted as such a barrier surface to the wind, or in other words blocking up part of its free passage through the lattice work, caused, for the instant so large an addition to the wind resisting surface, that the lateral stress on the bridge was increased beyond its upsetting moment, so that the train's presence was the cause of the bridge being blown over. Another form which this theory has assumed, viz., that the carriages were blown over against the eastern girders, and that the impact thereof coupled with the train's motion acting against those girders upset a portion of a structure whose weight (of the fallen part) was 29 times or more than the weight of the engine and train, is equally untenable. If it was possible that the failure of the bridge was due to either of such causes then we must stand aghast, and wonder why those who were entrusted with the design and construction of such a work had not fixed the upsetting moment very much higher, indeed in every way have provided to the fullest against the destruction of the bridge by causes, the frequent occurrence of which, both before and during the construction of the work, must have been a constant source of warning. Many attempts in the engineering journals have been made to calculate the upsetting moment of the fallen part of this bridge, but without more precise data as to the actual areas acted upon, these can at best be but very rough approximations. For the present, then, and until I obtain certain facts, for which I have applied to the Astronomers-Royal of England and Scotland, Professor Grant, Dr Robinson of Armagh, and others, I refrain from committing myself to an estimate thereof. Then in order to calculate with anything like precision the stresses acting on the bridge we must know much more than is assumed in the calculations which have been made, for instance the precise direction or line of effort of the gale, the retarding effect of open lattice bars as compared to solid plate to which attention has been drawn by Mr T. Claxton Fidler; the retarding effect also of the leeward girder, as well as the retarding effect and tendency to lift a flat surface like the underside of a pair of lattice girders carrying a roadway between them.* In

* As to the very decided character of this lifting influence of the wind see a paper by Col. C. W. Pasley, F.R.S., Vol. III., Trans. Inst. C.E., A.D. 1839,

calculating this moment of stability, too, I observe that the areas of the columns are taken as flat surfaces. The late Professor Rankine, however, in regard to the stability of chimneys pointed out that a round chimney exercises but one half of the retarding effect on wind as compared to a square chimney;* an important correction, therefore, in the calculations has to be made for this. One thing which it is well to notice here, that as compared with other structures the width of base to the vertical height of the piers in the case of those piers of the Tay Bridge which fell is not much the same as in some other structures of a like class which have stood the test of many years, but in less exposed situations—the proportion of the batter of the Tay Bridge piers in this respect seems to be about $\frac{1}{8}$th of that adopted in the Great Crumlin Viaduct, which has been looked upon as unique in its design and economy of material. If, therefore, the proportions adopted were considered necessary in the case of such an example as the Crumlin Viaduct, it would point to the fact that a very much greater width of base to height was necessary in the piers of a structure so exposed to gales as the Tay Bridge, in order to ensure its safety, and in consequence, too, of the greater length of structure like the Tay Bridge. It also clearly further points to the necessity of a greater breadth of base for the piers. While then after having examined the bridge for myself in its present state, and having collated facts relating to it, the cause of failure, it seems to me, is not far to seek. Indeed, had the original design been carried out, I am of opinion that the wreck of the great work such as we now contemplate would never have been before us.

In the original design (and this was carried out until the death of Mr De Bergue, the first contractor) it was intended that all the high

---

to which my attention has been recalled by the kindness of Mr James Meldrum, C.E. I am also indebted to Professor Piazzi Smyth for most valuable testimony in regard to wind pressures, and the variations in its velocity and pressure produced by the shapes of channels through which it is blowing, all of which I purpose to refer to in the discussion. The Astronomer-Royal, too, has kindly promised me information bearing on this matter.

* "Civil Engineering."

piers should be constructed of brick in cement up to the level of the underside of the girders, like the first 14 piers at the south end. After Mr De Bergue's death, the contract passed into the hands of Messrs Hopkins, Gilkes, & Co., of Middlesboro', and the structure of the remaining high piers was altered; this alteration includes the piers of the wrecked portion of the bridge. The alteration, so far as I have been able to gather by enquiring of those engaged in, or for, the construction of the bridge, was primarily influenced through the difficulty of getting the 15th pier from the south end to settle down perpendicularly. From the borings which were made across the river bed in the line of the bridge it was assumed that the rock was continuous,* or nearly so, so that the piers when sunk to their intended depth would rest hard upon it. Some of the original drawings of the bridge show this. It appears, however, from the statement of some persons who were engaged in the borings, that sometimes boulders and detached masses of stone were passed through prior to the actual bottom being reached, so that a pier meeting with one of these in its descent, and the curb at its bottom coming in contact therewith, was by its own weight actually canted over. In the case, of the 15th pier from the south end, that is to say, the first pier in which the superstructure is altered by substituting braced cast-iron columns for brick work, that pier is shored up by material thrown up around its base so as to give a broader area of foundation, upon which additional brickwork is built up around the original pier to nearly high water level.† This pier having been brought to a stable condition, it seems on the part of the engineer or contractor, or both, to have been feared to place upon it and the succeeding high piers, the heavy permanent load of a superstructure of brickwork raised throughout to the underside of the girder, so that from this pier, that is to say, including itself

* See *Engineer*, 4th April, 1873.

† I was at least so informed at first. Since, however, the paper was written I have had the advantage of some explanations as to the manner in which this pier was steadied, and of which Mr Anderson has promised to send me a drawing, which I shall communicate to the Institution when received.

onwards throughout the highest portion of the bridge, the lighter superstructure of braced cast-iron columns was adopted.

The structure of these cast-iron columns is, I regret to add, singularly at fault in the light of what is plainly the effort which they have to discharge in carrying the permanent "dead load" of the bridge and its transient "live load." This remark applies in a two-fold form, for the reason that the structure of the piers which carried the highest girders (those which have fallen) and that of those piers which carry the immediately adjoining portions on each side thereof essentially differ. In the case of the higher piers each of the sets of three legs or struts forming the boundaries of the elongated hexagon (which figure they constitute in plan), is straight throughout its entire length, the outer leg or strut having a batter of 1 in 82. Then these legs, or struts, carry at their top a triangular box girder, as shown at Fig. 1, Plate X., and the main girder rests midway between them. It will, therefore, be seen that the single outer column of the three at each side of the hexagon, has the same load to carry as the two inner legs carry together. One half, therefore, of the "dead" and "live loads" of this part of the bridge is carried by the two outer columns of the hexagonal towers, whilst the other half has double the number of columns (these furthermore carrying the loads vertically). A more erroneous distribution of the load it would be difficult to produce, for the two outer raking columns had twice the work to do of carrying the girder of each of the four inner ones.

It is true that the outer columns were 18 inches diameter as compared to the inner ones which were 15 inches, but not being perpendicular they were in a less favourable position to resist the downward stress of the load. Had the load been directly placed on the four intermediate columns, by which I mean had the lower booms of the girders rested directly upon the portion of the box girders immediately over their heads, and the two outer ones used for shoring up the structure against lateral wind pressure, the bridge would have had a much higher moment of stability; but the original design having been departed from, namely, of carrying the brick in cement to the full height, which would have given an equal distribution of the load, as shown at Figs. 6 to 9, it became impossible with the floorage of stone-work of the dimensions upon which the braced columns were ultimately erected to provide a proper distribution of the load, for in constructing them no other form than a hexagon could produce sufficient width of pier head for carrying the highest girders when founded on the ashlar caps of the dimensions with which the submerged portions of the piers are finished.

It is, I think, plain from what I have seen that the builders of the bridge found the width of the pier-caps much less than what they should be, for the six iron columns (though without much regularity in this respect) are for the most part pushed as far out on the edges of the caps as they can be. It is not to be forgotten either that the triangular box girders on which the main girders rest are not tied together: they consist simply of two triangular boxes each corner respectively resting on its corresponding column. In place of this had they been connected by other cross girders so as to form a continuous box-girder hexagonal-top to the columns, the stability of the bridge would have been enhanced, and I of course assume this when speaking above of the advantage of having utilized the outer columns of the piers as shoring columns.

I further noticed in examining these columns that provision was made for the introduction of three tiers of deep iron girders at about equal intervals in the height of the columns, which would have added to the stability of the structure; indeed, in an excellent model of these columns in the Museum at Dundee, all these deep iron girders are shown *in situ*. We may, therefore, well ask why they were omitted in the actual structure, for the flanches and bolt holes for receiving them were cast and still remain in those portions of the columns, so many of which are either lying upon or hanging by the bracing around the pier roots.*

* Since this was written my attention has been directed to this point by the President of the Court of Enquiry, to whom it has been suggested that

With regard to those piers which carry the girders on either side of the highest portion, here also there is a glaring oversight in the use of material to the best purpose. Fig. 10 is a side elevation of one of these piers, from which it will be seen that the six columns or struts are all vertical excepting the upper ten feet length of the two outer columns. These are inclined inwards, as shown until their heads come in line with the heads of the other two columns, and a straight box girder rests upon the whole. It will be seen at a glance that nothing could be worse than this arrangement of the outer struts to resist the pressure of the load, this being further aggravated by the absence of any direct cross ties at the angle, the weakest portion of these columns.

With regard to the bracing of these columns, it was for a structure having such functions to discharge most defective, for none of the joints which I examined seemed to have fitted, whilst the holes through which the bolts passed in the lugs and ties were $\frac{1}{8}$ inch or more larger in diameter than the bolts passed through them. We can judge from such looseness of structure how abnormally those lugs and ties and bolts were strained by wind stresses, or the oscillation from passing trains, when the openness of the bracing joints prevented each part of the structure from bearing its proper proportion of the stress. Such spaces, too, were productive of a further evil by allowing the salt water of the river spray to enter the joints, thereby rusting the bolts with the rapidity with which salt water oxidizes iron. I was indeed surprised at the extent to which in so short a time these bolts had been converted into rust, so much so that had this structure been in other respects stable, the bracing bolts would (for safety) have had to be replaced every four to six years. *

---

these formed part of the apparatus by which the girders were raised to the top of the piers. Such may very well have been the case, and I observe that Mr Grothe, in p. 59 of his pamphlet on the Tay Bridge, refers to the use of stays bolted between the columns for carrying the hydraulic apparatus by which the girders were raised. On this point, however, I reserve what I have to remark further on the matter for the discussion.

* I am informed by Bailie Thomson, of Dundee, that he has in his possession one of these bolts nearly, if not quite half way, converted into rust. It

The holes in the flanches of the columns were also much too large for the bolts; some that I measured were fully ⅛ inch too large, whilst it has been said that other holes were nearly half an inch larger than the bolts, and the joints of the columns do not appear to have been tight, indeed the salt water seems to have got in.

Nor can I omit to notice the diagonal bracing of these piers. It consisted of what were mere ribands of iron, one end of which was bolted to the lugs at one corner of the rectangular spaces of the columns, whilst the opposite end was coupled by a pair of short plates, through holes in which corresponding to holes in the bracing ribands, gibs and cotters were passed for tightening them. Now, according to the direction of the wind stress or oscillation stresses, that is to say, as the wind blew from either an easterly or westerly point, or the bridge oscillated from east to west by passing trains and *vice versa*, so the stresses on the diagonals were alternately those of compression and tension, that is to say, the same member had alternately to discharge the function of strut and tie. Not having, as I have previously remarked, the requisite data for calculating these stresses, excepting subject to considerable correction, we cannot for the present arrive at the tensional and compressile stresses on these diagonals—but as practical men we cannot have a doubt that although the diagonals may have had sufficient section for the tension stresses, yet for compression such a section was useless. Furthermore, it is difficult to conceive any arrangement more likely to produce the eventual destruction of the fabric than the gib and cotter joints above named, for the very essence of such an arrangement is to allow of motion between the parts, according to the direction of stress applied to the structure. Such a joint cannot be tightened unless it has room for further draw. Such a system of diagonals can only be effective, when they are of the requisite section to act as struts resisting the maximum stress applied to them and in any case fixed by bolts tightly fitting all the parts so coupled, so that there shall be no motion between the parts. In American

---

is appalling to conjecture the life of a structure depending upon one such increasing source of self-destruction.

bridges, I understand, it is the regular practice to bore all the holes and turn the bolts to fit them tightly.

In respect of the nature of the iron used for casting the 10 feet lengths of tube of which the piers were formed, on examining the fractures of the fallen piers I was struck with the great number of cases in which the lugs were torn off by the diagonal bracing ties, and not unfrequently large portions of the casting pulled out of the body of those parts of the tube from which the lugs protruded. And as to the bolting, there is the most glaring absence of the want of careful inspection. In some cases four and five, possibly more, washers are used, in others two and three, in others one; in others again parts of washers.

Before leaving this part of the Tay Bridge I should wish to point out what is plainly another source of weakness, viz., the insufficient length of the holding down bolts by which the iron columns are attached to the pier heads. These bolts extend only through the first two courses of ashlar, and I do not remember observing that in any case they were broken through, but that generally their insufficiency of holding through the light weight of masonry attached to them is made manifest, by the fact of the courses of ashlar through which they pass being turned up and broken right off at the course joints. If not quite torn up, as in the case of the fourth, seventh, eighth, and ninth piers counting from the north end of the broken bridge, the pier heads are lifted and shaken on the western side, as in the case of the fifth pier. It is plain from the manner in which the pier heads are ruptured that the holding down bolts should have gone far enough down into the substructure of the piers, so that the weight of the masonry enclosing these bolts should have been four or five times in excess of the lifting force which would cause such a breaking up of the caps as is now to be seen.* It is too painfully

* With reference to the holding down bolts, I am, since reading this paper, informed by Mr Anderson, of Dundee, who built several (the greater number I believe) of the brick in cement and stone work portions of the piers from the fifteenth northmost pier northwards, that in the case of the two or three northmost piers of the high or mid-section of the bridge, as well as in he

easy to find fault and become wise after the failure of such a nationally useful work as the Tay Bridge, and I can only remark

---

case of the two or three southmost piers thereof, the holding down bolts not only were carried down through all the courses of the stone caps of the piers, but that they extended to some two feet into the brick in cement portion. It is inconceivable that any good reason can be assigned for these variations in the lengths of the holding down bolts, such an arrangement making the thirteen fallen spans their weakest point. Such being the case must alter altogether the notions which have been expressed up to the present time as to the manner in which the bridge gave way. In place then of beginning to fall from either the north or south ends I am now disposed to believe that the bridge yielded by the pressure of the wind at the centre part "bagging" it into a long curve having the versed sine east and west, and that the stress thus produced on the piers in their narrowest direction; that is to say, north and south from either side of the centre actually caused the extreme northern and southern ends to be pulled outwards off the box girders which carried them. This remark of course applies to the northern and southern 980 feet lengths. The "bagging" effect of the wind equally applying to all the lengths of girders individually. A further study, too, of the present state of the bracing at the extreme ends of the northern and eastern ends of the bridge seems to favour this view, and, to point out the necessity for the piers of such a bridge having to be made very much wider in their breadth of base than the width of the Tay Bridge pier base. Indeed if a girder bridge be again re-erected there it is certain, from this view, that the present piers, by which I mean the brickwork and masonry portions thereof, are insufficiently wide to carry braced columns for supporting the main girders at such a height and span. As it is certain that the facts relating to this part of the structure will be sifted by the Court of Enquiry, I deem it right to state here, that it will be necessary to take down the masonry and brickwork of each of the piers to the ends of the holding down bolts of the fallen portion to ascertain exactly this alleged irregularity in their lengths. If such irregularity be proven what are we to think of the constructors of the bridge? As it seems to me that certain questions as to the structure of the brickwork and masonry of the fallen piers, other than those to which I have directed attention in my paper must arise, I deem it desirable to annex here the remaining facts with which Mr Anderson has kindly supplied me.

The bricks for the inside of the piers were compressed bricks, and made at Pitfour by Messrs Robert Small & Co. The bricks for the outside lining for the two or three south end piers, were made at Dunbar. The remainder of the bricks of those south piers which were built of brick throughout, were, for the portion above high water level, from Pitfour; the lining of the submerged portions, to about 5 feet above high water level, was of Dunbar bricks.

how much more congenial it would have been to myself to have found therein excellence of design and thoroughness of execution, than having to point out the absence of both, as so conspicuous.

To return, however, to the iron piers, there can be little doubt but that in a strictly normal condition such piers, even with all their want of the proper application of the true principles of the distribution of materials, were strong enough to carry the superstructure, yet with a very low factor of safety, quite irrespective of their inferiority to the piers of solid brick work in cement of the original design. But then it seems to have been overlooked by the engineer who designed these piers and by the contractor who built them—that the final step taken in their construction was to entirely destroy the possibility of their remaining in a normal state. For what was done? We are told by Sir Thomas Bouch and by Mr Gilkes that these cast-iron tubular legs, some 18 inches and others 15 inches in diameter, were filled with concrete. If we consider the effect of the changes of temperature to which a structure exposed like the Tay Bridge was subjected from the highest summer heat to that of the lowest winter cold, we shall find that it is next to impossible that a cast-iron tube of 15 or 18 inches diameter, and from 1 to 1⅝ inches thick, of Middlesboro' metal filled with a concrete core in the summer, would resist the stress of contraction through a range of temperature lowering by even say 65° to 70° Fahr., to which it would be exposed on a very cold day in winter.* Yet this is the fact, or set of facts rather, with which we have to contend in considering some of the reasons of the failure of the bridge.

Leaving out of consideration the contraction of concrete over that range of temperature as being infinitesimally small, we find on calculation that a hoop or tube of cast-iron 18 inches diameter, in a fall of 68° Fahrenheit, will contract in length quite $\frac{1}{38}$th of

* We must not forget that the range of temperature during 1878-9 was far greater than this, and that prior to the fall of the bridge at the end of 1879 the temperature had descended by three degrees Fahrenheit below the lowest point of the protracted low temperature of 1878-9.

an inch, which is considerable in view of the elasticity of cast-iron being, sensibly *nil*. It is evident that in those cases wherein the concrete solidly filled the tubular columns of the piers that unless the concrete became compressed or crushed by the contraction of the casing around them, that casing must have ruptured. I have made a careful examination of the concrete placed in some of the columns. In certain cases it appears not to have properly set, but in others it has set "as hard as sandstone." In these latter cases there can hardly be a doubt but that the tubes were burst, especially exposed as they were to the unusually long winter and abnormal continuation of low temperature during the winter of 1878-79. If so, then, during the last twelve months of the life of the bridge, its piers, so far as regards the iron superstructure thereof, must have been in a "ricketty" condition, ready to break off and topple over so soon as a gale occurred of even less intensity than sufficient to equal the upsetting moment of the bridge in its normal condition. Furthermore, water appears to have been present inside the cast-iron columns, whether "water of extrusion" due to the setting of the concrete,* or water getting in through the joints or filtering down from the roadway, perhaps, cannot be said; for judging from the nature of the concrete which filled these columns it is only fair to expect that out of it a quantity of water had settled into the bottom of the columns waiting only to be frozen and thereby expanded to rupture them. That either one or other of these causes most probably did burst these columns I shall presently show from the state of the eastern leg of the first pier from the southern end of the standing portions of the bridge, but before directing attention to this and to another source of weakness, I wish to point out that even allowing the most favourable construction for the non-realization of the first view, viz., that the concrete did generally set hard, and that in so doing it contracted, as

* It was not a novelty to fill the columns with concrete. This had been done in previous cases, but in such previous cases "weeping holes" were provided to allow of the escape of water after setting. Judging, indeed, from the views expressed to myself by the late William Froude, F R S., no greater mistake could have been made than in filling up the legs.

some concretes are apparently known to do in setting—a thin space would thereby be allowed for the intrusion of water, which it seems certainly was present, from the rusty condition of such portions of the interior of the columns, as I could examine. In this case, then, the filling of such columns with concrete, for the avowed purpose of protecting them from the necessity of painting to avoid rust, has been a fatal mistake. There are facts, too, in connexion with the fall of the girders and piers which seem to prove this view, for the girders have not fallen (according to the divers) a long distance eastward from the piers as they would have done if the overturn had been on the lower part of the eastern iron portions of the piers, but they lie in the Tay about 30 feet to the east of the piers, and the cast-iron tubes filled with concrete remain in fragments, many of them resting on the flat stone capping of the brick piers, as shown in the photographs which I am enabled to show, by the kind permission of Mr Murton, the solicitor to the Board of Trade. This shows that the cast-iron columns, with some exceptions, must have broken up at their bases the instant the girders were overturned, and which they would the more easily do under the varying direction of the stresses to which they were subject by the looseness of the bracing to which I have already made reference.

It has been frequently asked why these columns were filled with concrete, and the greatest surprise has been expressed by many engineers at such a course being adopted, for its tendency was to reduce the factor of safety of the bridge in the manner I have pointed out.

I have further to mention that care does not seem to have been taken to ensure uniformity in the thickness of the metal of which the legs of the piers are formed. In some that I measured the metal at one side was 1⅜ ins. thick, on the opposite side an inch only, and from the "parting" of the moulds being but too visible in the tubes, it is clear that they were cast on their sides, in place of on their ends, as they certainly should have been, under the pressure of a high column of fluid metal to ensure their solidity. It is not then even probable that all the columns were sound, for as Mr George

Barker and others have pointed out in the columns of *Engineering*, and as every one acquainted with tubular castings knows, hollows or "blow holes" are frequently present in the walls of the metal, whose presence cannot be known until the metal is cut into or broken through.

I now direct attention to Fig. 12, which is a drawing of the above water portion of the first pier counting from the present standing south portion of the bridge. You will see that the lowest eastern column shows a large piece of the tube absent, exhibiting the concrete core of the interior; this, I think, unmistakably indicates that either the contraction of the tubular columns on the concrete, or the freezing of water therein, or possibly vertical compression, either some time before, or perhaps at the very instant of overturn, burst out this piece of metal. The presence, however, of such a hole at such a point of the piers shows that forces have been operating there which were destructive of the life of the bridge.

As to the primary step of the fall. Putting aside the theory that the bridge yielded first at the part where the train was situated, and because the train was there, and examining the appearance of the ends, more particularly the present directions of the projecting pieces of the rails at the north and south ends of the standing sections of the bridge, and considering the positions of these in relation to the arrival of portions of the wreck on the northern shore of the Tay, I incline to the opinion that it was the northern end which first gave way. We must not forget that these 245 feet girders were jointed together in sets of four and five; that at the middle joint they were bolted down to a pier head; and that the northern end simply rested without attachment on a box girder at the end of the northern section of the structure, as shown at Fig. 5. With a strong wind blowing I have observed the floor of suspension bridges lifted; and in view of this, with a gale acting on the western side of the girders as well as beneath them, with a leverage (from the fixed middle joint) of 490 feet, it is reasonable to suppose that the lifting effect thereof on the under side of the floor of the girder, would so reduce the insistent weight thereof on its resting points, that the friction by which it resisted lateral movement was thereby much reduced, and facility afforded for turning it off the north end resting surface. The bend of the projecting rails indicates this to have taken place whilst the fracture of the transverse bracing of the north end pier indicates the strain to have been in that direction. The transverse bracing of this pier is so broken up, that fears were entertained of its continuing to carry the end of the southernmost of the northern girders which rest upon it. So injured indeed is this pier that it is temporarily shored and bound up by wooden spars. Another point in proof of this as having been the primary movement in the fall is the state of the northernmost of the south piers. In this the bracing is but little injured, as may be seen from the photograph, and the rail ends are bent round eastwards. Now, had the southern end of the bridge gone first, we should expect to find the bracing of the northernmost piers there, to be broken up like that at the north end, but such is not the case—the lugs which held two or three of the upper tier of ties only have gone, or just what we might expect from the tendency to tear the upper part of the pier asunder, by the girder being dragged off from it, endwise. It was stated in evidence before the Court of Inquiry at Dundee, by one of the witnesses, that he saw the north end of the bridge go first; but this evidence does not seem very reliable, nor so much to be trusted as the order of arrival of the wreckage on the northern shore. Mr W. B. Thompson, of the Caledon Shipbuilding Yard and Tay Foundry, Dundee, who constructed the air-bell apparatus and other appliances used in the structure of the Tay Bridge, and who has watched the work from its outset to its completion, assures me that what were portions of the flooring of the bridge were cast ashore first, at Broughty Ferry, and that the next thing cast ashore was the wooden "slide ventilator" of a first class carriage. Mr Thompson was on the shore at the time, and saw these portions of the wreck cast up in the order I have mentioned. From the fact of the north end of the bridge being so much nearer Broughty Ferry than the southern portion of the fallen girders, inside which the train lies, he concludes that the pieces of flooring must have come from the north end, from which they would more easily be floated out, than similar pieces from the south end of the bridge, with a wind directing them to the northern shore of the estuary, and would therefore naturally arrive there, before wreckage proceeding from the southern portion.

With regard to the submerged portions of the piers of the Tay Bridge, the present state of some of them shows that brick in cement is not the best combination of materials of which to have constructed them, situated as they are in an estuary having a very rapid tidal flow. These piers in some places show the cement to be loosening and coming out, and there are indications of considerable rubbing down of the surface of the piers on their western cutwaters by tidal action, but more especially by the "shoving" of ice against them during a thaw. In view of these facts, it will be necessary to place iron shoes on the western cutwaters of the piers, to prevent the operation on them of these continuously destructive forces.

It is important that in whatever may be done in the re-erection of this bridge, that the possible operation at the same time of the three forces of wind, tidal, and ice action may all be present, and helping each other together to destroy the structure; this points out that the transverse breadth of the piers must, with the same height of bridge, be, consistently with a sufficient factor of safety, almost double the width of the present piers.

The report of Major-General Hutchinson to the Secretary of the Railway Department of the Board of Trade, is a document of such importance in the matter, that having been obligingly supplied with a copy thereof by Mr Calcraft of that Department, I am fortunate in being able to append it. The parts printed in italics therein are italicised by myself.

As to lateral oscillation, I am informed by several persons, and in particular by Bailie Thomson of Dundee, who was frequently standing on the centre part of the bridge during the laying across it of the Newport water-pipe whilst trains were passing, that the oscillation had a range of several inches.

I fail, in view of what I have seen for myself of the character of the structure, to comprehend how Major General Hutchinson could report that "the ironwork has been well put together, both *in the columns* and girders." Did General Hutchinson really closely inspect the columns? Did he inform himself of the three tiers of deep girders? Did he ascertain the depth, and variations of the depth, of the holding-down bolts? If so, his report is, to say the least, incorrect, for it has been abundantly shown how unfit was the structure of the columns for the functions imposed upon them. That General Hutchinson had misgivings as to the permanence of the brick-in cement columns is clear, for he recommends "very careful attention" to be given, to ascertain that "no scouring action is taking place in the foundations, particularly in the case of those piers which are subjected to a strong current."

The shifting character of the bed of the Tay estuary is a matter of significance in reference to the permanence of bridge piers. It is, I believe, the most shifting bed of any river in our island. In 1876 it was surveyed by Captain Stanley, "in consequence of complaints that the lighthouses were subsiding." . . . . "Since the last survey was made about ten years ago (*i.e.*, ten years prior to June, 1876) the sandbanks have shifted very considerably, the water being in some places sixteen or seventeen feet less than the depth marked on the existing charts." *

It is noticeable, too, that General Hutchinson had misgivings as to the effect of wind strains on the bridge. In short, the bridge was opened without any knowledge or observation on his part of the effect of wind on the structure. Such a condition of matters speaks too plainly to require further comment by me, and I trust that in the discussion the points in the report to which I have now alluded, will receive special attention.

In stating what I have here but only briefly epitomised as some conclusions resulting from a personal examination of the wrecked bridge, I particularly desire to avoid casting reflections on any one. The facts I have placed before you speak but too plainly for them-

---

* See my "Prehistoric Iron and Steel," p. 203-4.

selves, and point to conclusions which I prefer to leave each member to draw for himself. For no engineer at the present time is more sympathy to be felt than for Sir Thomas Bouch.

To return, however, to the more immediate purpose of this paper —namely, the bridging of the Forth—we have to consider the best system of structure by which that object can be attained; and, ere the work has proceeded much further, to determine if the proposed plan of this work cannot be improved upon, not only from the view-point of the strict application of mechanical principles, but so as to ensure the most rapid completion of the works, the restoration of the confidence of the travelling public in trusting their lives to such spans at such heights—for after the failure of the Tay Bridge some effort will be necessary to revive the trust of the public in works of this class.

To deal with this question, it is in the first place necessary for me to describe the bridge proposed by Sir Thomas Bouch. That part which crosses the river is in two spans of 1603 feet 6 inches each, and therefore of greater length than anything of the kind yet attempted or even proposed. It is true that the great bridge now being erected to connect New York with Brooklyn (the East River Bridge), has one span of 1595 feet 6 inches, or but 8 feet less than one of the suspension spans of Sir Thomas Bouch's design for crossing the Forth; yet, as the latter is not a bridge for carrying passenger or goods trains, but for tramway cars drawn by ropes, and ordinary carriage and foot passenger traffic, it does not form by any means an adequate criterion with which to compare the Forth Bridge design. This bridge is to be in total length about 2620 yards, or but 20 yards short of one-and-a-half mile. At the south end there is to be a gradient of 1 in 77 from the land abutment up to the first of the great spans. This portion of the work, consisting of 17 spans of ordinary lattice girders carried on piers, calls for no special remark. At the north end the gradient from the great span to the Fifeshire shore is 1 in 88, and consists of 12 spans of lattice girders like those at the south end. It is the portion of the proposed bridge that lies between these which I propose for this Institution to consider.

At either side of the deep water at this part of the Forth are to be erected the towers for carrying the outer ends of the four great suspension chains and two girders, on the lower part of which the roadway is to be laid. On Inch Garvie is to be erected the central tower for carrying the other ends, as shown in the elevation (see Plate XIII.) These towers are to be of the enormous height of (roughly speaking) 600 feet, or about 175 feet higher than the great chimney at St Rollox Chemical Works.

From a height of 25 feet above high water level, the supporting towers for the large spans will consist of cylindrical columns four feet in diameter, formed of rolled plates of mild steel, having base and top pieces of cast-steel. Each tower will have sixteen columns, in groups of four columns each, all braced together. A pier for each group of four columns will be brought up from the foundation with brickwork and concrete to the level of 18 feet above high water level, on which will be placed a strong girder framing for distributing the weight over the piers, and on which the columns will be erected. On the top pieces of each group of columns will be placed a framework on which the chain saddles will rest. The saddles will be of mild steel, semi-circular in section at the top for placing the steel pins which are to secure the ends of the suspension and anchoring chains. The back or main anchoring chains will be anchored in masses of brickwork and concrete; the supplementary anchoring chains, from the saddles of the central towers, will be anchored in the girder framing on which the columns of these towers are erected. The large span girders will be lattice 40 feet high in the centre, and 19 feet high at the ends. There will be two main girders 16 feet apart, centre to centre, braced top and bottom, for each span of single line of roadway; and the two roadways, 100 feet apart, centre to centre, will be connected together by light girders, in the manner of horizontal diagonal bracing, between the adjacent main girders. The main girders will rest at each end on cross girders provided for them between the columns of the towers, and they will be further supported from the chains passing over the towers by vertical suspension* bars 50 feet apart. The suspension chains will each consist of four links in section, and there will be four chains to each single line of roadway, one on each side of each girder, and they will be connected to their respective girders at the centre of the spans by a pin passing through both chains and girder. "The contract for the supply of the steel chains required for this bridge has been placed with T. Vickers & Co., of the River Don Works, Sheffield. The total weight of the chains will be about 10,000 tons, and the amount of the contract is £210,000."* From the points of connection with the chains of the first eight suspension bars, reckoning from the towers in each case, oblique tie-bars will converge to the ends of the girders, provision being there made for rivetting the ends of the ties to the girders. The links of the whole of the chains will be formed of high class steel bars, and connected with steel pins. The suspension bars, the oblique tie-bars, and the vertical bars between the central towers, will also be of the same quality of steel. The back or anchoring chains, and the horizontal chains between the central towers, will be trussed. The roadway to be placed on the bottom members of the 1603 feet span girders, and on the top members of the whole of the other girders, and will consist of cross girders, with timber way beams and planking. The under side of the 1603 feet 6 inches span girders was originally intended to be 150 feet above high water, but it is reported that at a recent meeting of the North British Directorate, it is now proposed to obtain the consent of the Board of Trade to a lowering of this by from 15 to 20 feet.

In the light of our present appliances for facilitating construction, no one cognisant of the means at command of a modern contractor will doubt that, given unlimited time, and unlimited capital, the proposed bridge can be constructed. But that it will be constructed in *five* years, as is the estimate upon which the prospectus of the Company has invited the subscription of capital, is in the remotest

---

* "Steel," by Jeans, p. 178.

degree unlikely. The East River Bridge, to which I have already made some reference, has already been *ten* years in construction, being partly delayed through financial difficulties, and Mr Farrington, the master mechanic, who has been connected with that structure since its commencement, estimates that it will take about two years more to complete. I have already said that the East River Bridge is an insufficient criterion by which to judge altogether of the Forth Bridge; yet, as it is a much lighter structure in every way, it is scarcely reasonable to assume that with the far greater difficulties which the Forth scheme presents, it can be a completed work, making a return to its proprietors, in much less time.

It is a singular drawback in the structure of suspension bridges, that none of the bridging proper—by which I mean the actual crossing portions of such a bridge—can be laid until all the piers and towers are raised to the full height, the saddles placed, and the anchoring constructed. In most other forms of bridges the works can proceed simultaneously, both vertically and horizontally, and the time required for the construction is thereby shortened.

Now, as to the question of the fitness of the accepted design of this bridge: on looking at the elevation we see that the great girders are of dimensions by which they are not able to support themselves, the ratio of their central vertical depth to length being one-fortieth only. Furthermore, the work of the chains is entirely utilized in carrying these. Each girder is, as nearly as I have been able to estimate, from 1600 to 1900 tons in dead weight at least, and from the structure it is clear that about two-thirds of this is a permanent dead load upon each pair of suspension chains, to which has to be added the load produced by the tension of the diagonal back stays. The girders not contributing to their own support are then, by the material in them in excess of what is sufficient with a proper factor of safety of say 4 or 5 to 1 to carry the live load, a source of weakness to the stress-resisting portions of the bridge, viz. the chains. Owing, however, to the manner in which the back ties are fastened—viz. to the ends of these girders—it has become necessary to make these girders of stiffer section than what is requisite for carrying their own "dead" and "live loads;" for, acting as they do under the stress of these back ties, like a pair of struts abutting against each other at the centre of span, the girders themselves and the chains would sag to a considerable extent with a heavy train at the centre of span, unless the girders had sufficient stiffness to resist the tendency to their ends being raised or curved upwards by the combined action of the "dead" and "live loads" tending to straighten the catenaries by their downward stresses, or drag at the centre. The ends of these girders are said to be free to move horizontally, but rising and falling motion is resisted by sliding bearings and by a vertical anchorage.

From this it follows that, whilst the back-ties are essential to produce the requisite stiffness of the structure, and to pull back the true catenary curve of the chains; yet, fastened as they are to the extremities of girders which derive their support by an attachment of suspension at intervals to the chains, they are not applied in a manner to obtain the maximum effect from that mode of stiffening the chains. The back-ties, I conceive, should be fastened to a part of the structure independent of the horizontal or roadway girders, and in such manner that their stress should not be imparted to these girders strutwise. This might be effected by connecting the back-ties of both spans to a horizontal braced and tied framing at the central towers, thus linking the back-ties of both spans together, thereby utilizing to the best effect the whole metal of the bridge by putting it in tension; and by similarly attaching the back-ties at the shore towers, the chains could be so stiffened endwise, that the cross girders which are to unite the two bridges could be lightened, that is to say, upon the assumption that these back-ties can be strained to a sufficient degree of tightness—an assumption with ties of such a length and section almost, if not quite impossible to realise. It may perhaps be thought that the proposed structure of the 1603 feet 6 inches girders is essential to produce stiffness from swinging by the action of a storm of wind; this, however, cannot be so, for these girders being of less section to resist transverse bending than bending downwards, are especially ill-calculated to stiffen the bridge against wind stresses. In the report of Messrs Barlow & Pole, dated June 1873, 10 lbs. per square foot is adopted for wind pressure. Professor Rankine, however, gives 55 lbs. as highest registered pressure, and lately it would appear that as much as 60 lbs. per square foot has been registered in England. In such a bridge, what is wanted is sufficient back staying * of the catenaries, by attaching them to an unyielding part of the structure, thereby producing in the first place longitudinal stiffness by tension—which also means the production of transverse stiffness to resist storms—and therefore the reduction to a minimum of both swinging and sagging.

If the design of the Forth Suspension Bridge had been made on the mode I have here pointed out, there is no doubt that the height of the towers, and therefore the length of the suspension and anchoring chains, might have been reduced, with a corresponding economy in material. The mode of fastening the back stays I have herein suggested, would amply provide for the movement of the different parts by expansion and contraction during change of temperature; for, as the length of each tie is proportional to the lengths of each half of the catenary, its expansion and contraction will be a constant proportional to the length of that part of the catenary between the point of tie attachment and the chain saddles, and as all the parts are exposed to practically the same changes of temperature at the same time, the tensile load will remain constant at all temperatures.

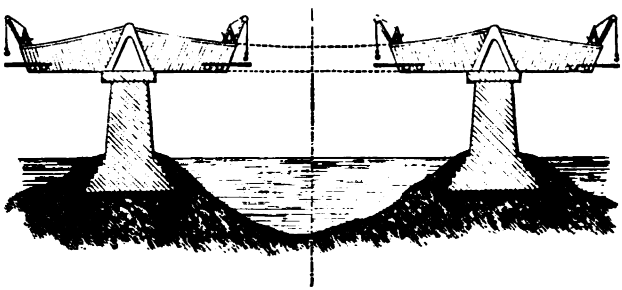
From this mode of tying the catenaries being productive of the requisite stiffness in the manner I have described, it follows that stiff girders for carrying the roadway and live load become unnecessary. In Sir Thomas Bouch's design the girders which he proposes are carried by vertical suspension links at 50 feet intervals, yet the dimensions of the girder are sufficient to carry itself with points of

* That is to say, always on the assumption that they can be sufficiently supported so that their own weight does not come in as a serious preventive to their being drawn tight.

support 250 to 300 feet apart. If these points of support 50 feet apart are used with the mode of securing the back staying herein pointed out, the roadway and "live load" might with ample security be carried upon lattice girders not more than 6 feet deep—which means, in other words, that at least two-thirds of the material in the great horizontal girders of this design would be got rid of—and as the surface of metal would be thereby reduced very considerably, the total stress on the bridge during a storm of wind would be proportionately diminished. The horizontal bracing, too, of such roadway girders might be made so stiff that its construction would be like a lattice girder lying on its side with booms 6 feet broad, thus producing a maximum stiffness against wind pressure. One essential defect of Sir Thomas Bouch's design is the great height above the roadway at which the axis of the centre of gravity of the structure must lie, owing to the entire weight of the chains, girders, &c., being carried from the very top of the columns. The destructive effects likely to arise from this cause, through the tendency of the wind to overturn the bridge, appear not to have been considered. Besides, to practical men the recommendation of a wind-stress of 10 lbs. per foot, shows plainly that the report of Messrs Barlow & Pole of June, 1873, is of no value when based upon such a low assumption of wind pressure.

But whilst having so far dealt with faults, and pointed out certain remedies for the faults, in the accepted design for the Forth Bridge, I have not dealt with the more important question, namely, whether a class of structure altogether superior to a suspension bridge, which could be erected at less cost, in far less time, and one in which more confidence might be placed, cannot be devised? I hope to answer these questions in the affirmative, by now directing your attention to a design for this bridge, in which the axis of the centre of gravity is extremely low, which has been originated by a well-known member of this Institution—Mr Andrew Barclay, F.R.A.S., of Kilmarnock. In his regular business Mr Barclay has had much experience in calculating and designing beams, and this has rendered him peculiarly qualified for considering the question of the safest and most rapid mode of constructing a wide span bridge; and I think that you will find the ingenuity and boldness which he has displayed in his design for the Forth Bridge, not only is in keeping with other instances of originality of thought and perception of fitness for the end in view, which have on previous occasions been brought before this and kindred bodies of engineers; but further, that it merits the serious consideration of all who are interested, before the scheme which for the present stands as accepted, is proceeded with.

Mr Barclay's design is shown on Plate XIII., and he proposes to construct the bridge in the following manner:—Having got in the foundation piers of masonry on either side of the Forth and at Inch Garvie, and these raised to the requisite height to give a clear headway of 150 feet at high water, he proposes to build on this the first section of the towers up to the level of the first crossties, tying the section together with lattice bracing. The vertical face of the two opposite sides of the base of each tower constitutes the root of a triangular beam of such a section of metal as will stand the compression due to the weight of half the span loaded with a train at its extreme end, and having a factor of safety of five for compression. These beams are braced by back ties to a vertical tower at the centre of each of the two end beams. Each half projecting out over the piers constitutes half of the 1600 feet spans, the other half of these spans being made up of similar projecting triangular beams from the great vertical rectangle standing on the Inch Garvie piers. Each half then of each span is an independent structure, and in no way depends upon the other half for its support. The two parts are, however, connected together by a low truss, and have expansion joints at their point of meeting to allow of alterations of length by the variations of temperature. An important point to notice in the design of this bridge is that each of its main three sections is self-balanced, and therefore self-supporting. It is not to be forgotten that in an original design of Fairbairn's for crossing the Menai Straits, he proposed to build the tube, in working outward from the piers, by adding 10 feet lengths of tube at each end of each section simultaneously, thus maintaining at all times balance of structure, as shown in the woodcut. This scheme he submitted to Robert Stephenson. It was abandoned on account of the difficulty



felt in those days with less efficient contractors' plant than we now possess, of ensuring the proper simultaneous attaching of the successive ten feet sections, besides which casualty was apprehended from both ends of the gradually lengthening tubes being left unsupported against wind stress. The land sections of each half of the two end triangular girders being further held by vertical anchoring ties passing down through the shore piers, whilst the weight of the great central rectangle of the Inch Garvie piers gives steadiness against overturning on the end piers thereof. The great central rectangle of the middle portion of the bridge, as well as the rectangular towers of the two end portions, are further steadied by holding-down bolts passing down through the five masonry piers. After the lowest section of the towers and the corresponding part of the central rectangle are completed, Mr Barclay proposes to build each of the three sections of the bridge both upwards and outwards simultaneously, the outward building to go on precisely at the same rates at opposite sides in order to maintain at all times a balance of structure. In this manner all the portions of the compression member of the girder grow outwards. Service tie-rods are to be used to support them horizontally until the first section is completed, when a permanent tie-rod will be attached from the projecting portions to a horizontal tie-rod in the end towers and central rectangle. In this manner each section of the bridge will be constructed both upwards and outwards until the spans meet in the centre, and that without the use of any scaffolding, for one of the excellencies of such a mode of constructing a bridge is that as it grows in length and height it constitutes its own scaffolding.

In designing the proportions of the three great triangular members of this bridge, the lower member or root has a section for compression equal to the section of all the angular tie-rods up to the highest portion of the beam, and this member gradually decreases in section as the number of tie-rods decrease in proceeding to the centre of the span. In this manner each tie-rod is exactly proportioned to carry the load on the portion of the bridge extending half way on each side of itself and the two adjacent tie-rods. Thus, as the last tie-rod has only one half of such weight to carry it is of lighter section than all the rest.

The rails are to be laid on the lower side of the horizontal members, each of which constitutes a rectangular tube of lattice work, inside which the trains will run. The proposed construction of this member will consist of two troughs, one at top and bottom, connected together by ten feet of open lattice work, and Mr Barclay proposes, for the sake of preventing damage to the bridge in the event of a train getting off the rails, to bolt on either side of the lattice tube a pair of beams against which the wheels of the train would run in the event of the train getting off the rails, the presence of these beams preventing the train from coming in contact with any part of the iron structure, thus obviating serious damage to the train or to the bridge. In constructing a work of this kind the time occupied is an element of the first importance, and as compared with the design of Sir Thomas Bouch it will be seen at a glance that Mr Barclay's design provides nine points at which the bridge can be constructed simultaneously in all directions, whilst the design of Sir Thomas Bouch has but three such points; so that the probability of the bridge being constructed in a minimum of time compares largely in favour of Mr Barclay.

Another point, and perhaps one of the most important in comparing the two designs is not only the structure of the three vertical members of each bridge, but also the difference in their heights, the total height of Mr Barclay's bridge being 346 feet from the roadway, compared with 450 feet of the corresponding portion of the piers of Sir Thomas Bouch's design. In the latter design, too, the leverage for wind stress has to be calculated for the whole height of 600 feet (more strictly 596 feet), as the towers are continuous from their roots to their summits, whereas in Mr Barclay's plan, as each of the three main members of the bridge rests solidly on masonry 150 feet high, the wind stresses have only to be calculated for 346 feet.

Lastly, in comparing the two designs, simplicity of structure and non-liability to accident seem to favour Mr Barclay's, as there is no risk to incur of men working 600 feet in the air, nor the raising of 10,000 tons of suspension chains which, in order to maintain the requisite balance of forces, must be raised simultaneously over the 1600 feet spans and anchoring to that height; nor is there the risk incurred of having the life of the whole bridge depending upon anchoring chains and their anchors, from the yielding of which some suspension bridges have been known to fail. I cannot avoid directing especial attention to the anchoring, upon the efficiency of which the life of the bridge so much depends. There is not only the constant direct pull of the anchoring chains tending to destroy it, coupled with the swaying stress over the whole bridge due to wind action, but there is also the destructive effect of wave-blows to be withstood, all three of which may occur at any time simultaneously. What the effects of wave-blows are we can notice from the oft-destroyed Eddystone lighthouse, whilst I have had frequent opportunities of observing the destruction worked by them on the sea-walls of the South Devon Railway when engaged for some years in the practical study of engineering there. The weights of Sir Thomas Bouch's bridge I have not been able to obtain at present, for the reason that, since the failure of the Tay Bridge, the design and proportions of the Forth Bridge are under reconsideration, and therefore not wished to be made public. To Mr Barclay I am, however, indebted for all the calculations of his bridge, which have been elaborated by himself and his assistants to the fullest extent, and, I should add, that throughout the design of his bridge Mr Barclay has adopted a factor of safety of 5, and has assumed a wind-pressure of 112 lb. per superficial foot, in place of the 10 lbs. recommended by the Astronomer Royal, this being about double the pressure of the severest gale recorded in this country. The live load is assumed at the rate of 1¼ tons per lineal foot of span; and consistently with the uniform factor of safety of five, Mr Barclay has fixed the stress of the combined dead and live loads as 6·5 tons per square inch of section of metal throughout the bridge, if made of steel. The following figures give the weights of the whole bridge, including the Queensferry and Fife land sections, for the bridge to be constructed of steel:—

Rolling load = 25 cwts. per lineal foot for single line of railway.

Platform, rails, sleepers, chairs, &c., = 4 cwts. per lineal foot for single line of railway.

Tension and compression strains on steel = 6½ tons per square inch.

Wind pressure = 112 lbs. per square foot.

	Tons.	
Main spans, ...	12,998·94	
Horizontals, main girders, and diagonals, (mid channel), ...	2,190·00	
Stays between bridges (mid-channel), ...	200·00	
Part at end piers, ...	480·00	
Main columns, ...	1,200·00	
Bracing, ...	300·00	
End spans, ...	1,000·00	
	18,368·94	
Add for joints, ...	2,296·12	
	20,665 06	
	2	Bridges.
Total, ...	41,330·12	Tons.

If the working load be reduced from 25 cwts. per foot for rolling load to 15 cwts. per foot, it would reduce the weight of the bridge from 41,330 tons to 27,078, thus effecting a saving in weight of 14,252 tons.

If the working load be reduced from 25 cwts. per foot for rolling load to 23 cwts. per foot, it would reduce the weight of the bridge from 41,330 to 38,479, thus effecting a saving in weight of 2851 tons.

NORTH BRITISH RAILWAY, TAY BRIDGE.

Newcastle-on-Tyne, 5th March, 1878.

SIR,

I HAVE the honour to report, for the information of the Board of Trade, that in compliance with the instructions contained in your Minute of the 15th ultimo, I have inspected the Tay Bridge, forming a portion of the Tay Bridge Railway, of the North British system.

The Tay Bridge Railway, in conjunction with the Forth Bridge Railway, for which an Act of Parliament has been obtained, will shorten the existing route between Edinburgh and Dundee (via Stirling) by 28 miles; and by means of these two railways and a new railway about to be constructed between Arbroath and Montrose the journey between Edinburgh and Aberdeen will be reduced by 23 miles.

In consequence of the magnitude of this bridge, of which T. Bouch, Esq., M.I.C.E., is the Engineer, it was considered desirable to have it inspected before the lines north and south of it were ready for traffic. The inspection of the bridge accordingly took place on the 25th, 26th, and 27th ultimo, the weather fortunately being favourable.

The Tay Bridge carries a single line of rails, is 3,450 yards in length, and consists of 85 spans of the following descriptions :—

11	spans	of 245	feet each,	lattice girders
2	„	227	„	„
1	„	164	„	bowstring girders
1	„	162·8	„	lattice girders.
13	„	145	„	„
10	„	129·25	„	„
11	„	129	„	„
2	„	87	„	„
24	„	67·5	„	„
3	„	67	„	„
1	„	66·7	„	„
6	„	28·9	„	„
85				

In addition to which there are adjoining the north end of the bridge,—

1 span of 100 feet, bowstring girders.
3 „ 29 „ plate girders.

In the 15 spans exceeding 145 feet and with the 100 feet bowstring girders wrought-iron cross girders have been employed; for the other spans cross girders of timber.

In the 13 spans of 227 feet and upwards and in the bowstring girder spans the roadway is carried on the bottom booms of the girders; in the other spans on the tops of the girders.

The girders are arranged in continuous groups, generally of 4, 5, or 6 each, with proper provision for expansion.

They are supported on piers of varied construction, the foundation in all cases being formed of iron cylinders lined with brickwork and concrete. Counting from the south end,

Piers 1 to 14 are entirely of brick in cement.

Piers 15 to 48 are brick for 5 feet above high-water mark, finished with a stone belting, upon which are carried groups of cast-iron columns braced together, Piers 49 to 77 consist of groups of cast-iron columns braced together, starting from the cylinders and encased in brickwork to a height of 5 feet above high-water mark.

Piers 78 and 79 are cast-iron cylinders throughout, filled with concrete.

Piers 80 to 84 are cast-iron columns.

Piers 85 to 89 of brick in cement.

The greatest height from the level of the rails to high-water mark-spring tides is 92 feet; this occurs at the centre of the large spans, whence towards the north side there is a sharply falling gradient of 1 in 74, with a gentler fall towards the south end; at each end of the bridge there are curves of 20 chains radius.

The permanent-way consists of double-headed rails, fished at the joints, in 24 feet lengths, weighing 75 lbs. to the yard, secured by oak keys in cast-iron chairs weighing 80 lbs. each, fixed at 3 feet average intervals to longitudinal timbers 17 inches wide, and varying in depth between 7 and 14 inches. There are 4 spikes in each chair. Throughout the length of the bridge each rail is provided with a guard-rail.

Between the longitudinals the floor of the bridge consists of 3-inch planking covered with a waterproof composition.

A substantial hand-rail is carried along each side of the bridge.

For the purpose of adequately testing the structure, the North British Company placed at my disposal six new goods engines, weighing 73 tons each, and each measuring 48½ feet over all. The total weight employed be ng thus 438 tons, and the total length of engines 291 feet, or as nearly as possible 1½ tons to the running foot. Under this test the deflections were as follows :—

Of the	227 and 245 foot	girders	varied between	1·8	inch and	1·2	inch
„	166 (bowstring)	„	„	1·2	„	0·9	„
„	163	„	„	0·6	„	0·6	„
„	145	„	„	1·0	„	0·6	„
„	129·25	„	„	0·6	„	0·6	„
„	129	„	„	0·9	„	0·6	„
„	87	„	„	0·6	„	0·6	„
„	67·5 and 67 and 66·7		„	0·3	„	0·3	„
„	28·9	„	„	0·2	„	0·2	„
„	100 (bowstring)	„	„	0·6	„	0·6	„
„	29	„	„	0·2	„	0·2	„

These results are, in my opinion, to be looked upon as satisfactory. *The lateral oscillation, as observed by the theodolite with the engines running over at speed, was very slight, and the structure altogether showed great stiffness.*

The dimensions of the various parts of the girders have been carefully worked out, and the iron has in no case been submitted to a greater strain than five tons to the inch.

Upon a careful examination of the brickwork and masonry, they appear to be of a substantial character, and to be showing no signs of settlement. *The iron work has been well put together, both in the columns and girders.*

The following are the only requirements that came under my notice:—

1. Transoms and ties for preserving the gauge should be provided between the longitudinals.
2. The fireproof covering of the floor requires repair in several places.
3. Some slack places in the rails require adjusting.

To reduce as much as possible the expansion of the girders in hot weather, I should strongly recommend their being painted white.

It will not be desirable that trains should run over the bridge at a high rate of speed, and I would suggest 25 miles an hour as a limit which should not be exceeded.

A certificate will have, of course, to be given that the single line shall be worked with the train staff and block system.

Very careful attention will be required to ascertain from time to time that no scouring action is taking place in the foundations, particularly in the case of those piers which are subjected to a strong current.

When again visiting the spot *I should wish if possible to have an opportunity of observing the effects of high wind, when a train of carriages is running over the bridge.*

Subject to the above requirements and remarks, I see no reason why, so soon as the adjoining railways are completed and inspected, the Board of Trade should object to the railway on the Tay Bridge being used for passenger traffic.

I have, &c.,

C. S. HUTCHINSON,

The Secretary, *Major-General, R.E.*

Railway Department, Board of Trade.

The discussion on this paper was commenced on the 24th February, 1880, by

The PRESIDENT, who said they had met that evening to discuss Mr Day's paper, read at the last general meeting, in which he gave a probable cause of the lamentable failure of the railway structure over the Frith of Tay, and a description of an alternative plan for such structures, proposed by one of their members—Mr Andrew Barclay. The subject had been studied by many of the gentlemen present, and would probably elicit differences of views; but he had no doubt these would be expressed consistently and with moderation. He then asked Mr Day if he had any further remarks or explanations to make on the subject of his paper.

Mr ST. J. V. DAY said—In the month that has elapsed since the reading of my paper on the Tay and Forth Bridges, much discussion has taken place on the subject outside the walls of this Institution. It has been suggested by many persons—some, I believe, members of this Institution—that it was somewhat irregular to discuss the subject of the Tay Bridge catastrophe during the progress of the investigation now being made by the Court of Inquiry on behalf of the Board of Trade. I think it right to state that a few days subsequent to the reading of my paper, I received a communication from Mr Rothery, the President of the Court of Inquiry, asking me questions regarding the structure of certain parts of the bridge, in relation to the views expressed here with reference to the models of some parts thereof in the Museum at Dundee, and which Mr Rothery had first heard of from the reports of my paper in the newspapers. These questions had reference to certain broad vertical flanges provided with bolt holes, for holding stiff transverse girders, and to be seen on several of the fallen columns, as will be clearly observed by inspection of the photographs which I have placed round the walls of this hall, and which have been supplied to me by an order of Mr Murton, the solicitor of the Board of Trade, to whom in that respect I am much indebted. After receiving the aforesaid communication from the President of the Court of Inquiry, it occurred to myself that it might be inconvenient to the Court if I were to make any further public statement upon the matter of the Tay Bridge failure until after the Court of Inquiry had finished its investigation. I accordingly wrote to the President of that Court, asking how far such further statement or discussion might be irregular or inconvenient, and am glad now to be able to read you an extract from Mr Rothery's letter of the 14th instant, in which he not only does not suggest any restriction whatever upon the free discussion of the facts I have brought before you, but in which he recognises, in a manner which cannot be otherwise than gratifying to this Institution, the value which he considers must attach to the discussion of the structure and fall of the Tay Bridge by us.

Mr Rothery writes: "Thanks for your letter of yesterday's date. By all means attend the meeting appointed for 24th, and say whatever you wish to say upon the subject. The more discussion the matter undergoes by so competent a body as the Institution of Engineers and Shipbuilders in Scotland, the better."

Since the reading of my paper, some extraordinary statements have been published to the world with reference to the wind-stress for the structure of the Forth Bridge to resist, made by Messrs Barlow and Pole, in 1873, in their report on Sir Thomas Bouch's design for the Forth Bridge. In that report it is stated that—

"In a structure of this magnitude, and placed in such an exposed situation, the probable effect of wind must form an important subject of consideration. It is known that suspension bridges of large span have heretofore suffered considerably from this cause, and it is necessary therefore to examine carefully what kind and amount of strain the wind is likely to cause on such a structure, and what means Mr Bouch has provided for resisting it.

"The first question of course is, What is the maximum force of wind per square foot which may be expected to act on the bridge? On inquiring into this, we found much obscurity in the data available.

"The ordinary source from which such estimates are taken is the well-known table presented by Smeaton to the Royal Society in 1759. This table gives 6 lbs. per square foot pressure for 'high winds,' 8 lbs. or 9 lbs. for 'very high,' and 12½ for a 'storm or tempest.' There are still higher figures for 'great storms or hurricanes,' but these are of doubtful authority, and only apply to tropical meteorology.

"In this uncertainty, it was suggested that we should make an application to the Astronomer-Royal, in order to ascertain what information he could afford us on the point, with the aid of the valuable meteorological records kept by him at Greenwich Observatory.

"We accordingly had an interview with Sir George Airy on the 29th March last. He courteously placed at our disposal his official registers of the wind, and pointed out and explained to us the diagrams of the heaviest storms that had occurred for many years; and he afterwards put in writing his opinion on the point in question.

"The Astronomer-Royal says: 'We know that upon very limited surface, and for very limited times, the pressure of the wind does amount sometimes to 40 lbs. per square foot, or in Scotland probably to more. So far as I am aware, our positive knowledge, as derived from instrumental record, goes no further. But in studying the registers it is impossible not to see that these high pressures are momentary;* and it seems most probable that they arise from some irregular whirlings of the air which extend to no great distance—I should say, certainly, to no distance comparable with the dimensions of the proposed bridge;† and I think that the fairest estimate of the pressure on the entire bridge would be formed by taking the mean of the recorded pressures at one point of space for a moderate extent of time, as representing the mean pressures on a moderate extent of space at one instant of time. Adopting this consideration, I think we may say that *the greatest wind pressure* to which a plane surface

* This written opinion of the Astronomer-Royal caused me to correspond with him on the subject of wind-stress, and I have here to acknowledge his great kindness in furnishing all the information I ventured to ask for. With regard to the momentary high pressures, or gusts of wind of two or three seconds' duration only, the Astronomer-Royal now coincides in the views I have expressed to him of their sufficiency to produce ruinous effects, and that "it is a matter of common sense that a structure ought to be framed to resist the strongest known pressure."

† In a letter dated subsequently to the discussion, from Dr Robinson, of Armagh Observatory, replete with information on wind-pressure, &c., he mentions that "I once observed here a squall, which blew for six minutes at the rate of 125 miles an hour. This would, on the common theory, give the pressure of 32 lbs. on the square foot. And before it had reached this place it had passed over several miles of cultivated ground and wood; its intensity on the sea must have been far greater. However, it must be remarked that these violent squalls are sometimes of no great breadth. The one which I have mentioned must have certainly been more than half a mile in breadth (therefore as broad as the two great suspension spans of the Forth Bridge) But another (which I had no means of measuring) cut a lane through Lord Enniskillen's plantation at Florence Court, a quarter-mile broad, levelling every tree in its course for a distance of some miles. Still, even a quarter of a mile of the bridge, if exposed to the pressure of 50 or 60 lbs., could not have resisted it. I scarcely think it safe, in such calculations, to take a less pressure than 70 lbs. as the maximum."

like that of the bridge will be subjected in its whole extent *is 10 lbs. per square foot.*'*

"We entirely concur in this opinion, which we consider highly authoritative and valuable; and we may therefore safely adopt 10 lbs. per square foot as the side pressure due to the wind for which Mr Bouch has to provide.†

. . . .

"The side surface of each span exposed to the wind (but making an allowance for some parts which may be assumed to bear directly on the piers) is given by Mr Stewart at about 14,000 superficial feet.

"This is for one surface only—*i.e.*, the one first exposed to the wind. But behind this there are three other similar surfaces, one about 15 feet away, the second about 120 feet away, and the third one 35 feet away. The wind must rush past these after passing the first one, and although each will be, no doubt, to a certain extent in shelter from those in front of it, we cannot suppose that they will be free from the wind's action. Possibly it would be a fair estimate to double the surface of the front face; but as an outside estimate we have taken three times, or 42,000 feet. To this has to be added 8000 feet for two trains which may be on the bridge, giving 50,000 square feet of surface exposed to the horizontal action of the wind. Allowing, therefore, 10 lbs. per square foot, we get a force of about 225 tons.

"This will produce, we find, a certain effect of tension and compression on the stiffening girders which must be included in the general strains on these parts.

---

* In a subsequent letter to myself the Astronomer-Royal points out that the Greenwich observations are of little use in dealing with wind pressure so far north, but that those obtained at Edinburgh form a better criterion. On this point I shall hereafter bring forward the important testimony of Piazzi Smyth.

† Rankine ("Civil Engineering,") states that pressures as high as 55 lbs. per square foot have been registered in this country, and since his time it is stated that pressures as high as 60 lbs. have been recorded.

"Some large suspension bridges originally built without stiffening, have suffered materially in gales from a disturbance of the platform, which has been thrown into waves of oscillation, as if acted on by forces from above or below, instead of horizontally, as the wind is usually assumed to act. It is difficult to account for this kind of action except by supposing the existence of irregular eddies, acting partially in oblique and unexpected directions.

"It is, obvious, however, that with the strong stiffening arrangements * adopted by Mr Bouch no such effect need be apprehended in the Forth Bridge.

"... The effect of the wind on the towers has also to be considered. It will consist partly of the direct pressure of the wind on the surfaces of the towers and partly of the action of the suspended span, the lateral pressure of which must be borne by the towers at its two ends. Making an ample allowance for these we find that their combined effect will be to add a strain of only a small fraction of a ton (from ⅛ to ¼) per square inch to the compression of the cast-iron pillars on the lee side."

I felt this part of Messrs Barlow & Pole's report, based as it is on what they and we had every right to consider as the highest authority on wind pressures, namely, that of the Astronomer-Royal, to be so startling that on the 4th inst. I wrote to the Secretary of the Board of Trade as follows:—

"As I am desirous for public purposes to be officially informed of the stresses fixed by the Board of Trade for the steel of which the Forth Bridge is to be constructed, I trust it will not be considered irregular on my part in applying to you for this information. I am desirous to know if it be the fact that the tension stress of 6½ tons per square inch, as advised to the Board of Trade for bridge structures by a committe of engineers appointed by the Board, has been adhered to in this case, or whether the greater stress of 8 tons per square inch,

* Can this be said to be "strong?" See Fig. on Plate X., which shows two at least of the back ties of about 400 feet in length to be attached to the ends of the girders by some five ⅞ths rivets only.

as currently reported to have been allowed by the Board for this particular bridge, is correct. I also desire to know if a different stress has been fixed by the Board of Trade for the suspension chains and girders of the Forth Bridge."

I received the following reply on the 10th inst.:—

"Board of Trade, Railway Department,
"London, S.W., 10th Feb., 1880.

"Sir,—I am directed by the Board of Trade to acknowledge the receipt of your letter of 4th inst., requesting to be informed of the stress fixed by this Department for the steel of which the Forth Bridge is to be constructed, and whether any different stress has been fixed for the suspension chains and girders. In reply I am to inform you that *the matters to which you refer are under consideration.*

"I am, Sir, your obedient servant,
"HENRY J. CARNEGIE."

Subsequently I communicated, as mentioned in the preceding footnotes, with the Astronomer-Royal, also with the Astronomer-Royal for Scotland, Sir William Thomson, and Professor Grant on the subject of wind pressures, and I have to express my special thanks to each of the gentlemen whom I so addressed for the very valuable information which they have supplied me on the subject of wind stress. I have also received some important facts from Dr Robinson of Armagh Observatory, Ireland, on the subject of wind pressures, &c., but through the closeness of my engagements of late it has not been possible as yet for me to communicate with him on points on which I desire further information before we can fully discuss the serious bearing of this subject on the structure of long span bridges in exposed situations. On noticing the formation of the hills bounding both sides of the Firth of Tay, I was particularly struck with the conical shape, broad at an upper part of the opening and rapidly tapering to its narrowest point at Dundee, as shown in Plate XV., in which the waterway is represented in flat tinting, the low even land by lines running east and west, and the declivities of the hill sides by lines running north and south. The several numbers giving the vertical heights in feet above the Ordnance datum. Applying to a valley of this formation the well-known law of Bernouilli, namely, that the quantity of fluid flowing through a tapered tube is constant at all parts, or in other words that whilst the rate of flow varies inversely as the section of tube, the pressure of the flow varies directly as that section, it occurred to me that the pressure on the Tay Bridge would be increased by the wind rushing at a very high rate of speed through a channel having the shape of the estuary of the Tay; and in this view I am confirmed both by the Astronomer-Royal for Scotland and by Dr Robinson of Armagh, although Sir William Thomson and Dr Grant appear to think that no very serious increase of velocity and pressure on the Bridge when extending over so large an area as the conical valley of the Tay would take place.

I append in a foot-note the mathematical formula expressing this law. The Astronomer Royal replied that "on the various questions which arise in reference to the disaster of the Tay Bridge I might perhaps have stated privately my opinions, but I am not so willing to give them for the purpose of being brought forward in public discussion," and he referred me to the Edinburgh observations as being more useful. Sir George Airy has also most obligingly provided me with the tables of wind pressures at Greenwich for the 24 hours on either side of the time of which the instant of fall of the Tay Bridge constituted the middle point, which although not bearing very directly on the matter at a place so far distant is yet extremely valuable for meteorological purposes. To the Astronomer-Royal for Scotland I am, however, indebted for much valuable information on this subject, from which I extract the following. The conclusions at which he arrives being as follows:—

"Guided by such circumstances as these, I should say that nothing is more probable than that the flooring of the Tay Bridge was momentarily lifted up in the height of the gale and then banged down again by positive upward and downward most intense forces notwithstanding that the general motion of the whole wind was, and could only be, horizontal.

"In fact according to the view already expressed touching the more rapid rate of increase of intensity in the variation over increase in the general motion of the whole wind, the latter has only to overpass a certain velocity of travel and the variations with their effects at right angles to their current will become the more serious to any engineering structure, and especially if made of material with a tendency to snap under sudden strains.

"The hold on the wind possessed by the valley of a river is so notable that in a far more open locality than the Tay Bridge, viz. Granton on the Firth of Forth, I have known observations of a registering anemometer there totally objected to as showing wha the wind was in Edinburgh at the same time, because Edinburgh was not in the Firth's influence equally with Granton.

"That hold being allowed a percentage of the theoretical increase of velocity in fluids flowing through a conical aperture must follow as a matter of course where the channel contracts, unless indeed it could be urged that the friction against the bounding hills on either side was so powerful as to destroy the accelerated velocity as fast as it was created. But against the probability of such a thing ever taking place in practice, I would relate that I have had daily experience in former years of violent winds under most unexceptionable circumstances for good observation, and an invariable result was, that where a jutting-out hill decreased the free passage for the wind over the plain country, and necessarily increased the friction, precisely there the wind was strongest, and blew up actual pebbles into one's face, when before and after passing that obstruction, it only blew sand into one's eyes.

"The chief example of such intensification of the wind was near the Cape Observatory.

"The stronger these South African winds the very much more gusty and fitful they always become, so that if the mean strength of the wind increased by steps in simple arithmetical progression, the strength of the gusts, or the intensity of the variations in the wind, increased far more rapidly as in terms of the square or perhaps cube."

Dr Robinson writes :—

"I have no doubt that the velocity of wind passing down such a funnel-shaped valley as that of the Tay will be considerably increased, The case is quite analogous to that of a tide in such an estuary as that of Bristol, where at Chepstow it rises three times its height in the Irish Channel.

"Or in the Bay of Fundy where it is said to rise a hundred feet. As to the lateral friction against the hills, it will retard the part of the current which is near them, but this retardation will decrease towards the centre, exactly as in the case of rivers, where the flow of the stream is more rapid in its middle than at its edges.

"It might be supposed that the wind concentrated in the valley would relieve itself by rising above the hills, but this would scarcely affect its velocity below, for it could not rise without condensing the air above it and thus establishing a *head* of increased pressure.

"It seems to me to be quite possible (judging from your sketch) that the velocity of the wind at the centre of the Tay Bridge may have been ⅓rd greater than what it was at the sides."

In regard to this vertical lifting effect of the wind on the under side of the flooring of raised platforms, such as the under side of a lattice girder or other bridge, the paper of Colonel C. W. Pasley, C.B., in the third volume of the Transactions of the Institution of Civil Engineers is of permanent value, and coincides exactly with the view expressed above by Piazzi Smyth; and I am fortunate in having these views corroborated by so high an authority as Sir William Thomson.

With such facts before us we must certainly feel surprised at the suggestion of the Astronomer-Royal of a pressure of 10 lbs. to the square foot being sufficient for the stresses of the Forth Bridge to be calculated upon; indeed it is perfectly clear from the foregoing testimony that the pressures per square foot of the wind on the Forth and Tay must be so largely higher than this that it is not to be wondered at that the Board of Trade are still inquiring into the proper stresses for such a structure to be calculated upon. It has frequently been suggested that the action of wind blowing against a flat surface produces a partial vacuum on the lee side of that surface. I am not aware of any experimental demonstrations of this fact; but a few days since Mr J. T. Bottomley, F.R.S.E., was at my house when we discussed the subject, and he suggested the making of an experiment which would prove whether such a vacuum was produced or not. I will not take up your time by explaining the nature of the experiments made by Mr Bottomley, but he unmistakeably demonstrated that there was a partial vacuum so produced. Such being the case the amount of such vacuum, not yet determined per mile of wind-rate, falls as an element which must be taken into consideration in calculations of long span bridges, and until this is experimentally known it must be confessed that we are in ignorance of another important element essential to the proper calculation of the scantling of metal in a long span bridge.

After the freest possible discussion of this matter had been suggested by the President of the Court of Inquiry, it was thought by some of those most interested in this matter that it would be desirable for them, along with myself, to visit the wreck of the Tay Bridge in order to discuss the matter in a much more thorough manner, with actual observation of the facts before us, such actual personal observation of the facts being made by several persons instead of by only one. Accordingly, yesterday, several gentlemen, members of this Institution, and others not members, visited the wreck of the Tay Bridge, where we had the good fortune to meet with Mr Waddell, the well-known contractor, who is at present engaged in lifting the fallen girders; Provost Brownlee of Dundee; Bailie Thomson; and Mr Henderson, who kindly provided the steam-tug "Unity" for our use in making the necessary inspection.

We first examined the southernmost broken pier, namely, that one to which I drew special attention, and which is shown at Fig. 12 of the drawings accompanying my paper. The cross ties are $4\frac{3}{8}$ in. in width by $\frac{1}{2}$ in. bare in thickness. They are fixed at their upper end to the lugs of the columns, and attached at their bottom ends by two side plates, 13 in. long and $\frac{5}{16}$ in. thick, to the lugs at the bottom of the opposite column. The lugs, of which there are two, are from $\frac{7}{8}$ to $1\frac{1}{8}$ in. thick with a maximum depth of barely 6 in.

The side plates are attached to the diagonal stays by gibs and cotters, and the two side plates pass in between the two lugs with a hollow space between them. They do not fit well into the space between the lugs, and, indeed, a more defective arrangement for the fastenings of such a structure could not well be devised, for there is nothing to prevent the lugs being broken off or cracked by the strains produced in tightening the nuts on the bolts. We observed that the bolts joining the columns of this pier to the foundation pieces were broken through all round, and that the bolt holes were cored, with the exception of one, which, not being in the right place, rendered it necessary to bore another hole by its side.

With reference to the large piece cracked out of the eastern pillar of the southernmost pier, a careful examination of the fractured surface shows that, at the upper part the crack was old, the rust on it being of that deep brown which age alone produces. The lower part of the crack showed a bright yellowish red rust, the colour of a recent crack. Here, too, it was distinctly noticeable that the metal of which the castings had been made had been poured too cold, for "cold-shorts" were apparent. The bolts, of which there were several *in situ*, though broken, in no case filled the holes. The holes were fully three-sixteenths of an inch larger than the bolts. The eastern part of the flange of this column is cracked quite through. The bracing of these piers has been so frequently referred to that I need not here make further allusion to it, with the exception of stating that the diagonal portion is useless in compression, and that the horizontal cross-ties uniting the tops of the 10 feet sections consisted of 1½ inch round iron rods, which are attached to brackets of a peculiar construction, bolted to the channel irons forming the other part of the horizontal bracing. These brackets are held by bolts passing through holes in their corners, and the iron bracing rods are stretched by nuts on their screwed ends passing through other oval holes, whose minor diameter is very much larger than the diameter of the braces themselves. The centre of these holes is about 1⅛ inch below the centre of the lowest bolt at the ends, therefore giving a leverage of that length tending to break the bracket

These brackets in many cases are broken off—the sizes of the holes through which the 1½ inch round bracing bars passed being 2 inches by 2¼ inches, or, in other words, ½ and ¾ inch respectively in their minor and major diameters larger than the bracing itself. The sole plate on each column is about 4 feet square, and held down by four bolts, as stated in the body of my paper. The sole plate is united by gussets at the corners, and in the intermediate spaces by fillets with the base piece above, and to which the columns are bolted. The ashlar of this column is very much shaken, all the joints at the upper part thereof being loosened.

In No. 2 south pier, the thickness of metal in the north-west column was on one side about an inch, and on the other 1¼ inch. The south-west column of the same pier has its metal 1 inch by $1\frac{5}{16}$ inch. The outermost holding-down bolt of this column has no nut on its head. The head appears to have been broken off short when screwing the nut, and it has been left in that state, being painted over. One of the nuts of the holding-down bolts of this column is split right through at one side, and this split appears to have existed there since, and to have been produced in the act of screwing it up. The two top courses of masonry in this pier are shaken.

On No. 3 pier, the lower tier of cast-iron columns and bracing is standing, and the ashlar is slightly shaken on the western side.

In No. 4 pier, the masonry is very slighty shaken, the ashlar joints made with cement about 1½ inch thick. The bottom end of one of the columns suspended over the side of the pier by the bracing has not only very serious indications of "cold-shorts," and a number of blown holes, but what startled us more here than in any other case was to find these holes filled with lead, which it is evident was designedly put there. Clearly then throughout the whole life of the bridge some persons must have been cognisant of some sources of its frightful innate incapacity. With regard to the joints of the columns of this and the other piers, we observed that some were grooved, and some slightly spigot and faucit. Indeed, as to the joints generally there is no regularity.

With regard to No. 5 pier, the thickness of the metal in the south-west column is barely $\frac{7}{8}$ths of an inch, whilst the east column of this pier is on one side as much as $1\frac{5}{8}$ inch thick, and on the opposite side $\frac{7}{8}$ths of an inch thick only. You will see how great is the irregularity in the castings of which these piers are composed.

The next column flange joint of this pier showed that it never had been close, as for a length of 14 inches the concrete with which the columns were filled had run through an opening of that length and filled up the space between the two flanges.

These are but a few of the facts which I have thought proper to bring under notice in addition to those mentioned in the paper, but even though but few they speak but too terribly to an institution of engineers.

I have therefore now to leave the matter in your hands for discussion.

The PRESIDENT said he had no doubt that every one had thought that there was such a margin of strength in the Tay Bridge, that these matters of faulty workmanship pointed out by Mr Day would not have affected injuriously its stability; but it appeared that their collective effect had been very fatal, although previously no one had thought there was very much wrong.

Mr JAMES G. FAIRWEATHER said, while he deeply sympathised with Sir Thomas Bouch in his present position, he was, however, extremely desirous that the true cause of the disaster at Dundee should be satisfactorily brought to light. They would at once see that he believed thoroughly reliable and accurate information to be of the utmost consequence, and further, that they should be thoroughly consistent in their statements. He regretted to observe that Mr Day's paper was devoid of consistency in one or two particulars, and it would be extremely difficult for any one reading Mr Day's paper to find out really what his opinion was as to the cause of the disaster. Still a great many of Mr Day's statements were unfortunately too true. At page 134 Mr Day informs us that "those who have read the several theories which have been propounded as to the cause of the failure must, on careful consideration, have been surprised at the opinion most generally expressed," and so on. Now, he (Mr Fairweather) had shown elsewhere that the bridge would have fallen on the 28th December although the train had not crossed it that night, but at the same time he believed that the train assisted considerably the other forces then acting against it. He was sure that they must have felt surprised at the part played by the concrete in this bridge, according to Mr Day. He failed to see what possible advantage could be gained by getting certain facts from the Astronomer-Royal and others, more especially as we are told that the Astronomer-Royal recommends 10 lbs. per superficial foot as a proper allowance for wind pressure, as it is quite well known that 55 lbs. per square foot of wind pressure was what they might expect in a gale. Mr Day said that 10 lbs. was estimated as the greatest wind force, as given by the Astronomer-Royal. He would like to ask Mr Day where that statement was to be found. He imagined that a cipher had been omitted, and that it was 100 lbs. that was meant. So far as he saw, the three tiers of cross girders, 3 feet 6 inches deep, were simply used in the manner of scaffolding. They had been used to raise the girders, but removed, like other scaffolding. It appeared to him that one of the principal defects of the bridge was the want of breadth of base. The piers were almost parallel, and he thought they should have been spread out, as indeed they had been in Sir Thomas Bouch's design for a bridge across the Beelah in Westmoreland. He believed that the bridge had been blown over just in consequence of the want of breadth at the base of the pier to resist overturning. Then the insufficiency in the length of the holding down bolts was but too plainly seen in the case of two or three of the piers which had been turned over. It certainly did seem absurd, to say the least of it, to have holding-down bolts capable of lifting, before breaking, say about 200 tons, and that they were, in some cases at least, only attached to two courses of ashlar, 15 inches thick, weighing say about 6 or 7 tons. Now, with regard to the concrete in the columns, Mr Day indicates it as a cause of failure due to contraction of the columns on the concrete, and in one part of his paper he says that concrete contracts but to an infinitesimal extent; and he gave a calculation to show that the columns would contract but the $\frac{1}{10}$th part of an inch to the diameter. The members could judge whether that could do much damage or not. Then Mr Day also explained that concrete had been known to contract. He would like to ask Mr Day to point out one single column of the bridge in which this bursting action had taken place. There were 58 piers made of cast-iron columns still standing. The piers of many modern bridges consisted of columns filled with concrete, and they did not find that injurious consequences followed from that, and they could not suppose that the concrete behaved differently in the case of the Tay Bridge. Mr Day had spoken about the rust, and its evil effects; but when they considered that the waves had been beating over them since the accident, they could not be astonished. That the columns should have been cast on their side seemed extraordinary.

Mr JOHN PAGE, in reply to the President, said he had visited the Tay Bridge, and Mr Day had given a most faithful description of the structure. He himself had never seen such bad work. The masonry and iron-work were very bad.

Mr JAMES E. WILSON said since this unfortunate accident had occurred, which they all mourned over, he found people were all wise after the event. The Tay Bridge was gone now, and there was no use in discussing that. Any one could go and find out the bad work which it displayed. The discussion, he should think, ought to have been about the Forth Bridge, and they ought to adhere to that. Mr Day had come forward and advocated a bridge designed by Mr Andrew Barclay of Kilmarnock, which certainly was right in theory, but which, he maintained, was not original. He talked about the balance of weight in building that bridge, but he would find that he had got a shearing strain to contend against in the practical working of traffic on the bridge, which would only take a few years to destroy it. He thought that they should take a broad view of the subject. He did not consider either the proposed design of Sir Thomas Bouch, or that of Mr Barclay, to be the right one for bridging the Forth.

Mr Charles C. Lindsay said he believed the bridge first gave way by the collapse of one or other of the central piers, and stated three reasons for supposing this to have been the case, viz.:—The transverse deflection due to the wind pressure along the thirteen spans was a maximum at the central portion—the centre of pressure of the wind was at its greatest height there—and the effect produced by the brakes of the unfortunate train was greatest there. As regards the transverse deflection, he explained, that in all text books on the stability of structures, the moment of stability was calculated merely for an unit of length, without reference to the total length. This might be sufficient for short structures, but in the case of long retaining walls or the fallen portion of the Tay Bridge, where the breadth was very small compared with the length, he considered it was necessary to take into account the bending moment. In applying the principle to the Tay Bridge, he stated that the feet of the twelve piers were rigidly fixed, whilst the superstructure was of a yielding nature. As in the case of a uniformly loaded beam the bending moment and consequently the transverse deflection produced by the wind would be greatest at the centre; this effect combined with the extreme height of the centre of pressure of the wind and the tangential force produced by the train would produce the maximum overturning moment in the adjacent pier. The action of the brakes, he thought, had not been noticed before. He stated that he crossed the bridge going north a few days previous to the accident, and was much impressed with the bad treatment the bridge received from passing trains, and had expressed himself very decidedly on the matter to an eminent engineer that same day. He observed that when the train reached a position near to where the ill-fated train went down the Westinghouse brakes were put on suddenly, the effect being to throw the momentum of the train, with a weight of about 130 tons and a speed of about 25 miles an hour upon the structure. Doubtless, on the night the bridge was destroyed, the brakes were used in the same way, and the longitudinal strain produced had its worst effect at the central span where the transverse deflection was greatest, and where he believed it became a tangential centrifugal force, giving the final blow to the structure. The hexagonal form of the piers with the load projecting over the rectangular part seemed to him to be the principal element of weakness in the whole structure. He knew of no bridge with hexagonal piers similarly loaded. Such piers ought, if it were possible, to be braced so that the moment of resistance could be taken round the base of the outer columns; but in this case he considered that all calculations of the moment of stability, in which the leverage of the pier had been taken as half the distance between the outer columns, were worthless; seeing that there was no rigid continuity to the outer columns either internally or externally where the bracing was in two planes angled to each other. He believed that the columns turned round on their bases individually, and that the main strength of the piers to resist overturning lay in the ties and lugs pointing upward to the east in the central portion of the piers. The ties crossing them would buckle, and the horizontal transverse channel irons would move outwards horizontally as if hinged, while the bracing to the outer piers would have but little effect, being out of the plane of resistance. An examination of the ruptured ironwork would, he considered, bear out what he said.

Mr JOHN THOMSON said that he thought there was much about the Tay Bridge and the circumstances of its fall which the Institution might well consider. One or two points had been brought out already. He was not disposed to go the whole length of condemning the bridge in a sweeping manner, because he had the greatest sympathy with the gentlemen who carried out the work and the great difficulties they had to contend with; but still he thought there was a great deal in this bridge well worthy their most serious consideration. On examining the first fallen pier on the south side they found that the whole strain had come upon the ties. He thought that the weakness of the structure lay in the ties of the piers. These ties had been aptly called mere ribands, and it was perfectly clear to him that the whole bridge had collapsed like a parallel ruler. The snugs were gone there and still more extraordinary, the flanges on the eastern side, and the bolts on the westmost side were every one broken, showing clearly that the bridge went in that way, and he had not the slightest doubt that the bursting of the column had been caused by compression. They saw evidence of an old crack; indeed he was of opinion that the bridge had the elements of destruction in itself and that it was merely a question of time how long it would have stood. Many of the bolts they saw had old cracks in them. In a foot-note Mr Day stated that he had been informed by Bailie Thomson of Dundee that that gentleman had in his possession one of the bolts nearly, if not quite half way converted into rust. This was a mistake, the crack extended half way into the bolt and showed rusting. There was a great deal had been said about the use of cast-iron and the castings. The castings undoubtedly were not what they should have been, but he did not think the destruction of the bridge was due to the castings. He thought the columns were too small; they ought to have been properly stayed with cast-iron or channel iron struts. In point of fact the pier ought to have been so stiff that it would have turned over in itself without collapsing in the manner it had done. Every one of these snugs are broken, showing that the strain was over them all and that the whole of the columns collapsed. In reference to the renewal of the bridge he was of opinion that the remaining portion of the bridge might be so stiffened with diagonal struts properly bolted into the uprights as would make it of sufficient rigidity to sustain the work it had to do without taking it down. As to the foundation, although there were two or three of the columns which had turned up the masonry, still it seemed they had been sufficient to bear the columns; and if in rebuilding the bridge they put a heavy bed of concrete at the bottom of the columns, it would be a far more efficient foundation than they had, and better than starting the columns from the piers. He did not know that the variation in the thickness of the columns was a very serious matter, as it was a downward pressure they had to withstand, and not like water-pipes, where the pressure was from the inside. He could bear out what Mr Lindsay had said about the formation of the bridge. He thought that there was a vital defect in the curve that was formed on the north end, and still more unfortunate that the gradient should be something like 1 in 70. He thought that a very heavy curve, with trains running over that part of it at a very high speed; and he had the authority of an eminent engineer in Dundee, who had often timed the trains, for saying that at the high girders the trains ran at the rate of from 40 to 43 miles an hour. The south end of the bridge was much stronger than the north, as the two branches there form a good abutment, and if the same had been on the north side, it would have greatly improved it in strength. It was very remarkable that the water-pipe leading to Newburgh on the bridge had a lengthening tendency, to the extent of 2 or 3 feet, showing that the bridge was drawing out; and therefore, in any future reconstruction of the bridge, that point should be kept in view.

Mr William Clapperton said that Mr Day, in assuming the wind pressure on the side of this railway bridge at so many pounds per square foot, and then, when the train came on to the bridge, added so much more, had certainly made an error; for, if the wind had impinged upon the train, it was taken away from the bridge, so that instead of adding to the wind pressure on the bridge, he ought to have deducted it.

Mr J. M. Gale said he was one of those who thought that, however strongly the piers had been braced together, the bridge would have been blown over on the night in question. It appeared to him that it might be proved very easily, and they had had in the scientific journals abundance of data, that a wind pressure of 35 lbs. on the square foot would have been sufficient, upon one of the long girders of the bridge, with a train on it, to have thrown it into the Tay, quite irrespective of the manner in which the pier was braced. If the piers had been more strongly braced, the result would simply have been that the girder would have been thrown a little further from the piers, instead of dropping right down as it did at the foot of the piers, just as a chimney stalk falls when blown over by the wind. The materials fall down at the base of the chimney because the moment the strain came on the outer edge the whole thing collapses. No bracing of the piers could have preserved the bridge from ultimate destruction during such a gale of wind as it had fallen in. The large girders were joined so as to form three continuous girders of four and five spans each, and the wind pressure upon a train passing from south to north would be partly borne by more than one pier. As it travelled the side pressure would be borne by the second and third, then the third and fourth piers. And now the train goes on to the fourth pier, and at that point the girder was not continuous, it was not rivetted to its neighbour. The whole strain came upon the fourth pier, and it was just at the fourth pier that the accident took place, part of the train falling on the one side of it, and part on the other. The girder was not continuous, and could not distribute the pressure on to the fifth pier. It can be shown that 35 lbs. pressure of wind was sufficient to turn over any one of those piers with a train on it, and therefore it cannot be wondered at that the bridge fell. With a maximum wind pressure of 10 lbs. on the square foot the Tay Bridge would have been perfectly safe.

Mr J. G. FAIRWEATHER said he quite agreed with what Mr Gale had said, that the bridge did not fall over like a tree, but like a chimney stalk. One point which he had not seen noticed he would like to direct attention to. If they looked at the photographs exhibited in the room, they would see that the sloping strut on the outside of the curve became vertical at a lower point. The tendency of the horizontal component of the force would be to act upon this point, and bend this small column over.

Mr T. A. ARROL asked whether there had been any subsiding of the stone-work of the piers that had cast-iron columns above them. If that were not the case, perhaps the piers might be carried up entirely of brick, if the area on which the cast-iron columns rested would be sufficient. He would infer, from all that he knew about the bridge, that if the original design had been adhered to, the structure would have been still standing. As to Mr Thomson's remarks in reference to the equal thickness of metal not being of importance, on the principle that there was wind from each side, he thought they were justified in taking the columns as a cantilever, and that if the thin side of the cantilever was on the wind side, the columns would therefore have a tendency to break more easily. He did not think there was much in the concrete part. Mr Day acknowledged that the joints in the columns were very poor indeed, and if the joints were poor at the top, the connections with the stone-work might be as bad and allow all water to escape. The main portion of the strain was continuous upon these pillars, not a shearing strain, and it was not of the same importance to have tight fitting in the joints of the columns as the bracings. So far as they had got data, there seemed to be about the bracing far too many small pieces. He thought that was a common failing appertaining to all bridges. There ought to be as few bolts put in as possible, as they had seen in this case that corrosion in them had been very great. Mr Day referred to Mr Bottomley's experiments in wind pressure. He was satisfied, from present information, that no conclusion could be come to upon it.

Mr A. A. HADDIN thought they might consider this bridge without reference to its supports; for, although the supports had been solid, if they considered that the storm put a weight of 40 lbs. on the square foot upon the side of it, it would not have stood. He thought so, looking upon the connected girders as one continuous beam fixed at one end, and, except for the friction on the rollers, free to move along its whole length in the direction of the force applied. The bending moment of a length of four spans at 40 lbs. per square foot of exposed surface would be about 318,000,000 ft. lbs. In five spans it would be about 498,000,000 ft. lbs. The deflection due to this would in all probability be sufficient to carry the girder off its support.

Mr ALEXANDER SIMPSON quite agreed with Mr Gale that no matter how rigidly the piers of this bridge might have been bound together, the wind would have proved too much for it. He also agreed that if the piers had been solid, the bridge would have been standing yet.

Mr J. G. FAIRWEATHER said some of the joints of the girders were not immediately over the centre of the piers, but were a considerable distance from it. Supposing we take one of the girders on the curve at the north end as an example, where some of the piers consist of four columns, he naturally expected that the joints of this girder would have been upon the centre of the piers. Now, whether the bridge had moved to that extent or not he could not say; it might have done so.

Mr JOHN THOMSON said that the reason why the piers were not carried out in brick was because the foundations were found insufficient to carry this enormous brick structure, which explained the adoption of the cast-iron piers. He agreed with Mr Gale that the force of the wind would have brought down the bridge, however strongly the piers had been braced together. But he was very much of opinion that the cast-iron columns gave way first; but whether they yielded at the point that Mr Gale explained was another question. It is supposed that the bridge gave way at the north side first. Now, people who had been on the bridge when trains were passing said that it had a feeling of moving forward at such times. If that motion was anything strong, the action of such a strain would affect the high girders, and people said that they saw the north end of the bridge go first. Further, he thought that it was only the high girders that gave way, the continuity of the bridge being thus broken. In regard to Mr Arrol's remark as to the strength of the columns, he (Mr Thomson) said it was not of so much importance as in a cast-iron pipe used for conveyance of water. He would not say that it was equal to having equal metal all round, but had the whole of all these columns been rigidly steady, the lateral pressure would not have come on any one column, but on the whole pier.

Mr ALEXANDER SIMPSON thought Mr Thomson was wrong; for the pressure of the wind on the girders could not be brought equally on the whole of a pier of this construction. The wind acting on the girders with such a long leverage as 90 feet had a tendency to lift the columns of the pier on the windward side and throw the weight upon those on the leeward side

Mr T. A. ARROL said that Mr Thomson was mistaken as to his opinion. His remark was with reference to the cast-iron piers, he wished to know if Mr Day was aware why they substituted cast-iron for brick in the columns. He thought the difference in the relative strength of cast-iron and brick was great.

The discussion was then adjourned for a fortnight.

The discussion was resumed on 9th March, 1880, when

Mr ALEXANDER SIMPSON said that practical members would pardon remarks from inexperienced bridge-builders. It must not be forgotten where the great structure of the Tay Bridge lay. He thought that Mr Day had reason to consider himself justified in the details he had given of its condition by the amount of time that the Commission of Inquiry had already spent over these details. But he thought the whole of the members would agree that while it was the duty of every one to expose dishonest work, if such there be in any undertaking, yet at the same time it would be a great pity for them to be too ready to give undue credit to the reports as to blemishes that might have been found in the Tay Bridge. It would be a pity that the members of this Institution should attribute to these defects the results that had happened, and he was not sure but some of them had done so already. Notwithstanding all these details and the blemishes that had been pointed out, he was inclined to agree with Mr Gale that no matter how good the castings of the piers might have been, or how well they had been tied together, yet the storm that night would have thrown the bridge where it now lies. He would be very sorry indeed to have it supposed that he meant to cast any reproach on the designer or those who erected it. They all knew that hitherto bridges had been made very heavy, and that the wind pressure had been but a small factor in the erection of such structures; but with iron bridges and a proper disposal of the material, bridges are now very much lighter, and in exposed situations the wind has become a very important factor. These things must all be taken into account in this discussion. They knew that about the year 1873, it was thought that the foundations of the piers were not sufficient to carry solid brick work, and it was decided to make them of iron. He thought it would be found that about that time, the report referred to by Mr Day at last meeting of Messrs Barlow & Pole with regard to the Forth Bridge was issued. As Mr Day had said these gentlemen had made every inquiry as to the wind pressure and had consulted the highest authorities, who agreed that 10 lbs. per sq. ft. was ample allowance. Now, nobody in that meeting would believe that 10, or 20, or even 30 lbs. per sq. ft. blew down the bridge; therefore he hoped they would be careful as to who they blamed for this terrible event. The highest authorities in England said that 10 lbs. was enough to allow for wind pressure. This accident proves they were wrong; and therefore he thought their first duty was to seek to arrive at the true figure to be allowed. There was no difficulty in putting up a bridge sufficient to stand against whatever pressure could be brought against it, and however exposed its situation might be. He thought they ought to be careful how they in this matter went in for wholesale condemnation of this bridge. In his opinion it was quite easy to erect a structure on the piers that are still left standing in such a manner as it would be able to withstand all storms. They knew that the piers sustaining the larger spans were 31 feet in diameter at the base. That gave about 750 sq. ft., and if he was right in his calculations the structure as it was erected had a pressure of 1½ tons on the square foot at the base of each large cylinder. He was convinced that a good structure, stable, and sufficient in every respect, could be erected upon these cylinders with a pressure of 2 tons on every square foot, that would stand every pressure that could possibly come against it. No doubt the weakness of the bridge consisted in having the upper and iron portion of the piers too light—the lateral moment due to wind pressure was therefore greater than the vertical moment due to weight. Now, if they increased the weight of the pier, instead of having it 60 tons to make it say 300 tons, so that the vertical moment would be much greater, then he believed the structure would be quite safe.

Mr J. G. Fairweather wished to refer to what Mr Day said regarding the inspection of the bridge by the Board of Trade official, General Hutchinson. He thought that Mr Day had been rather hard upon that gentleman. They all knew very well that Government inspection rather inclined the other way. Now Mr Day asked "Did General Hutchinson really closely inspect the columns? Did he ascertain the depth and variations of the depth of the holding down bolts?" These were serious questions to put to General Hutchinson, but they would agree with him that it was almost impossible for any one in the course of a cursory examination to go into details, as Mr Day would seem to expect. It was quite impossible for any one even spending three days to do that. There was an Inspector who looked after details commissioned either by the Railway Company or the Engineer, and it was quite ridiculous to think that General Hutchinson could see inside of these piers to see how far down the holding down bolts went. It was only when they saw the piers overturned that they could quite clearly see that the bolts did not go sufficiently far down into the masonry to be of any use. It appeared that these bolts were put in more for ornament than for use. It had been supposed that the superstructure was quite sufficient to give it the required stability and very little was depending upon the bolts; but it was seen that it was far from being stable. Mr Alexander Simpson thought they could easily make the bridge stable yet, although it had been overturned. Now, unless they introduced a factor of safety of four for lateral stresses, he would have no confidence in its safety. He regretted to say that it was his opinion that the bridge must be taken down to the very foundation; and, besides, it should not and could not be safely constructed as a single line bridge, on the existing foundations.

Mr J. M. Gale rose to make an explanation of what he had said at a previous meeting, as two gentlemen who had spoken to him about it had misunderstood him. They seemed to imagine that his opinion was that the girders themselves, by the force of the wind upon that occasion, would have been overturned however well the the piers had been braced. Now that was not his opinion. What he meant to say was that that pier was so essentially weak that they might put any construction upon it as they pleased, brace it as securely as they could, and put as perfect castings in it as ever were made, yet a pier of that construction could not have stood the pressure upon it on that occasion.

Mr T. A. Arrol said with reference to the vacuum behind the bracing parts there was a simple experiment that shows that there was a vacuum. By cutting a piece of paper the size of a penny and placing it on the penny, then letting them drop, the paper would follow the penny immediately, which showed there was something drawing it down. He quite agreed with Mr Gale as to the piers, that they could never have stood out the storm of that night. He thought, notwithstanding the lengthened inquiry that was taking place, that they would not get much light on the subject out of the examination of the witnesses. If the Board of Trade could get off responsibility by blaming the bad workmanship that might be considered something; but with all due deference to the workmen he thought they had not the best opportunity for noticing the nature of the work that was put into the bridge, and in his opinion the evidence of the foremen which went to show that all bad bits of workmanship noticed were discarded, was more to be depended upon. The whole thing seemed to lie in this that a pressure of not more than 40 lbs. to the square foot had been brought upon the bridge that night, and it was incapable of standing it; but if a factor of safety of even 4 had been provided for, the bridge would have been standing yet, notwithstanding bad workmanship.

Mr Day, in replying, said—With regard to your own remarks, Mr Chairman, I quite agree that on the night of the gale the Tay Bridge came to an end partly through the enormous number of small and large faults in the structure and partly through its defective design. With regard to what Mr Page said, I have only to express my thanks to him for his corroboration of what I stated. The remarks of Mr Thomson, I think, were the most important made at last meeting, and more especially when he pointed out what I should have done but that my communication last night was longer than is usual—namely, the fact of the bracing of the columns having been broken away in one direction showing the failure of the lugs. Mr Thomson also pointed out that the flanges on the eastern side in the direction of the fall were broken, the bolts remaining in the holes, whereas on the westmost side every one of the bolts was broken; and that in many of the bolts we looked at there were cracks, which I consider are important points. What Mr Thomson said about the action of the expansion joints of the pipe which conveyed water from the Dundee side I hope will be borne seriously in mind. There is nothing in the construction of the bridge which shows so clearly the action of the Westinghouse continuous brake tending to destroy the bridge in one direction as the action of these expansion joints in the water pipes. I fully endorse every word Mr Thomson said in regard to that. The remarks of Mr Clapperton about the effect of the wind on the bridge and the train struck me at the time as peculiar, and on fuller investigation, I think that his statement, to the effect that the force of the wind which impinged on the train should not be added to the pressure exerted on the bridge, but should be deducted, speaks for itself. Mr Gale in his remarks about the diagram which is before us almost took the words out of my mouth; but I think he was wrong in stating, as he did, that the girder and the piers fell down like a falling chimney stalk. I have seen fallen chimney stalks, and I never saw one which fell down in a heap at the foot; and as a matter of fact the piers of the Tay Bridge did not fall straight down, for the nearest portion of the wreck is about 30 feet from the eastern side of the pier. The case which Mr Gale put of a fallen chimney stalk is not at all analogous to these girders. With regard to Mr Gale's remarks as to the bagging effect of the wind acting upon the central piers, I concur so far as they went, but he did not explain what it was my intention to have explained—namely, that if it be the fact that we can regard the three actions of the four and five girders respectively as acting independently—although they may have acted all conjointly; we don't know enough about that yet—there is a possibility that that central pier of each set to which the girder was fixed was bent over and produced a curve having a versed sine sufficiently deep not only to have drawn the girders endwise over the piers themselves, but also to have drawn the piers together—that is in the north and south direction. Certainly in a bridge of this kind, having long spans, it is necessary to take into consideration the breadth of the base lengthwise of the bridge—which clearly has not been sufficiently provided for in the case of the Tay Bridge—quite as much as the breadth transversely of the length of the bridge. Mr Arrol asked me if I could inform him if the piers with cast iron columns had subsided at all. My observations have not gone sufficiently far to enable me to judge, and at present I should not like to hazard a conjecture; but it appears to me that they have in some way yielded, for some of them have been bound round with iron hoops. Whether the necessity for that has been caused by the expansion of the cement or by some other cause, I am not at present prepared to say; but it is the fact that some of the piers are bound round with iron hoops to keep them together. The bracing, I think, has been completely disposed of; it has undoubtedly proved insufficient: and in regard to the lugs you have doubtless read the evidence adduced at the recent examinations in Dundee by practical men from both sides. I think that evidence speaks too plainly to require any further discussion by an Institution such as ours. The cement joints of the ashlar caps were from ¾ to 1½ inch in thickness. At last meeting reference was made to wind stresses, and it was suggested by some one that probably there was an error of a cipher in the figures advised by the Astronomer-Royal for wind pressure for the Forth Bridge. I have been in correspondence with the Astronomer-Royal since last meeting, and I have a letter from him in which he says it is a matter of common sense that a bridge should be so constructed as to sustain the highest wind pressure in the locality. Now, I have it for a fact that at Granton, on the Firth of Forth, and other places near the Firth of Tay, there have been wind pressures experienced of from about 30 lbs. per square foot and upwards. It is therefore perfectly unintelligible to comprehend how the Astronomer-Royal ever could advise 10 lbs. per square foot as the pressure for that bridge, or that the reporters could have seconded such a proposal. With regard to what Mr Simpson said this evening, I agree with him that it would be a sad thing to exaggerate any blunder which has been made; we must all in this case have a deep feeling of sympathy with Sir Thomas Bouch, and the North British Railway Company (I cannot for the present include the contractors), upon whom the weight of this terrible catastrophe has fallen. But we must get at the truth. I have seen, and so have others, flange joints in the bridge where there was no meeting at all on one side, and wherein the so-called cement with which they were filled was nothing more than sand from the Tay mixed up with the rubbish of the contractors' yard and a very slight amount of lime wash or some slight cementing material, and where that had run through the joints at the time the piers were originally erected I think Mr Simpson's remarks in reference to wind pressure were also most opportune. We almost forget that in the past in the case of large span bridges, such as the Britannia and Saltash Bridges, that wind pressure has been a factor of greatly less importance than in such great spans as are necessary over the Firth and Tay Estuaries. Until the more recent experiments of Barlow and others we have been almost entirely dependent upon the classical experiments of Sir William Fairbairn at Millwall —I call them classical experiments, for in a sense they were so— which he made preparatory to the construction of the Conway and Britannia Bridges. We must ascribe all honour to Fairbairn; he did his best under the circumstances; but nevertheless he was largely in error owing to the general ignorance at that date of the proper distribution of material, yet even allowed for a wind-stress of 50 lbs. per square foot. Sir William Fairbairn pointed out that the proper direction in which to collect the metal was at the upper and lower member and to unite them by thin vertical ribs. Most of us know the magnificent experiments which led to the structure of the Conway and Britannia Bridges. With regard to the action of wind upon lattice girders our ignorance is extreme. Mr Arrol referred to-night to a simple experiment which shows that there is a considerable vacuum formed behind an object against which there is a strong wind blowing. I mentioned something of the kind last night; and until we really do know the amount of vacuum which is so produced we cannot know thoroughly the stress with which the wind comes upon a lattice girder. The wind-stress is not so important in comparatively small spans; but when we come to great span bridges, such as the Forth Bridge, of over a third of a mile per span, there the wind-stress is the principal stress of all—it is the largest stress of all the structure has to bear. The stress of the dead load and live load combined is not so much as the stress of the wind, acting with the pressure with which we now know that it does act, over so large a length of girder; and for that reason, to take the wind-stress allowed for moderate span bridges in the past is not enough. It is distinctly stated in General Hutchinson's report that he had examined the iron-work, and found it to be "well put together in the columns and girders." I ask any gentleman who was present with me when we examined the bridge a fortnight ago, if, as an engineer, he would put his name to a statement that the iron-work had been well put together. I think I may surmise, with a fair amount of safety, that the eyes of those now inquiring into the structure of bridges are pretty well opened to the character of official inspections. Although I am perfectly convinced that it might be inconvenient to have a constantly resident official inspector on the part of the Board of Trade, I am also convinced that when we find contractors are capable of putting into a contract such work as we know, and which so many members of this Institution saw for themselves, was put into the Tay Bridge, it is high time some strong measures were adopted to put a stop to such reprehensible practices We must also remember, and it is significant, I think, this point that Mr Arrol alluded to—namely, the wind stress that would have overturned the girders quite independently of the columns. I think there is no doubt that 25 to 35 lbs. would have blown them over, and that irrespective of the structure of the columns, they were utterly unable to resist the stress they had to bear. A great deal was said about this bridge throughout the country before it was opened and after it was opened, and I suppose a great deal more has been said since it has fallen. But Mr Gilkes, one of the contractors, read a paper to the Cleveland Institute of Mechanical Engineers, in which he stated that it would take 96 lbs. of pressure to overturn the bridge. The following are his memorable words:—"A consideration of the action of the wind on this bridge will dissipate the often advanced theory that at some period it will be blown over. The exposed surface of one large pier is about 800 square feet, and of the superstructure which depends upon it about 800 more; and so, giving 800 feet for a train above, we have 2400 feet. 21 lbs. per square foot is the force of a very strong gale, but it would take no less than 96 lbs. per square foot on the surface given to overturn the pier. Even the most severe hurricane on record would equal only one half of this resistant power."

Mr Barclay wished to explain that he had observed vacuums existing in passing behind another object, such as the injector and annular orifice around a central one. He had, with a 30 lbs. pressure, lifted water 20 feet. That was a vacuum equal to 10 lbs. of a pressure of 30 to 35 feet, which showed there was a vacuum behind any object when a current of air was passing behind it.

The latter part of the discussion was then confined to the Forth Bridge, and Mr Barclay's proposed mode of bridging similar spans.

Mr Charles C. Lindsay said that at this stage of the discussion he must take exception to the coupling of the unfortunate Tay Bridge with the proposed Forth Bridges. Mr Day stated that his reason for doing so was the failure of a typical example of a long-span bridge. Now, the spans of the Tay Bridge come under the category of short spans; therefore his reasons for coupling the two bridges does not hold good. Although he (Mr L) did not look upon Sir Thomas Bouch's design as a good solution of the question of bridging the Forth, there are many ingenious points about it which Mr Day has condemned and proposes to alter, insomuch that the safety of the structure would certainly be endangered if his proposals were adopted. Referring to the large girders, it can be proved that the limiting span of a steel lattice girder is about half that of the Forth Bridge, but in that bridge the girders have been designed, supported, and stayed so that the dead load on the chains due to them is very much less than what Mr Day has stated—viz., two-thirds of their weight—their carrying power is very great, whilst the stays are designed to distribute passing loads as well as retain the chains in the catenary form.

In order to retain the chains in the catenary form under all conditions of load, expansion, and wind pressure, Mr Day proposes to fix the radiating stays rigidly to the piers. This in his (Mr Lindsay's) opinion, would ensure the failure of the structure; and the compensation which the method of attaching them to the ends of the girders of varying depth—as designed—will give, would be lost in his method, and buckling or rupture would ensue.

The Forth Bridge is still being investigated by a commission, and it is to be hoped that due consideration will be given to the effect of wind pressure, load, and expansion; and also to the tendency to produce change of texture in the metal which may be caused by vibration and extreme cold, especially in the piers and back stays.

As regards Mr Barclay's proposal for bridging the Forth, priority of invention or design may be claimed for a Frenchman of the name of Poyet, who proposed the same form of bridge eighty years ago; and Captain Brown, who was consulted by Telford in connection with the proposed Runcorn Suspension Bridge, and the Menai Bridge, erected a suspension pier at Leith sixty years ago, in which the same principle—that of the braced triangle—was involved. He used an auxiliary catenary to carry the central portion of the bridge, a system which has been perfected by Mr Ordish, who also utilises the catenary in supporting and stiffening the oblique tie rods. Motley, Curtis, and Sedley have also proposed suspension bridges formed of braced triangular systems, and the latter patented the form of bracing—by struts and ties—which Mr Barclay has introduced.

In designing bridges of this description, the strains produced in the main girders by the oblique ties may be tensional or compressional as may be desired. In the first method the tension would be a maximum at the centre, and the girders must be left free to move horizontally at their ends. In the second method, adopted by Mr Barclay, the compressive strains increase to, and become a maximum at, the piers, whilst the expansion has to be provided for at the centre.

Beginning at the centre of his diagram, we find a girder of 100 feet span, and say 15 to 20 feet in depth, put down at the weight of 7·88 tons. Now, it would be impossible to design a girder of that span for the lightest work at less than 19 to 20 tons. By extending Mr Barclay's figures, it will be seen that 7·88 tons is due to the flange section of 51·1 square inches, and there is nothing allowed for latticing. This error seems to have been made in the weight of all the girders, consequently the compression due to the increased weight must be added in all the sections to the piers, where the girder is stated to be compressed to the extent of 6827·8 tons. The weight of this girder is given as 251·49 tons, and the area of the flanges 1624·2 square inches. If rectangular and solid, this would represent a mass of steel 48 inches by 33·8 inches in section.

Mr Barclay seems to have sacrificed everything to his idea of facility of erection, and the lowering of the centre of gravity. In supporting his girders by oblique tie rods fixed at different heights (he believed this was original on Mr Barclay's part), Mr Barclay has adopted the very best method for increasing the compressive strains in the girders, and the tensional strains in the oblique supporting ties, to an inordinate degree. If he had fixed his ties to the top of the piers, thereby obtaining increased leverage with little or no additional material in the piers, he would have reduced the tension due to the load in the lowest tie near the piers in the proportion of the cosec 23° to cosec 74°, or 2·55 : 1·04; and also have reduced the compression due to the load in the heaviest girder in the proportion of cotan 23° to cotan 74°, or as 2·35 to ·28. This proportion would decrease as the ties near the centre of the bridge, but taken as a whole the decrease in material would be about half, if the ties had been fixed to the top of the piers.

Any loss of stiffness or rigidity which would ensue by attaching the oblique ties to the top of the piers could be made good by bracing.

The material for this bracing is to be found in Mr Barclay's superfluous bracing ties, for some of them are of no use. He referred to the ties pointing upwards and attached to the oblique ties between the vertical bracing struts.

Mr Barclay had given no details, but it would be interesting to know what section he would introduce, so as to take up and distribute these excessive strains; and it would be desirable to have some information as to his provision for expansion.

In his (Mr Lindsay's) opinion, Mr Barclay has designed a bridge which no engineer would think seriously of erecting.

Mr J. G. LAWRIE said—In considering the construction of the Forth Bridge, either in conformity with the design of Sir Thomas Bouch, or with the modification proposed by Mr Barclay, the question naturally arises whether, in stretching across wide spans, or across any spans, the girders should be placed as in Fig. 1 or as in Fig. 2. See diagram, Plate XV.

In Fig. 1 the girders are shown detached and separate. At AB a train is shown, 250 feet in length, and 150 tons in weight. One half of the weight of the train in this position acts upon each of the girders. At CD a train is shown resting wholly upon the girder GH. If this girder is divided at GH—if the two halves are hinged at H, and pulled together at G—the action of the train CD is with its *whole* weight to separate at G the two halves of the girder, while the action of the train AB is to separate the two halves at G, with *one-half* of its weight. In Fig. 2 the weight of the train EF is always divided betwixt the two piers. If, as before, the girder be divided into two halves and hinged at H, the pull asunder at G never exceeds that due to one-half of the weight of the train.

If in Fig. 1 the girders be joined together instead of being kept separate, the action of the train upon the one girder or upon the other is modified by the strength of the joining and by the quantity of material the joining contains. But the strength of the joining and the quantity of material it contains is, by construction, to a large extent less than the section at GH in Fig. 2. While this is the action due to the weight of the train in the different constructions, and it is of great importance, the vibratory effect upon the bridge of the train in rapid motion is of still greater importance; and if the effect of a gale of wind on the side of the bridge be added, the superiority of the one construction shown in Fig. 2, over the other shown in Fig. 1, is beyond question.

In the girder constructed as in Fig. 2, the material is applied directly to perform the work to be done; and, with equal strength, the construction in Fig. 2 requires less material than the construction in Fig. 1.

The experience derived from the bridge that has fallen proves that a satisfactory bridge of the same height is attainable without difficulty. The Forth Bridge, as designed by Sir Thomas Bouch, is in reality a bridge built with girders of the common construction, as shown in Fig. 2, though admittedly of a strength insufficient for the width of span, and depending for support on the suspension chains. No doubt, if these chains are made of scantlings that are heavy enough, the bridge will stand, but the application of the material is injudicious and wasteful. The material used for the chains, with the connections that are necessary to support the girders, which are of themselves insufficient, would, if added to the girders, produce greater strength with greater economy.

The construction of this bridge is in a sense public property, and if the scantlings which are to be used were made known, such a comparison could be made of the two constructions—one being common girders *per se*, and the other being the girders strengthened with suspension chains—as would elicit conclusively the superiority of the one over the other. It does not appear that in a work so important nationally, a publication of the scantlings should now be withheld.

With respect to the Tay Bridge, there can be no doubt, in the mind of a practical man, that pillars of iron are much superior for the piers to brick and cement; but the iron should be malleable iron, and not cast iron. It can scarcely be necessary to mention to practical men of experience that the bolts used in the structure should fill the holes—that the holes should in fact be rimmelled and the bolts turned. To have the holes a quarter of an inch larger than the bolts is as improper as it would be to have the rivets a quarter of an inch smaller than the holes. The arrangement of the pillars in the hexagon form, which was adopted in the bridge, seems to be quite satisfactory. It is now obvious that the defect of the bridge to a large extent consisted in the narrowness of the base, and that again partly arose from the narrowness of the top. With a double line of rails, and a corresponding base, the bridge would have been very much better adapted for its purpose.

The theory of Sir Thomas Bouch—that the train left the rails, and by collision with the side of the bridge occasioned the wreck—is untenable. The engine and tender would weigh 65 to 70 tons, and I do not believe that a gale ever blew which would remove that engine and tender from the rails. If the engine and tender struck the side of the bridge, the accident must have occurred, and the gap in the bridge must have existed, before the train crossed the bridge.

To make definite calculations of the strength necessary for the scantlings, or to check the sufficiency of the scantlings used in the bridge, is not attended with intricacy, but requires more information respecting details than the Institution possesses.

Mr Barclay said that Mr Lindsay in his remarks referred to such an array of figures that to go into them there was not possible; but perhaps he might have an opportunity of going into them afterwards, and seeing whether they were correct or incorrect. With regard to the drawing of Mr Sedley's bridge, which Mr Wilson had handed to the Chairman last evening as being the same as his design, he had made an enlarged diagram of it, which he now exhibited, with the view of showing that the design was not the same at all. If Mr Wilson would just look at the drawing again, and compare it with his, he (Mr Wilson) would see that what he was stating was true. The design which he had left with the Chairman was that of a perfect lattice girder tapered down to the centre: it might be parallel, but for lightness it was tapered down; it had a top and an under boom, the top boom being in tension, and the lower boom in compression, and there were the usual struts and ties of a lattice girder. He then exhibited and explained an enlarged diagram which he had made of a section of the bridge proposed by himself, laying especial stress on the fact that all the inclined bars were in tension, and the one horizontal member in compression. He also pointed out that he had introduced rods for the purpose of stiffening the ties against their sagging; but these could be theoretically kept out, and if they were kept out it would lighten the bridge, and do away with any objection on the ground of weight due to them. The reason why the lower and shorter ties were of greater transverse section than the upper and longer ties, was because, in addition to carrying the rolling load, they had also to carry the load above them, the shorter tie bar at the bottom had to carry the weight of all the metal in the section above it, and it was on that account the tie of greatest section. The next tie bar above it was of a less section, because the amount of superincumbent metal it had to carry was not so great; and so on with each successive tie bar to the highest. With regard to whether the design was new or not, he did not pretend to say whether his plan was new or not; but it was not the suspension bridge of Sir Thomas Bouch, and neither was the suspension bridge of Sir Thomas Bouch new. The question, however, was, whether was Sir Thomas Bouch's design or his the best for crossing the Forth at Queensferry? If the calculations were made by competent persons, and if the matter came before a competent committee in London, it would then be seen whether his design was right or not.

Mr JAMES E. WILSON asserted that the drawing that Mr Barclay exhibited was an exaggerated form of Sedley's Bridge, the design of which he handed in at last meeting. It was after Sedley's plan. Any one looking at it and Mr Barclay's would say that they were the same. It was merely a bridge made up of two cantilevers connected by girders. Now if they turned to page 158 of Mr Day's paper they would find that he preferred to call them triangular beams. He did not care what they were called. Mr Day said at page 158—"These beams are braced by back ties to a vertical tower at the centre of each of the two end beams. Each half projecting out over the piers constitutes half of the 1600 feet spans, the other half of those spans being made up of similar projecting triangular beams, from the great vertical rectangle standing on the Inch Garvie piers. Each half, then, of each span is an independent structure, and in no way depends upon the other half for its support. The two parts are, however, connected together by a low truss, and have expansion joints at their point of meeting to allow of alterations of length by the variations of temperature." Mr Barclay might call his bridge "triangular beams" if he chose; but it was just the same as Sedley's—a plan that had been worked out by men like Mr Baker, the late Mr J. P. Smith, and Professor Rankine, and as Mr Baker said, they might make many modifications of the two cantilevers and connecting girder.

Mr BARCLAY said that any one could see that his bridge was practically different altogether. Certainly the one looked a triangular structure like the other, but it was entirely different. There was not a compression strut in the structure, except the under boom which was common to them both. The strut in Sedley's design would have to sustain a pressure of 1200 tons, on a length of 325 feet, and he calculated the pressure upon 200 feet strut to be 1300 or 1400 tons if the girders were reduced to that height.

The PRESIDENT said there was some similarity in the designs, but the principle was decidedly different.

Mr FAIRWEATHER said so far as he could see from the information given in the paper that Mr Day had brought forward regarding Sir Thomas Bouch's design, that they could not very well discuss Sir Thomas Bouch's bridge. He thought that they would require a great deal more information about the Forth Bridge than Mr Day had brought forward. Perhaps Mr Day had brought forward as much information as it was possible for him to gather, seeing he could not get access to the working drawings, although he himself had had access to them. It was, therefore, difficult for them to decide what was the best form for crossing the Forth, and the best method for the North British Railway to get to the North. They had had any amount of designs brought forward for this purpose; but the great difficulty was, they must restrict the bridge to two 1600 feet spans. Now, he thought it was a great mistake that they should resort to such an extreme span as that. He thought a much better bridge could be designed than had yet been seen, by reducing the spans. There was no difficulty in it, so far as he could see; and he was working on a design of this sort just now, as an exercise. There was one thing he wished to ask Mr Barclay. They had in his design very long ties and very short ones. He would like to know what would be the effect of the unequal stretching with a rise or fall of temperature, or while under a stress? The difference in the length of rods seemed to him to be a radical defect. He thought that there was a difference between Mr Barclay's bridge and Sedley's. What he thought the North British Railway ought to do was not to attempt to cross the Forth at Queensferry. His idea was that they ought to cross at Alloa. He did not consider the shortest route was always and necessarily the best one. If the North British Railway Company put on a fast steamer, and accelerated their trains between Burntisland and Tayport, they would then have the best and shortest route from Edinburgh to Dundee. Then the next thing that Company had to consider was the conveyance of minerals, for which they considered the bridge was really wanted. He pointed out a suitable route on a map from Edinburgh to the North, and said that if they must have a bridge across the Forth, it should be carried over at Alloa, the cost of a bridge at which point would not be more than £50,000 or £60,000. Then he would much prefer that the Tay Bridge be entirely taken down, and another bridge built across at Newburgh, where there was an island, so that a very small span would suffice. Of course they must keep up the height, so as not to interfere with the navigation to Perth.

Mr Ralph Moore said that it would be very easy to make a tunnel under the Forth, either at Alloa, above or below Queensferry, at Bo'ness, or Dalmeny, or at St. Davids. At Bo'ness and Alloa the substratum was in the coal measures, and at St. Davids the calciferous sandstone; so that it would be quite practicable. The difficulty would be to get up to the level again. At Bo'ness they were working minerals at a depth of 150 feet below the sea. It would be easy to make the tunnel quite dry.

Mr T. A. ARROL said there were a great number of errors in Mr Day's paper, even in the data given, so that it would have been better if he had not condemned Sir Thomas Bouch's design in the wholesale manner in which he had done. He stated that there were 4 ft. diameter columns to be used in the structure, while they were only 3 ft. 6 in. There was a point worthy of consideration in connection with the columns, which had not been noticed, which was, whether mild steel which will stand 27 to 30 tons per square inch tension, will stand as much as common iron in compression. Then Mr Day also stated that of high-class steel chains there were to be 10,000 tons used, whereas it is only stated to be 8000. He had also stated regarding the main girders, that each girder will be from 1600 to 1900 tons in dead weight at least—that is, that one of those girders will have a dead weight of 1600 tons. Now, the whole span weighs, with the two girders and half of the diagonal bracing, only about 1550 tons; it is hardly fair that weights should be brought forward in this way without being correct. Then Mr Day remarks, "It may perhaps be thought that the proposed structure of the 1603 ft. 6 in. girders is essential to produce stiffness from swinging by the action of a storm of wind; this, however, cannot be so, for these girders being of less section to resist transverse bending than bending downwards, are especially ill calculated to stiffen the bridge against wind stresses." Now, these girders are 100 feet deep by 41 feet broad at the centre, and 19 feet at the ends; he did not think there could be a better principle brought forward. The diagonals are box diagonals, and braced the full depth of the girders, 41 feet deep at the centre, and 19 feet deep at the ends, the whole forming a warren girder. There was another point to which Mr Day drew attention. Mr Day was not aware, apparently, that the diagonals were carried; he said they would sag. The verticals carried rollers on which the diagonals rested, and they therefore had only to bear the strain due to keeping the main chain out of the catenary curve. Then Mr Day stated in his intermediate paper, that there are only five $\frac{7}{8}$ inch rivets put in to keep the main chains from resuming the catenary curve, whereas there are at least 130 $\frac{7}{8}$ inch rivets at each end of all the girders tending to keep the chain out of the catenary. (See Plate X.) The links are on each side of each girder. There was only one point for which Mr Day gave Sir Thomas Bouch any credit, namely, in his having formed the main girders so as to be able to resist compression brought on by the diagonal ties. He thought, instead of the wholesale way in which he condemned Sir Thomas Bouch's design, that Mr Day should have given them data by which they could have gone into the matter for themselves. He agreed with Mr Lindsay in many of his remarks on Mr Day's proposed design. The main girders were to be 6 feet deep, and the diagonals taken back on to the columns. If it was intended to run the train between the girders, then 30 feet of their depth to resist wind pressure must be lost, as they could not be braced on the top; but if it was intended to run the train on the top of the girders, it would be a girder 100 feet deep and 6 feet broad, and would form one of the best designs to dance the train into the river. In reference to Mr Barclay's design, there were several points he would like to refer to. The end piers were carried up 15 ft. higher than they necessarily should be, as the train could with perfect safety be run on the top of the girders. He could not see why he had put these three pillars under the cantilever on the shore side. Then there was the bracing of the main span; if he made it of lattice work, it must be 15 feet deep, and 77 feet between each girder, it would be very expensive work. The bracing of the columns, from the size and weights given, appear to be of flat bars, and they would be of as little use as the Tay Bridge bracing, as there must be at some time compression brought upon them. Then it was brought forward as a great point in Mr Barclay's design—easy construction. He must say that those massive stone piers for supporting the columns would take a very long time to build. There was, as nearly as he could calculate, between

80,000 and 90,000 cubic yards of material in each of these piers. That would take a considerable time to build, taking into account that the workmen must wait on the weather. He was sure that these piers would hinder the speed, and affect the simplicity of the erection, not to speak of the extra cost of the material. Then with regard to the point of weight of the bridges; Mr Barclay's was to weigh 41,000 tons, while Sir Thomas Bouch's would be 35,000, inclusive of the whole piers. The first 150 feet of Sir Thomas Bouch's design of piers will only weigh about 3700 tons, whereas Mr Barclay will require to build at least 400,000 cubic yards of, say, brick work. In reference to Mr Fairweather's remarks in favour of crossing the Forth at Alloa, he ought to remember that extra mileage run is extra cost, and that the North British Railway would lose a great part of their passenger traffic if they acted upon his suggestion of putting on a steamer, and thereby causing people going to Dundee to spend half-an-hour at sea.

Mr Barclay asked Mr Arrol to state the strain per square inch. He might state, for Mr Arrol's information, that his calculations were for 6½ tons to the square inch; and he knew, from good authority, that Sir Thomas Bouch had based his upon 8 tons per square inch. Now, if he had calculated upon 8 tons, it would reduce his design to less than 34,000 tons. Then with regard to the piers, they were not quite decided upon yet. He did not know the number of cubic yards in the piers. He had shown the design of this bridge to Sir Thomas Bouch, and he proposed these three piers to be taken out. He did not think it would detract much from his design although it should take a few hundred yards more masonry, seeing it was a structure intended to stand securely.

Mr Arrol said, with regard to the strain on Sir Thomas Bouch's bridge, he thought it was Mr Day's province to bring forward that information when he brought the design before them. He could not see that Mr Barclay's bridge would be self-supporting if he required the piers on the shore side of the cantilever. If it were self-supporting on the river side, it should be on the other side, after it was up.

Mr BARCLAY said if he took away three of the piers at the outer end, he would require to put something in the inner, and so it was perhaps just as well to put them there where it required to be stiffened.

Mr J. M. GALE did not wish to say anything about the designs of the bridges under notice, but it occurred to him, that looking to the enormous size of these structures, it would require a much greater amount of traffic than existed between Edinburgh and Dundee to induce people to give their money to construct them. It appeared to him absurd to spend so much money on such a work.

Mr BARCLAY said there was one remark made by Mr Arrol which he had forgotten. He stated that ties in the centre of the triangles would act similarly to those in the Tay Bridge. He could assure him it was quite different. These were never slack like the Tay Bridge. Had there been a strut out in the two ends of that bridge, those columns would never have gone as that had done.

Mr CLAPPERTON exhibited a design of a bridge which had been sent from a gentleman in Fifeshire for crossing the Forth, and said that he thought they had rather wandered from their subject during a part of that evening. He supposed they had met to discuss the merits of the different kinds of bridges, not of different routes of railways—whether they should approve of Mr Barclay's design, or that of Sir Thomas Bouch. In his own opinion, the style of bridge he now introduced to them for crossing large spans was superior to that of Sir Thomas Bouch; but it was not new. In fact the best illustration of it was shown in the Exhibition of 1862, when Sir Charles Vignoles showed his beautiful design of a bridge for a span of 800 feet, crossing a ravine 1000 feet deep, by taking two of these and putting them together. He built them on shore, upon rollers, and then brought the two together until they joined, when one or two men got on to the centre, and fixed the ends without any scaffolding whatever. As to the stability of a structure like the Tay Bridge, we were not here to discuss that; it is settled for us already. The weight of material, he believed, was in favour of the design brought forward by Mr Barclay. His plan required least material, and could be erected without much scaffolding; so that if they were called upon that night to say which was the best, he would vote for Mr Barclay's.

Mr Barclay said, as he had stated before, he did not mean to say that his was an entirely new design. At the same time he felt that it was different from all the works he had looked at. They were all based on the lattice-girder principle, but there was not a lattice-strut in his at all; all was in tension but the under boom. All those angular tie-parts formed the top strut of a lattice-girder, and they were all placed in the most economical manner, so that the weight was on the bottom of the column, and not on the top, as in Sir Thomas Bouch's. Then the back part, which some one ridiculed, was so close to the main pillar, and so straight, that it could be expected to stand.

Mr Alex. Smith said that in entering upon the consideration of Mr Barclay's design, he thought it would be well for any one who had serious objections to his design, to have taken the particulars as given by Mr Barclay along with him. Had that been done, he was satisfied they would have been saved many remarks that night. He did not see with Mr Fairweather that it was the business of this Association to suggest new routes to Railway Companies, and he did not think the Railway Company would construct lines at their suggestion. He could assure Mr Fairweather that all classes in Dundee would tell him that they must have a bridge across the Tay, near where the fallen bridge stood, whoever pays for it. He intended to have made some remarks on the construction of the Tay Bridge girders and their bracings, also in regard to the mode of fixing them on the piers, but he could not get a sight of the plans, and he did not think it proper to make his remarks without them, although there were many points in them objectionable as well as the columns: the whole structure seemed to him of the same character. They had only half discussed it, from want of the plans, and he could not understand why so many difficulties seemed to be in the way of their being seen. He had been erecting bridges for 25 years, and the plans of these bridges had always been open during their construction, as well as after they were finished; and therefore he could not see why the Tay Bridge plans could not be got. Something had been said about inspection of work, as if the manner in which the Tay Bridge had been inspected was the customary one; he just wished that the same degree of inspection had been given to that structure that was bestowed on work of a similar kind erected by the Glasgow engineers. He thought that the examination made by the Board of Trade justified all that had been said by members of the Institution regarding the character and construction of the work.

Mr FAIRWEATHER said all he meant to convey to the Institution was that he had an opportunity of inspecting the Forth Bridge plans any day, but of course could not bring them to any meeting. He thought it was Mr Day's duty to get the plans.

Mr GEORGE RUSSELL said that nearly every point that he had taken a note of had been alluded to by some of the speakers. One drawback with regard to Mr Barclay's design he would notice. The main part of his bridge was in compression, owing to the construction of the tie-rods. That must add to the weight. He thought a pure suspension bridge well stayed was the best design for such a span. Mr Barclay could dispense with the middle pier or column in the set of three, and also with those bars radiating in an upward direction, which did not seem to be required.

Mr DAY then said—With regard to the amount of information as to Sir Thomas Bouch's design, he had told them that it was by pure accident that the Tay Bridge had to be referred to at all, as it fell right in the middle of the time when he was writing his paper on Mr Barclay's bridge for crossing the Forth. He made every effort to obtain the fullest information possible with regard to Sir Thomas Bouch's design for the Forth Bridge. He communicated with Sir Thomas Bouch himself, who replied that he was not prepared to give any information whatever about his bridge, because he had promised a paper upon it to the Institution of Civil Engineers, London, so soon as the bridge was built or its construction well advanced, and that it would not do for him to give any information about it until then. He again wrote to Sir Thomas Bouch for one or two precise points of information. To this second application he had not been favoured with a reply. Having had to hunt all over the country for information, Mr Arrol would not consider it surprising that he had not been able to give him more or so much as he would have liked. Perhaps it was surprising that he had been able to collect so much. With regard to the wind-stress upon which the Forth Bridge was calculated, there was no doubt that the Astronomer-Royal in 1873 said a pressure of 10 lbs. per square foot was sufficient; that statement was contained in Messrs Barlow & Pole's report; and that was the report upon which, as he understood, the contract had been let. Now, he had it from the Board of Trade, with reference to the scantlings and stresses for Sir Thomas Bouch's bridge, that not a single point of that bridge had been determined upon. After that being the case he should like to know who was to give accurate information. The Assistant-Secretary of the Board of Trade wrote him that so far as he knew at the present time nothing had been settled, and that the working stresses fixed by the Committee of Engineers some four or five years ago for bridge structures, so far as he knew, were to be adhered to, and they all knew how far different they were from the stresses referred to in the report he had mentioned. Mr Smith had complained—and he could not say how pleased he was with the strength of his remarks—of the extreme difficulty of getting creditable information. It was not usual, indeed, he believed it was unprecedented, for the truth in regard to great engineering works to be so persistently withheld, and this only made it the more necessary that an Institution like this should discuss these structures as fully as possible. With regard to the Tay Bridge, they knew that it was not built according to the original design; it was altered as necessity arose during the progress of the work. But there did exist plans of that structure. He was shown in the Advocates' Library, Edinburgh, by the solicitor to the Board of Trade, a lithographed set of drawings belonging to the Board of Trade. Great efforts had lately been made to commence and carry on the structure of the Forth Bridge, and they had seen that these efforts so far had come to but little. At a meeting of the Company the other day, the chairman said the bridge was not going on as at present designed, and that nothing further would be done in the matter until a new bill was brought before Parliament to sanction the lowering of the height of the structure. Some allowance might, therefore, be made for the extreme difficulty he had in getting the meagre information he had to lay before the Institution. It was not often in the experience of this Institution that a discussion on a paper lasted so long, and he only hoped he had not been troublesome. It was exceedingly gratifying to himself that his paper had received the attention of so many engineers, not only members of this Institution, but that the substance of it was being discussed by the *Institute des Ingenieurs Civils* in Paris. Fault was found with him about the weight of the chains. He could not find the weight of the chains; but two or three days before his paper was read Mr Jeans published his work on "Steel," in which he stated the weight of the chains to be 10,000 tons. Mr Barclay's design had, he regretted to state, been entirely misunderstood, for in it there was not a single strut except the great horizontal one, all the rest were ties, and theoretically the stiffness might be got rid of. It was not a lattice girder bridge in any sense. But what surprised him was Mr Arrol's suggestion that the three intervening piers between the side towers and the furthest land spans might be got rid of. They might be theoretically, but practically, he would ask, what of the stability of the structure? They were the very essence of the life of the bridge during a storm, as having a horizontal strut of equal weight and length to the projecting cantilever, permanently tied down by bolts, passing down to a depth inside these columns, which would give a weight more than could possibly be overbalanced by any amount of wind pressure coming upon the overhanging half of the bridge. As to Mr Sedley's bridge, it was strictly a double triangle bridge or cantilever, and what was going to balance it supposing they had a storm such as he had the highest authority for saying they had not unfrequently experienced, when the wind blew at the rate of from 125 to 200 miles an hour for from four to six minutes, corresponding to a pressure of from 50 lbs. and upwards per square foot? Supposing a storm like that came down the Forth where would that bridge be? Where would Sir Thomas Bouch's bridge be? But the very certainty of the building of such a bridge as Mr Barclay's very much depended on these columns being retained in the design; such a bridge as Mr Sedley's could never be built for such a span. Fairbairn had shown that the limit of a girder bridge was about 1900 feet. To calculate these bridges was a matter of many months' work: it could not be done in the intervals between meetings. Sir Thomas Bouch, he had been informed, had had four Cambridge mathematicians calculating his design for about four years, if that be a proper criterion, so that they could easily understand the time such an investigation ought properly to occupy. With regard to the drawings, he might say that though he had not been so fortunate as Mr Fairweather, yet through the kindness of Mr Arrol, the Forth Bridge contractor, he had had permission for his confidential assistant, Mr Wilcox, to examine and make notes of the contractor's drawings, and he thought in many points they spoke for themselves, and that not very favourably to the design. One detail he might mention—viz., that some of the diagonal backstays for holding the catenary out of its true curve so as to give permanent back stress upon the chain and thereby stiffen it, were shown in the contractor's drawings as held by five $\frac{7}{8}''$ bolts. Somebody spoke, he thought, of shearing stresses destroying the rivets; but that was the same whether the girder was in tension or compression. The amount of the stress was the same in either case, however. The only duty which remained to him was to thank the Institution for the attention it had given to his paper.

The PRESIDENT said, in bringing this matter to a close, he thought he would only do right in moving a cordial vote of thanks to Mr Day for his ably written paper, and for the great pains taken in illustrating it by an extensive set of diagrams and drawings. They were also much indebted to Mr Barclay for the great amount of trouble and care displayed in preparing the design for a long span bridge. He had explained it to be a rough idea not thoroughly wrought out yet, and might not be novel in some respects, but suitable for crossing a wide river like the Forth. There were parts of the design which, in some respects, were superior to the plan of Sir Thomas Bouch. Then the principle of the increased compression or thrust in approaching the piers, longitudinally along the girder, or vertically, from the apex of the towers downwards, thus collecting the mass of the material towards the piers, was a feature of utility; there was also the question of facility of construction and other details, which time would not permit adverting to.

The PRESIDENT then moved a vote of thanks to Mr Day and Mr Barclay, which was heartily responded to.

Footnote referred to at p. 136.

Bernouilli demonstrated that the velocity with which a jet will flow, due to a given pressure, is constant in any section of a horizontal tube, so that p^{1} being the pressure and v^{1} the velocity in a section a, p^{11} the pressure and v^{11} the velocity in a section b, ϖ being the density of the fluid, then

$$\frac{p^{1}}{\varpi} + \frac{v^{1\,2}}{2g} = \frac{p^{11}}{\varpi} + \frac{v^{11\,2}}{2g}.$$

As the quantity of fluid which passes in a given time through the sections a and b is constant, the section a for example being less than b, v^{1} is therefore greater than v^{11}.

Note by Mr Barclay, received 17th March, 1880.

I may say, in explanation, that the 51·1 square inches in the great strut referred to by Mr Lindsay include only the section for resisting compression due to the rolling and dead load, as also the amount of section allowed for wind pressure, to which has to be added the weight of lattice work in the one great horizontal strut, as also the weight of the material in the top and bottom flanges to carry the rolling load, and also the weight of itself; which, when all these sections are added together, would make the total weight of the girder proper considerably more than would appear from the original diagram; but the strain exerted by this weight is included in the 6827·8 tons compression on the great horizontal strut, as also in the gross weight in the abstract;

and therefore does not require to be added. Mr Lindsay then goes on to criticise that section of the great strut at the root of the main columns, the dimensions, &c., of which he considers to be absurd. Surely Mr Lindsay has failed in his attempt to take a proper grasp of this colossal structure, when we consider it to be a cantilever projecting nearly one-sixth of a mile from the pier, and about 350 feet in height, and to be loaded with a train from end to end. I would say that no engineer competent to deal with this question would say that these quantities are absurd.

With regard to Mr Lindsay's criticism about the tie bars being fixed at different heights (I am certainly much obliged to him for his evidence of the originality of my placing them at different heights), these near the bottom give great stiffness and strength to what may be called the root of both the column and the horizontal strut to withstand the strain of wind pressure, and give solid footing to the train and confidence to the passengers; and there would be little difference in the weight, on account of the ties near the root being more than three times the length if taken over the top, and the columns having to be the full strength all the way to the top, would also require to have extra strength at the bottom to stand against the increased wind pressure surface and increased leverage by raising the wind pressure surface so high up, and the centre of gravity being so much higher up, the momentum of such a mass of metal as the columns and tie bars so high up would be enormous. The moment of inertia of the columns and ties in motion must be added to the dead pressure of the wind to overturn the bridge; besides, the cost of erection and time required would be much greater compared with the other design. But if Mr Lindsay had examined my drawings, which were in the hall both on the 24th February, when he was present, and on the 9th March, when the Secretary read his remarks, he would have found an exact drawing of what he recommends, with ties all taken over the top of the columns (See fig. 3, plate XV.), this would have saved him time making calculations which I had gone over before. I may here remark that I have also calculated another modification in which the first oblique ties is carried from half the height of the vertical column, the remaining oblique ties being spaced equally therefrom to the top of the column.

On Experiments on the Strength of Branch Pipes.

By Mr Thomas Kennedy.

Received 5th, and read 23rd March, 1880.

(SEE PLATES XVI. AND XVII.)

As many present may know, extensive contracts have lately been completed in connection with the water supply of Rio de Janeiro. The offer of the Glenfield Company, Kilmarnock, for sluice valves, and flanged specials connected with them, having been accepted, they proceeded to manufacture these articles according to drawings supplied by the engineer at Rio.

The pipes, which are of 80 centimetres, or about 31½ inches diameter, are laid in two lines, a few feet apart. At intervals, intercommunication arrangements are fixed. These were to consist of a flange tee piece (Fig. 1, see Plate XVI.) on each main, having a valve above and below it, and a valve on the branch, connecting it with the branch of the tee on the other main.

The test pressure was 300 lbs. per square inch.

The first tee piece cast to Fig. 1, about $1\frac{5}{16}$ in. thick, was tested by fixing a blank flange on each opening, and testing by water pressure from a force pump. Unfortunately this withstood the pressure, and 12 were cast before another test was made.

The two next tested burst, one just as the pressure reached 300 lbs., the other when it had been on for about a minute. The line of fracture is shown on the drawing. The section is 32·6 square inches; and were the strain equally distributed, it would be about 4400 lbs. tensional strain per square inch. The mixture of iron used was 12 parts No. 3 Glengarnock, 3 parts No. 3 Dalmellington, 2 parts of the above as gates and other foundry scrap. In those subsequently cast, about $1\frac{1}{2}$ parts No. 3 Maryport hematite was substituted for the Dalmellington.

Fig. 2 was now cast, $\frac{3}{8}$ in. being added to the thickness at the point of fracture, and a heavy fillet put on. The cross shading shows what was added. This and all subsequent ones were tested in the testing machine, with a blank flange on the branch. This burst at 290 lbs., showing that thickening the weak part had still further weakened it.

As the mains were partly laid, the lengthening of the branch would entail the lifting and laying farther apart of some of them. It was then decided not to lengthen the branch, but to add 10 inches to each end of the tee, and to increase the thickness at the weak point to 2 inches, gradually decreasing to $1\frac{5}{16}$ inches at the centre, the half farthest from the branch being this thickness. (See Fig. 3.) Notwithstanding that the section was double that of Fig. 1, the piece burst at 230 lbs., or 70 lbs. less than Fig. 1.

We now tried one of the original pieces. As the pressure was very gradually sent up, the various parts were callipered. We found that the sides were bulging out, the greatest bulge being 16 inches down from the flange; we found also that the branch was going in. At the bursting point the sides had gone out about $\frac{1}{4}$ inch, and the branch had gone in fully that. It was thought that if a pillar of an elliptical form, not to interfere with the flow, were cast from each side of the branch to the opposite side of the tee, it would hold out the branch. To test this we fitted a bar of iron from each side of the branch to the opposite side of the tee. At a pressure of 100 lbs. the side of the tee opposite the branch split from end to end. The bars were not driven into their place, they were merely tight enough to remain in position.

Fig. 4 we tried to support by adding outside webs to form shown by Fig. 3. Fig. 5, by adding a box girder to Fig. 3, at the weak point. Both were unsuccessful, as the bursting pressures of 200 lbs. and 180 lbs. show. Fig. 6 we tried by shrinking a bolt in a snug, cast 9 inches on each side of the point of fracture of Fig. 8. At 200 lbs. pressure the fracture went round one end of the bolt and back into the centre.

We were advised to try sudden cooling of the weak part. This we did by bareing this part of the mould as soon as the casting had set, and gently pouring on water. We thickened the casting to 2 inches all round. This, subsequent experience shows, strengthens the casting. As the chilled part burst at 180 lbs. the casting was weakened by chilling. The form is Fig. 7.

We now tried the effect of lengthening the branch. (See Fig. 8.) 10 inches were added to the length of the branch, $\frac{1}{4}$ inches taken from the thickness all round, and webs put on as shown. This burst at 350 lbs. As a strut could be put between the flanges from one line of pipe to the other, this was considered strong enough. It was considered that the webs on the side opposite the branch were useless, and Fig. 9 was tried with webs only to the centre. This burst at 300 lbs.

As the corner where the branch left the main pipe was the part which split, and in some cases the split extended only 8 or 9 inches on each side of it; this corner was taken off by a heavy fillet as in Fig. 10. This was found to be a weaker form than the square cornered one, having burst at a pressure of 280 lbs.

The fracture in Fig. 6 having passed round the end of the bolt, Fig. 12 (see Plate XVII.), was tried with a bolt the full width of the branch. At 450 lbs. the casting cracked in the corner and outwards to the bolt hole, water leaking under the bolt head and nut. This could have been made a very strong form by putting the bolt closer into the corner.

The engineer now found that the widening of the distance betweeen the lines of pipe was to cause more trouble than was at first anticipated. We decided to adhere to the distance originally fixed, and that the inter-communication be by two branch pieces, one immediately in front of the other on the pipe line, each having a branch valve of 22 inches diameter. The form sent to us is shown by Fig. 13. This is of uniform thickness of $1\frac{5}{16}$ and is not ribbed. It burst with a pressure of 330 lbs. We tried to strengthen the weak part, as shown on Fig. 14, by thickening from the centre to the branch and by putting in a heavy fillet, but as in Figs. 1 and 2 this weakened the casting, it having burst at 300 lbs. In Fig. 15 we thickened to 1⅝ inches all round and carried webs right round. We pumped this to 400 lbs. which it withstood, as did an occasional one which we subsequently tried. Having now got a form which gave a good margin over the stipulated pressure we declined to experiment any farther.

During the time that these experiments were in progress we consulted many people, but could get no assistance; I therefore hope that our experience may be of some general use. The data will enable any one to draw his own conclusions; it seems to me—

1st, That a cylindrical branch from a pipe is a weaker form than is generally supposed.

2nd, That thickening the metal at the branch only weakens the casting.

3rd, That stiffening it by webs or otherwise at that point only has the same effect.

4th, That the branch should be as long as circumstances will admit of.

5th, That thickening and stiffening should be on the side opposite the branch.

Mr A. A. HADDIN said their thanks were due to Mr Kennedy for the very excellent business-like paper he had given them, containing a record of so many results. He was satisfied it would be of great use to many of the members who were engaged in water supply works. He thought the paper was so conclusive and complete in itself that no remarks upon it were needed.

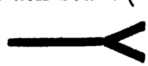
Mr W. J. MILLAR (the Secretary) said that in testing some cast-iron bars lately he came across some very peculiar ones, which broke off very short. From the mixture of which they were composed, he had expected high results. The bars were two inches deep by one inch broad. The central and greater part of the fracture showed strong iron; but at the corners there were silvery looking patches. From the general appearance of the surface of the bar, and from the appearance of the fracture referred to, he came to the conclusion that it had been chilled at the corners. It bore out very well what Mr Kennedy had stated in his paper as to the weakening of the parts of the castings which he had intentionally chilled.

Mr M'Gregor thought these were very valuable experiments of Mr Kennedy, and bore out very closely what was experienced in sea and land boilers. The junction of a dome with one kind of boiler was always a source of weakness; and in testing boilers he had met frequently results like those mentioned by Mr Kennedy. Boilers gave way in positions where these defects had proved themselves to exist in the pipes; in fact, so much so that it was found necessary to have additional strength in boilers at these places.

On the motion of the President, a cordial vote of thanks to Mr Kennedy was passed for his paper.

The discussion of this paper was resumed on the 20th April, 1880.

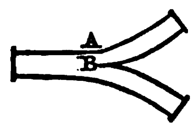
Mr James M. Gale said they had been troubled with some of their special castings in connection with the Glasgow Water Works, and he indicated the shapes of some of those that had given way by sketches on the black board (see Figs. 1 and 2).

Fig. 1.  Fig. 2. 

It was usual to make those peculiar shapes of pipes a little stronger than ordinary special castings. Many castings of these forms had shown signs of weakness. There was one put in at Jamaica Street which had stood 90 lbs. to the square inch of pressure for a time, and then gave way. He had put in a new casting of the same shape, and strengthened it all over, and had made the sockets deeper and stronger, and it had stood ever since. He quite agreed with the conclusion at which Mr

Kennedy had arrived, that it was necessary to make those castings considerably stronger than ordinary special castings. Mr Kennedy had experimented on 25 castings, at a cost of several hundreds of pounds, and therefore it was not extraordinary to hear him say that after they had got a form with a good margin of strength, they declined to experiment any further. He would like to make a remark upon what Mr Kennedy had said as to the strain brought upon the castings at the point of fracture. Mr Kennedy said that they gave way with about 4400 lbs. to the square inch at the point of fracture. Now, the good cast-iron that he knew Mr Kennedy's firm used, should stand more than that strain. It was quite certain that Mr Kennedy had not taken into account the great leverage that was put upon the point that gave way. In testing these castings, a swelling out on the broad surface was produced, and a contraction somewhere else, which must have produced a greater leverage than seems to have been considered. Then another point was that the first casting was tested by putting dead flanges upon all the openings. In the next casting that was tested, it was made a little stronger, but was proved in the proving machine in the ordinary way. This second casting, Mr Kennedy said, was weaker than the first; but he did not think that necessarily followed, as he was of opinion that the dead flanges upon the first casting must have added considerably to its strength. There was a similar casting supplied for the Loch Katrine Water Works, which gave way in a similar manner; but it had flanges, and was strongly bolted to large valves, and was still serviceable. There was another method of strengthening these castings which he had adopted, and that was by strengthening the flanges with strong brackets. Now, no doubt such an arrangement as that prevented bulging out on the flat side, where there was such a large pressure of water. He found that such pipes stood 100 lbs. pressure to the square inch. He had been consulted on the strength of these Rio castings a few years ago, when he had come to the conclusion that they were altogether too light, and that the distribution of metal was not scientifically arranged—that is to say, they had a greater pressure of water to contend with at one point than another, and yet they made the pipes of one equal thickness throughout. That was not right. He did not know whether the pipes were made in that way or not, but if so they were faulty.

Mr JAMES REID asked Mr Gale if he had ever tried to carry along the stays on these pipes, where the surfaces were so flat?



A, where pipe begins to flatten ; B, rib to act as a stay to hold flat sides together.

Mr GALE answered that he had never tried that; but he thought that would very likely strengthen the castings. They would act as ties in a locomotive boiler.

Mr JOHN THOMSON said they had made special pipes as described by Mr Gale; but they never had them in the proving machine, and consequently could not say what extra strain they would stand. He thought a very good way to stiffen the weak part of a branch pipe was to cast a round stud or column connecting the flat sides of the casting together, and in some cases they had put a core through when the connecting column was of large diameter. This seemed to suit very well. He thought they were very greatly indebted to Mr Kennedy for bringing his paper before them, and for the very valuable information he had given the Institution. He did not quite agree with Mr Gale that the branch pipe had yielded because of not having the dead flanges. He thought it might have been caused by being put into a proving machine. He believed that it was the putting them into the press, the one side being cut away by the large opening of the branch, the heads of the proving machine had a tendency to squeeze the sides of the pipe together. He was satisfied that special castings generally were often very much damaged in the proving machine; and it was not until he had had a conversation with Mr Kennedy, and heard his statements, that he had come to the opinion that the castings referred to, which had been proved in the machine, were not so damaged. In regard to the Rio pipes, it was quite true that at first they were specified to be all of one thickness, and he, as a founder, was very glad to hear Mr Gale say he was of opinion that they were too light, as from Mr Gale's extensive experience his judgment on that point was of great value. The pipes had not been tried with a working pressure, though tested here and in Rio; but he also thought they were too weak. This Rio main pipe was a very exceptional one. It was something about 33 miles in length, without any break, and the difference in head between the high reservoir and the service reservoir was something like 200 feet, and the greatest pressure at the lowest part of the main averaged 400 feet. Now, as this pipe when filled between the fountain-head and the city will contain about 26,000 tons of water, and will be flowing at a speed due to a head or pressure of 200 feet, one could not imagine what would ensue, were this immense mass of 26,000 tons suddenly stopped in its flow. He thought that the very momentum of such a mass was alarming. He did not know whether Mr Gale could give them any idea of the pressure of water under such circumstances, which no doubt must be greatly increased. He thought it was an open question whether the pipes were heavy enough. They were laid, but had not been tested by working. They had been filled with water, but it was not flowing through them yet. They were not all of one thickness, those nearest the fountain-head being reduced. There were three different thicknesses in these pipes. He supposed, however, that Mr Gale referred to the pipes laid in the lower part, and he had no doubt engineers would narrowly watch their working. There was a double line of mains 33 miles in length, and the working of that syphon was a very exceptional thing to try.

Mr Gale said as to the suddenly stopping of the water in the pipes, that any engineer who had had the management of a large main, knew that it was of the utmost importance that the water should not be stopped suddenly, and in the designs of the more recent water works, such as the large 44-inch mains for Liverpool, and the large mains for Manchester, it appeared certain that the ordinary stop valve was not applicable for such a column of water moving with great velocity and under great pressure, and Sir William Armstrong had devised a double slide valve which brought the water gradually to rest. By that arrangement one man was sufficient to close the valve. At Rio, if they had not adopted these valves, they would most certainly split the pipes, even the strongest one; but if they have double slide valves as in Liverpool, Manchester, and Glasgow, he did not see that that column of water might not be brought to rest safely. He had not considered the question as to the effect of these 33 miles as against the shorter distances under his own management, and whether or not the great length either added to or diminished the risk of a fracture in the event of a valve being shut. He knew that in closing a valve in a 36 inch main at 100 lbs. pressure, that just at the very end of the action of closing, the pressure bounded up 6 or 8 lbs. above the head due to the reservoir, and then it sank 6 or 8 lbs. below, and that these vibrations went on for 15 or 20 minutes gradually ceasing. He believed that this vibration was caused by the elasticity of the iron or of the water, and that a longer main would cause a more lengthened and a greater vibration.

Mr Ralph Moore asked whether safety valves would not avoid that action.

Mr Gale said they had these on the Loch Katrine works, on the pipes from Mugdock to the city; but there was a difficulty in keeping them watertight, and when they were wanted they often failed to open.

Mr Thomson said that he thought the length of the main with the column of water, would increase both the number and severity of the vibrations referred to.

Mr A. A. Haddin said with regard to the sudden stoppage of water in a long line of syphon main, he might mention the following:—A 15-inch pipe was led from a new system of ponds under a railway and up to a small well formed at the old inlet to the work. The flow into the original pipe was regulated by a sluice. The cope of the ponds and of the well were at the same level. When the sluice was suddenly shut the momentum acquired by the water carried it over the cope of the well, thus causing it to rise higher than its source. He found that from the water level of the pond to the bottom of syphon was 77 yards, with a fall of 14 feet, and thence to well 43 yards, with a rise of 7 feet to sluice. The cope of well had been raised 2 feet above the water level of the ponds. He would be inclined to think that this action would increase in proportion to the mass of water, and consequently in proportion to the length of the pipe.

Mr HALLEY said he thought that a simple way of strengthening the T pipe would have been by casting a rib of metal across the opening made for branch in the side of the pipe, thereby directly binding together the two sides where bulging out took place. He had seen large steam pipes so made and subjected to a high testing pressure without showing any signs of weakness. Another way of attaining the same end would be to put a steel bolt (galvanized if necessary) across the centre of opening in place of the rib. In either of these cases it would be necessary to swell out the pipe a little so as to keep up the required area through the pipe, which would, of course, be diminished by the insertion of a rib or bolt. He also took exception to one of the conclusions arrived at by Mr Kennedy, "that stiffening the T pipe by webs or otherwise at the point where the branch leaves the pipe weakens the casting," and was of the opinion that if the two bolts shown on Fig. 12, Plate XVII., had been carried through deep bosses as shown, and then connected with a rib strong enough to resist the bending in the same manner as a beam uniformly loaded, the pipe would have been materially strengthened—he considered a rib about 7 inches deep × 1½ inches thick would have been necessary. He would like to know from Mr Kennedy if he had observed at what pressure bulging had actually commenced, as from some figures he (Mr Halley) had put down, he considered the pipe would be bulged out with a pressure of 140 lbs, per square inch, this being about one-half of the pressure required to fracture it.

Mr Kennedy said with regard to Mr Gale's remarks about the effect of end pressure in the proving machine, that the way in which they found that the branch went inward was, they put a straight edge with a leg at each end across the branch; these legs rested on the end flanges, a wedge was inserted between the straight edge and the branch, which was pushed in as the space widened. The distance between the end flanges was measured, but it could not be observed that they went in. With regard to Mr Thomson's remarks on the effect of the testing machine, the effect of lengthening the ends would be to make them deeper girders in the line of the strain put on by the testing machine. Regarding the valves, they are single slide. There is a 4 inch bye-pass valve at the side; they were anxious to put in an 8 inch, but the engineer thought a 4 inch sufficient. A gentleman had asked at what pressure the bulging began. He might state that they noticed it distinctly when the pressure exceeded 100 lbs.

On the St. Petersburg Water Works.

By Mr John Thomson.

Received 23rd March; read 20th April, 1880.

(SEE PLATES XVIII., XIX., XX., XXA., AND XXB.)

The city of St. Petersburg, the modern capital of the Russian empire, stands on and around the lower branches of the river Neva, and on the shores of the eastern extremity of the Gulf of Finland.

The Neva is about forty miles in length, nine miles of which are within the boundaries of St. Petersburg. It takes its rise in Lake Ladoga, the largest lake in Europe, and after traversing a winding course of about thirty miles in one deep and rapid stream, breaks up into numerous branches, just as it reaches the city, forming many islands, and discharging into the Gulf of Finland by four main outlets. The bay above Cronstadt thus receives the waters of the Neva by four great channels of very considerable volume and breadth, the river before it divides being at some points over 2000 feet wide, and from 50 to 60 feet deep.

Besides some minor canals, the city on the south or Great side is intersected by four large canals, which traverse it in a generally semicircular form, the centre of which may be said to be the Admiralty, from which point three main streets or Prospects radiate, the most important of these being the famous Nevski Prospect, which is about 4 miles long, and 130 feet wide, and is the most splendid street in St. Petersburg; and which, for architectural beauty, extent, and variety, lays claim, and with some reason, to be the finest street in Europe.

The river Neva, or rather the southern arm of it, divides the city into two great sections—the Great side on the south, and the Petersburg side on the north. The last-named is built on the islands which form the delta of the Neva, the principal of which are the Wassili-Ostroff or Williams Island, and the Petersburg or Citadel Island, to both of which this paper has more special reference.

The Great side, south of the Neva, is elegantly and compactly built, and contains the principal streets and bazaars, the residences of the court and the nobility, and probably over two-thirds of the inhabitants. The whole city covers an area of about forty-two square miles, and contains a population of about three-quarters of a million. It stands on what were only malarious marshes up to the year 1703, when Peter the Great, desiring to have "a window looking out into Europe," laid the foundation of this imperial city, and determined by his own iron will to fix his capital there.

The site selected by this despotic monarch could hardly have been worse, so far as foundations for buildings and general sanitary arrangements are concerned; for, with the exception of a few feet of crust or solid ground, formed after many years of great labour, the whole sub-stratum is little better than running mud. And although we are at first struck with the great extent of the squares and open spaces, and with the elegant palaces and public buildings surrounding them, for which this city is famous, we cannot help thinking of, and admiring, the indomitable energy and perseverance that must have been exercised, in overcoming the obstacles presented by the marshy nature of the soil, in finding suitable foundations for these, especially for such magnificent structures as the cathedral church of St. Isaac (to form a firm foundation for which whole forests of piles were used, at a cost of over £200,000), the great column of Alexander, by far the largest monolith in the world—and the great water tower at the works of the St. Petersburg Water Company.

There are, however, few cities, if any, so well situated as St Petersburg, as far as a natural supply of pure fresh water is concerned; for, with the great volume of the Neva, broken up into its numerous arms and canals, intersecting the city in all directions, and uncontaminated to any extent by sewage refuse (that great destroyer of the purity of most of our rivers—St. Petersburg being yet without any regular drainage or sewerage works), an ample supply of pure fresh water is thus within easy reach of the inhabitants, and may almost be said to be at their very doors.

It is not to be wondered at, therefore, that until a comparatively recent date, the city was without any proper artificial supply of water; and the house porter or *dvornik*, who in his official capacity combined the duties of sanitary officer and water and sewage carrier in one, was regularly to be seen on the streets with his water barrel, on wheels in summer, and on a sledge in winter, pursuing with plodding patience his humble but necessary calling.

With advancing civilisation, however, and a growing desire for improved sanitary arrangements, this primitive state of things could not continue. Consequently, in the year 1859, a company was started to furnish the citizens with a full supply of water under pressure. This company at the beginning had very considerable difficulties to contend with, natural and otherwise; and the story of its early struggles could no doubt be very graphically described by our much-respected member, Mr David Rowan, who was intimately connected with the starting of the works, and by whom, if I am not mistaken, the first sets of pumping engines were designed and erected, while he was connected with the old and well-known—though now extinct firm—of James Aitken & Co., of Hill Street and Cranstonhill.

The St. Petersburg Water Works Company supplies the whole of the city south of the Neva, which, as has been before stated, is the main part of the city, and may be said to correspond to the portion of Glasgow north of the Clyde. The company is a Russian one, having its offices situated in St. Petersburg, and its directors resident there. It has gone on increasing its pumping power and extending its mains, so that its works are now of a very comprehensive character.

I do not propose at this stage of the paper to give any description of these works, my object being rather to give, in the first place, a brief account of the works constructed by my firm a few years ago on the north side of the Neva for the City of St. Petersburg New Water Works Company, and which were to a large extent carried out under my personal supervision and afterwards, if time permit, to mention a few leading particulars of the old company's works, and give an account of some of the peculiar difficulties we had to contend with in carrying out a large extension of the mains two or three years ago, on the south side of the Neva for this company.

The St. Petersburg Water Company having thus confined their operations to the south side of the river, the large and important districts on the north side, containing a population of about a quarter of a million, were left wholly unprovided with any artificial supply, the extent of the districts and the comparative thinness of the population, together with the natural difficulties presented by the several branches of the river intersecting the districts, not presenting, I suppose, sufficient inducements to tempt the existing company to erect pumping stations there.

In the year 1874, however, a company was started in London to supply these transpontine districts of St. Petersburg with water, Messrs Joseph Quick & Son, of 29 Great George Street, Westminster, being the engineers, while the contract for providing the pumping machinery and constructing the works was entrusted to the firm of R. Laidlaw & Son, Glasgow.

The districts supplied by the new company's works are the Wassili-Ostroff or Williams Island, on which are situated the Exchange, Custom House, Schools of Art, Mining College, Barracks, &c.; Old Petersburg or the Citadel Island, on which are the Fortress, Zoological Gardens, &c.; and the Viborg district on the main land, in which are built the Arsenal, Military Hospitals, &c. These islands or districts, as will be seen by a reference to the map (see Plate XXB.), are separated from each other by wide and deep arms of the Neva, and are not connected in any way by bridges of a sufficiently permanent nature to carry a water pipe across, and as it was not considered practicable to carry a pipe under pressure below the bed of the river, it was necessary to erect separate pumping stations in each district, with distinct mains, not connected in any way, so that in point of fact each district had to have a complete and independent water works of its own.

The supply of water in each case is drawn direct from the river, and is not passed through filters of any kind, and although it may shock the susceptibility of some of our sanitary friends, it is nevertheless the case that the principal pumping station at the Wassili-Ostroff is situated at the lower end of the harbour, almost as the river leaves the city, in fact, in much the same position as if at Govan or Partick on the Clyde, but nevertheless so great is the volume of water and so little is it contaminated in passing through the city, that it is as clear and limpid when pumped into the mains as when it leaves the lake at its source.

As the general arrangements of the three stations are very much alike, and the pumping machinery of the same design, a description of one of these stations is all that is necessary, and it will be sufficient to show the difference in extent of the three works to state that the Wassili-Ostroff has a pair of pumping engines of 120 nominal horse power, which are furnished with four boilers. The old Petersburg station has engines of about 80 horse power and three boilers, and the Viborg station is furnished with engines of about 45 horse power and two boilers.

The principal dimensions of the respective engines at these several stations are as follows:—Wassili-Ostroff, steam cylinder 30″ diameter × 48″ stroke, double acting pump 15″ diameter; Old Petersburg engine, steam cylinder 24″ diameter × 40″ stroke, and pump 12″ diameter; and Viborg engine, steam cylinder 18″ diameter × 32″ stroke, and pump 10″ diameter. With the exception of the Viborg engines, in which there is a slight difference, the pumps are half the diameter of the steam cylinders, or one-fourth of the area of the pistons, the mean pressure of water on the pump pistons is about 60 lbs. per square inch, and the steam pressure in the boiler 45 lbs. It will thus be seen that there is an ample margin of cylinder power which enables a high grade of expansion to be used, and the efficiency and economy obtained is exceedingly satisfactory.

At the Ostroff station 2½ million gallons have to be pumped in the 24 hours to a height of 125 feet, at the Petersburg station 1½ million gallons to 125 feet, and at Viborg station 750,000 gallons to a height of 100 feet, or a total quantity at the three stations to be pumped per day of 4½ million gallons, with one engine at each station only at work.

The combined pumping power of the three stations is thus equal to nine million gallons in the 24 hours, if all the engines are at work at one time.

There is nothing specially original or worthy of remark about either the design or construction of the engines, which are simple condensing engines with jacketed cylinders, except that owing to the marshy nature of the site and the difficulty and expense of getting a good foundation, it was decided to make the engines and pumps horizontal instead of vertical, as was at first proposed, placing the steam cylinder, main pump, air pump, and condenser all in line on heavy cast-iron soleplates; and that to enable the machine to be shortened as much as possible, it was decided to adopt the crosshead and double-return connecting rod arrangement, the crosshead being placed between the main pump and the steam cylinder, and the crank shaft with its double cranks and eccentrics, and with main and expansion valves between the condenser and steam cylinder. The steam cylinders are double-ported with slide valves, on which are placed variable expansion valves. The exhaust steam is conveyed to the condenser through the two rectangular pipes, or hollow beams which attach the condenser to the cylinder, and which also serve to carry the brackets for the valve levers.

The condenser, air pump, and cold water pump are all cast in one, the air pump rod being below, and the cold water pump rod above the crank shaft, and attached direct to the steam piston.

The main pumps, which are 15″ diameter and of the same length of stroke as the engine, are attached direct to the crosshead and are double acting, with adjustable packing pistons, and the valves, of which there are four to each pump, are of the ordinary double-beat Cornish type, and are of the same diameter as the pump barrel.

The two outlet valves are placed over the pump barrel, and the two inlet valves below the engine room floor.

The engines are single and independent of each other, and are each furnished with a heavy fly wheel and delivery air vessel, and there is a suction air vessel common to both engines, as will be seen by a reference to the plan. (See Plate XIX.) Between these there are the necessary valves to cut off one engine with its pipes from the other when it is working, as only one engine is intended to be working at a time. The engine seats and engine and boiler houses are of brick, and are large and handsome, and as the site is exceedingly marshy the whole is built on a massive bed of concrete, which has hitherto stood very well.

The district being perfectly level there was no elevation available on which a supply reservoir could be placed; it was therefore proposed in the original plans to erect a stand-pipe tower with stand pipes inside, and up the corner of which tower the boiler chimney was to be carried, thus serving the double purpose of conveying away the smoke and waste gases from the boiler furnaces and also protecting the stand pipes from frost, which, in a climate so severe as Russia, has very carefully to be guarded against. The piling and concrete foundation for the tower at the Ostroff station were actually put in, but so doubtful was the resident engineer of its capability of carrying so great a weight on so narrow a base that he hesitated to erect the tower upon it.

This tower was to be 135 feet high (see Plate XXA.), in which it will be seen that the stand pipe inside of it is double. It is 30 inches diameter at the bottom, tapering to 18 inches at the top, the upward and downward shaft being connected at three points by valves at the heights of 45, 90, and 125 feet from the ground, and the water can be pumped through either of these valves according to the pressure required.

In these circumstances the engineers were led to consider whether the towers and stand pipe could not be dispensed with altogether, and the water pumped direct into the mains.

I was not aware at the time, nor do I know yet, of any water works where this is done, as all the works that have come under my notice have either a reservoir, into which the water is pumped, or which serves as an outlet or escape for the surplus water, or a stand pipe is provided, generally where elevated ground suitable for a reservoir cannot be got, to give the desired head or pressure, and which, being open at the top, serves as an escape for the water and prevents overpressure in the mains.

It occurred to me that the object sought to be attained by these arrangements, viz., the maintenance of a steady head of water, without the danger of undue pressure, might be quite as efficiently accomplished by the introduction of a properly-constructed self acting throttle valve or regulator, by which the speed of the engine, and consequently the quantity pumped and the pressure required, might be regulated and controlled, the throttle valve receiving its controlling power direct from the water in the mains themselves, the pressure acting through a small accumulator or hydraulic cylinder fitted with a loaded piston and attached, either directly upon the throttle valve spindle, or through a series of levers in much the same way as the ordinary accumulator regulates the speed of the hydraulic pumps with which most of us are familiar. The loaded piston, moving up or down according as the pressure rises or falls in the pipes, and acting on the throttle valve, would regulate the supply of steam to the engines according to the work required from them, and the demand made upon the pumps through the varying consumption of water by the inhabitants at the different periods of the day.

It will no doubt be apparent that a valve such as I have described was not very difficult to arrange, but something more was required than merely shutting off some steam when the pressure in the pumps was too high, and admitting it when the pressure fell, if the valve was to be perfectly self-acting and thoroughly reliable under all the conditions that were likely to arise, and that was, that it should instantaneously shut off the steam entirely, should the pressure be suddenly removed from the pump piston through the bursting of the air vessel, or one of the mains in the vicinity of the pumps. This, indeed, was one of the main objects I had in view in first designing the valve. As from the experience gained in the working of the large pumping engines at the Odessa Water Works (the contract for which works was also carried out by R. Laidlaw & Son), the want of such a valve was very severely felt. These engines of which there are eight, of 100 horse power each, are placed on the banks of the river Dneister, from whence the supply of water is drawn, and after passing through filters is pumped through a 30-inch rising main to a height of about 400 feet over a stand pipe placed on the summit of a hill about a mile and a half distant from the pumping station, from whence it flows through 25 miles of 30-inch pipes directly into the city. It unfortunately happened on one or two occasions, during the term of our year's maintenance, that from one cause or other the rising main burst not far from the pumping station, and the load being thus suddenly taken off the pumps while the engines were working to their maximum power under a full head of steam, they at once "bolted," and a very serious break down was the consequence.

The regulating valve and hydraulic cylinder, as they are erected at the Wassili-Ostroff pumping station, is shown by Fig. 3, Plate XX. It was at first intended to place a water cylinder directly over and attached to the spindle regulating the valve, but the position of the steam pipes did not permit of this being conveniently done. One water cylinder, therefore, is placed between the two engines and made common to both, to which it is attached by the necessary pipes and taps, to form a connection with either as desired. The motion is conveyed to the steam valves by levers and bell cranks as shown. The weights below are slightly under what is necessary to balance the pressure desired to be maintained acting on the area of the water piston, and by this means the spindle of the piston is kept in contact with the weights above, and in this position the ports of the steam valve are supposed to be half open. When the pressure rises above what is required, the upper weights are lifted, and the spiral spring comes into action by being compressed as the piston ascends in the hydraulic cylinder, and the steam-regulating valve being proportionally acted on, shutting off the steam and so reducing the speed of the engine until the pressure gradually falls, and the weights and spring recede to their normal position again. Should the pressure be suddenly taken off the mains, by a burst or otherwise, the sustaining power of the hydraulic piston is at once removed, and the bottom weights drop on the india-rubber cushion provided for them, carrying the steam valve with them and instantly shutting off all steam from the engine. The regulator is simply a species of double-ported piston valve. A brass liner with two rows of ports cut in it is inserted into an iron case, and a deep brass piston with a diaphragm in the centre, to which the rod is attached, and with a row of ports above and below the diaphragm is made to fit easily inside of the liner. It will thus be seen that the valve shuts off the steam entirely, either by the pressure becoming too high or disappearing altogether. Another arrangement of this valve is also shown in which a double piston valve is shown, and a spiral spring to act against the pressure of the water in piston is adopted in place of the weights. The hydraulic cylinder is placed over the regulating valve and connected directly with it without the intervention of bellcranks or levers, which are objectionable. The dead weights were in the first place preferred because they would be less liable to get out of order, and also because it was thought they would act more swiftly and decisively in shutting off the steam, should a fracture of the air vessel or mains take place. Happily, these valves have never yet had an opportunity of showing their qualities by so acting, no failure of any part of the mains near the engines having taken place since their start to test them in this respect. This valve is to some extent an adaptation or modification of a self-acting gas compensator and bye-pass valve I designed many years ago for regulating the action of gas exhausters, many of which have been fixed by my firm, and have acted with great delicacy and precision. I ought to have mentioned that the hand wheel on the top of the column is for the purpose of raising the bottom weights or spring by means of a screw, and so keeping the valve open while the engines are being started by hand, and until the pressure is got up in the pipes, after which it is unscrewed and the weights are sustained by the pressure of the water in the piston as described.

It was evident, however, as the engines were single and the quantity of water likely to be consumed for some time would be comparatively small, that some escape for the surplus water would have to be provided, otherwise the pressure would rise unduly in the mains and stop the engines altogether. Accordingly the pressure and suction air vessels are connected by a 6-inch pipe, into which is inserted a spring loaded escape valve, and although at first the engines had to be driven as slow as eight or nine revolutions per minute, the quantity pumped was too large for the requirements of the districts, more especially at night when little or no water is used, but by the steady opening of the escape valve the surplus water passes gently back into the suction air vessel, and so the pressure is maintained as steady in the mains as if it had been supplied from a reservoir, the needle of the gauge not varying more than a pound, if even so much. It perhaps ought to be mentioned as a matter of some importance, in connection with this, that the pressure air vessels are 4 feet 3 inches internal diameter × 9 feet 10 inches high, or about 30 times the cubic contents of the pump. They thus provide an ample elastic cushion for the stroke of the pumps to work against, and no doubt the steady pressure obtained is greatly due to this. The suction air vessel, which is common to both pumps is 4 feet 3 inches diam. × 6 feet 9 inches high.

As a proof of the complete success of the arrangements I have been describing, it may be mentioned that during the first year after the works were opened, the districts were not once without water for an hour through any derangement of the pumping machinery, or the pressure-regulating arrangements connected therewith; and although these have now been in operation for more than four years continuously day and night, I am not aware that any stoppage whatever has taken place during that period.

It would thus appear that all such expensive arrangements as water towers, stand pipes, and even reservoirs, are not absolutely essential to obtaining a steady pressure, or even a constant supply, and that this may be as well accomplished by some such mechanical arrangement as I have just described.

The pumping engines at the Wassili-Ostroff are situated 250 yards from the Neva, and are at mean height above the average surface of the water of about 18 feet. The suction main is 22 inches diameter, of ordinary spigot and faucet pipes, and is laid at a depth of from 6 to 8 feet from the surface of the street It is connected near the river with the suction well. This well, a sectional elevation of which is shown by Fig. 1, Plate XIX., is formed of cast-iron cylinders, 6 feet diameter, having internal flanges, and was sunk to its position by excavating the ground inside, and loading the cylinder in the usual manner. It is fitted inside with a vertical framework, across the centre, running from top to bottom, and into the slides of which are placed wrought-iron frames, covered with fine copper wire gauze, forming the straining screen, which is easily removed for cleaning as required. On the one side of this screen is fixed the foot valve attached to the suction pipe leading to the pumps, and on the other is a screw sluice valve, to which is attached the pipe leading into the river. This pipe, which is also 22 inches diameter, is formed of wrought-iron plates, rivetted in lengths of 40 feet, and these lengths are attached together by cast-iron flexible joints, a detail section of which is shown by Fig. 1, Plate XVIII. This joint, as will be seen, is simply a spigot and faucet; the faucet is bored out parallel, and a belt about four inches broad, on the spigot end, is turned to a spherical curve, and made a good working fit in the faucet. The spigot and faucet are held together by a pair of eye bolts, attached to snugs cast on each piece, the round snugs cast on the faucet being the axis on which the joint moves. This joint is (if it can be called such in relation to a water pipe) only flexible in one direction, and is of course not tight under pressure, but being a good working fit, it is sufficiently tight for a suction pipe under water, and is well adapted to such a position as this.

Probably a better form of flexible joint, however, especially for large diameters, is shown by Fig. 1, Plate XX. It is known as Ward's joint, and was very successfully adopted by the engineer of the Toronto Water Works, in laying a 36-inch suction pipe, about a mile in length, in the bed of Lake Ontario. From the section it will be seen that the whole depth of the faucet is 12 inches, of which 9 inches is bored out to a true sphere, the boring out of the faucets having been done in the ordinary pipe turning lathe, by means of a very ingenious tool-holder, which was specially designed by Mr Laidlaw, sen., for this purpose. The spigot end has a small part turned to fit, and a deep groove is cast in to hold the lead, which fills the space left for it, and thus forming a ball and socket joint. These pipes, each of which weighed about two and a half tons, were made by my firm about five or six years ago, and were laid, I understand, from a couple of barges, on board of which the joints were run up, and from which they were lowered by powerful gearing, pipe by pipe, like a chain, into the bed of the lake.

It may here be remarked, that these and other forms of flexible joints that have come under my notice, are in my opinion only adapted for suction pipes such as I have described, or the conveyance of water or sewage under comparatively low pressure, or to a distance out to sea, for which purpose I think Ward's joint very well suited; but I have not yet seen, nor do I believe it practically possible to construct, a really flexible joint, at least for large diameters, that can be thoroughly relied on under the pressures and conditions that exist in ordinary water works.

The suction pipe, as will be seen by a reference to Fig. 2, Plate XVIII., after leaving the suction well, passes under the massive granite quay wall, through an opening cut in the wood piles that support the wall, and is carried out in a shallow trench cut in the bed of the river, to a distance of 150 yards, and into a depth of water of about 36 feet. The end of the suction pipe, with the rose piece attached, is kept up about 4 or 5 feet from the bed of the river, which is here of a sandy nature; and as at this point it is in the full flow of the current, it is believed that the purest water is obtained here. The laying of so great a length of heavy pipe in this depth of water was a work of considerable difficulty, and was accomplished by constructing two long rafts formed of balks of round timber fastened together, the two rafts being kept about 3 feet apart, and maintained in this position by cross batons at regular distances, and guard piles driven in at each side. On this platform or raft were placed the pile drivers, and guiding piles of sufficient length to come considerably above the surface of the water were driven in at fixed distances along the side of the pipe trench. Between the two outer sets of piles, centre piles were driven in, which were cut off by divers to the necessary height from the bottom, and on which the pipe, when lowered, would rest. The lengths of pipe being then launched out on the raft, and connected up together by the flexible joints already referred to, a sufficient number of pipe-laying tripod winches were placed in position across the pipe, and resting on each portion of the raft, and the cross batons connecting the rafts being then cut away, the pipe was safely lowered between the guiding piles into its position at the bottom of the Neva. A bolt being then passed through the piles above the pipe, the piles were cut off a foot or two above it by the divers.

The only part of the work remaining to be done after this, under water, was making the joint with the length of pipe that passes under the quay wall. The placing of this length of pipe in position, however, proved to be by far the most troublesome part of this portion of the work.

The massive granite quay walls which line each side of the river are built on a platform of wood, placed on the top of round piles, driven in as close as they can be put.

The platform from which the stone work starts is about 4 or 5 feet below the mean surface of the water, and is formed of two layers of crossed planking. The quay wall is about 12 feet thick, composed of heavy granite blocks, and the piling is about 14 feet through. It was considered advisable for many reasons, practical and otherwise, not to remove the quay wall at all, but to endeavour to cut through under it. Accordingly, by the directions of the resident engineer, a strong cofferdam was constructed in front of the quay wall, to enable this to be done, and a powerful steam centrifugal pump being set to work to empty the dam, it was found not to make the slightest impression on it; and it was soon discovered that the dam, although perfectly tight on three sides, was quite open on the fourth, the water percolating freely through the piles into the dam faster than the pump could remove it. In these circumstances, and while matters seemed at a dead lock, our representative, though not an engineer, conceived the somewhat bold idea of cutting through this mass of wood by means of divers; and an efficient staff, with reliable apparatus, having been engaged, they were set to work. By going down in relays, they managed in about three weeks to bore their way through this mass of timber with augers, cutting one pile at a time, and clearing a passage about 4 feet square for the pipe, through which it was launched, and being connected to the suction well, and to the pipe in the trench, completed this part of the work.

Before leaving this part of the subject, however, and proceeding to describe the canalisation of the district, and the arrangements for the distribution and supply of the water, it may be well to notice a few important points in connection with the starting of the engines, and the laying of the suction pipe between the well and the pumps, which may be worthy of the attention of the younger members of the Institution, at all events.

As has been before stated, the pumps are at a distance of 250 yards from the river, and at a height of about 18 feet above mean water level. It was therefore necessary to expel the air from this long line of pipe, by filling it with water before starting the engines, and this was accordingly done, by shutting the sluice valve in the suction well, and filling up the well and the greater portion of the pipe, by means of the steam centrifugal pump, the valves, pump barrel, and portion of the pipes above the level of the top of the well, being filled by hand. On the pumps being started, the water in the suction well began to fall, and the sluice valve being opened, the connection with the river was established. The engines and pumps worked very well, and no doubt would have continued to do so but for the presence of an unusual amount of air which came in along with the water, and which threatened a serious rupture of the whole machine. This air very probably found its way into the suction pipe through defective joints, caused by the very great difficulty experienced in laying and jointing the spigot and faucet pipes through the yard of the pumping station, which was little better than a swamp or marsh, the trench having to be closely sheet-piled all the way, while the running mud, which could neither be pumped nor shovelled, rose up through the bottom, rendering it scarcely possible to run up the joints in a satisfactory manner, many of them indeed having to be caulked up with cold lead. The superincumbent weight also of the 6 feet of covering soil with which they were loaded, would sink them deeper in the soft ground on which they rested, and would thus, no doubt, start or draw some of the joints.

The advanced period of the season, and the early setting in of what is always a very severe winter, rendered it next to impossible either to examine the joints, or to attempt to relay any part of the pipe; and it was hoped that, owing to the muddy nature of the soil in which the suction pipes lay, the leaks in the joints would rapidly fill up, which indeed very soon took place. Meantime it was imperative that the air, which was steadily coming in, should be regularly removed; and, after several expedients had been tried, the very simple and effective one was adopted of connecting the top of the suction air vessel, by a ¾ inch wrought-iron tube, with the condenser, so that, by the opening of a tap, the air in the suction air vessel was rapidly removed, and solid water took its place. This arrangement worked very well as long as it was required, but a difficulty of an unexpected and puzzling nature soon presented itself.

As the pump, after working a week or ten days quite satisfactorily began to show signs of knocking and very soon lost the "fang" altogether, the pipes were again charged and the pump started, and after working all right for about the same period a like result followed. This was repeated once or twice, when it became apparent that there was something radically wrong with the levels of the suction pipe. I was not in Russia when this part of the work was done, but on inquiring into the matter it was discovered, that owing to the difficult nature of the ground and the danger to the foundations of an important public building, the School of Mines, adjoining, the track could not be cut so deep as was intended; consequently the suction pipe, after leaving the suction well, was raised to within 6 feet or so of the surface, at which level it was carried along the street to the point where it turns off into the yard of the pumping station, when it gradually drops so as to get the necessary protecting cover of 6 feet in passing through the yard, which is considerably lower than the street, rising again to join the suction air vessel.

Of course, the evil was at once apparent—the small drop in the level of the pipe thus formed a syphon or loop in which the air coming in with the water and getting disengaged from it lodged, gradually trapping it, as it were, and ultimately cutting off the inward flow of the water altogether.

As the suction pipe could not be disturbed or relaid, there were only two ways in which the evil could be removed, the one being to carry a small pipe from the highest point with a gradual rise up to the air vessel, protecting it in some way from the frost, which, however, was found to be impracticable or at least inconvenient, and the other, or simpler one, which was adopted, of tapping the pipe at this part, and attaching a stop ferrule, to which an ordinary hand syphon-pump was attached, and by which the accumulated air was pumped out and water drawn. The pumps, on again being started, were found to draw solid water quite free from air, and to work quite satisfactorily, which they still continue to do.

It is curious to note that the periods between which this syphon or loop requires to be pumped are very much regulated by the rise and fall of the water in the river, and vary from a week to three or four weeks, and the time occupied in pumping it free of air varies from two or three minutes to half an hour.

It will thus be apparent how very important it is that in a long suction pipe with a considerable lift, such as I have described, the gradual rise of the pipe to the pumps should be carefully attended to—a point which is very apt to be overlooked by ordinary pipe layers.

The distribution of the water through the Wassili-Ostroff district was not difficult to arrange, and but for the obstacles presented by the marshy nature of the subsoil would have been a comparatively simple matter.

As will be seen by a reference to the map (Plate XXB.), the streets are laid out very much after the American fashion. Three main streets or prospects run across the island, parallel to the great Neva, and to each other, and are named the Great, Middle, and Little Prospects. These are intersected at regular distances by cross streets, each side of which is called a line, beginning at the 1st up to the 23rd line, in the latter of which the pumping station is placed, the whole district thus being laid out into regular parallelograms.

The main supply pipe, which is 16 inches diameter on leaving the pumping station, is led up the 23rd line and along the Great Prospect, gradually diminishing from 16 inches to 8 inches at the extreme end, at which is situated a very important establishment in Russia, viz., *the Custom House*. An auxiliary pipe is led along the quay in case of fracture to the main pipe in the Great Prospect. The cross mains running along the lines are chiefly 3 inches and 4 inches diameter, according to the extent and importance of the street, and as a valve is placed at each branch of the main pipe, any of the lines can be shut off as required in the usual manner.

The pipes are coated with Smith's solution, and have turned and bored joints up to 6″ diam., the larger sizes having inside sockets for lead and yarn joints. The turned and bored joint was adopted to facilitate the laying of the pipes, as owing to the shortness of the season in Russia during which such operations can be carried on, it was essential that this part of the work should be done as speedily as possible, if it was to be completed in one season, which was imperative; and although the turned and bored joint is generally understood to be only suitable to firm ground, it was used here with very fair results, not more than an average amount of leaky joints being found when the water was turned on.

The mains were required to have 6 feet of cover, which, considering that the frost often penetrates as far as 5 feet into the ground, and in severe seasons sometimes further, cannot be said to be too much. The trench had thus to be about 7 feet deep, and after cutting through about 4 or 5 feet of crust the whole substratum was found to be little better than running mud. The precaution was therefore taken of laying two pieces or blocks of wood under each pipe, and the turned parts being coated with brown oxide were driven home, often amongst water, so the wonder is that no more leaky joints were found than what existed after the pipes were filled.

The fire hydrants, of which there are upwards of 200 in this district, are of the usual ball hydrant form, and are placed from 150 to 200 yds. apart; they are protected from frost, and also made accessible at any time by the arrangement shown on Plate XVIII. A wooden box, about 3 ft. 6 in. square, is formed of half trees by the Russian *plotnick*, or rough joiner, who is very expert at the use of the axe. A platform is placed about half-way up, and another platform of wood at the top, which carries the street causeway stones, as also a heavy cast-iron manhole cover. The space between the middle platform and the top is usually filled with stable manure, and a close fitting lid is placed on the square spindle box when the stand pipe is removed. By this means the hydrant is perfectly protected from the frost, and as the same arrangement is adopted for the valves, the stuffing-boxes of the valves and the hydrants are easily accessible at any time; and altogether the wooden pit is found to suit the purpose very well, and is certainly very convenient.

There are many fire towers on the islands as well as throughout the other parts of the city, from the top of which a strict look-out is kept day and night without intermission by two watchers at a time, not by any means an enviable position when the cold is at 70 degrees Fahr. below the freezing point. These towers are lofty circular buildings with an iron apparatus projecting many feet above them, designed for making signals as to the part of the city in which the fire has broken out. This is done by hanging out balls or drums, similar to our storm drums during the day, and lanterns at night, the number and arrangement of which indicate the district in which the fire is raging.

The fire brigades are well drilled, very complete, and splendidly equipped, and are kept in constant readiness at all times.

The *chasts* or police stations, which are (as here) the stations of the fire brigade, are also connected by telegraph with each respective pumping station, so that when a fire takes place, which is not unfrequent, the large proportion of the houses being built of wood, the engineer is communicated with, and he by giving an extra turn or two to the screw of the escape valve and a little more steam to the engines, immediately puts any pressure that may be required on the mains; and although there is no stand pipe or tower to allow of the escape of air, the fire hose pipes are found to discharge a solid jet of water, even at the extreme end of the system, and to any required height, which is no unimportant recommendation for the system I have been advocating, and should lead to its further and more extended adoption.

The service pipes connecting the mains with the houses are mostly large, few being below 1½ inch diameter. The houses, or *doms*, as they are called, are simply large blocks of buildings named after the owner, or principal occupant, and let out to separate tenants in sections or flats, the principal block being towards the street, and the back buildings forming a hollow square with the windows all looking in towards the quadrangle. The largest of these doms on the Wassili Ostroff will contain about 500 inhabitants, and the average will be about 75 or 100.

The water is supplied to consumers either by meter or contract, as may be arranged, and the price also is subject to negotiation. The consumption is slowly but steadily increasing, a considerable portion of the increase taking place in the Viborg district, where it was least expected, largely due no doubt to the opening of a new and substantial permanent iron and granite bridge across the river at the end of the Litania Prospect, thus bringing this quarter into close connection with the principal parts of the city, and thereby greatly promoting building operations in the district.

In these circumstances the original proposal of connecting the Old Petersburg station (where the consumption is comparatively small and not greatly increasing) with the Viborg mains, by a pipe laid across the branch of the Neva, as shown on diagram, may possibly be revived; but the great width and depth of the river, which at this point is upwards of 1000 feet wide and 20 feet deep, and the difficulty and risk of constructing a cofferdam there, which is the only certain way of doing the work, will, I am afraid, prevent it from being carried out.

Altogether the future prosperity of the New Water Company is very promising, and although it may take a time to educate the inhabitants to a liberal use, both personal and domestic, of this very essential element of health, it will ultimately work its way with every household, and although a very cursory glance at the average Russian *mujik* is sufficient to show that he is not by any means extravagant in its use, still as it is a part of his religion to bathe regularly at stated periods, his education though slow will no doubt be sure.

Having thus somewhat fully described the works of the New Water Company, which have now been in operation about four years, and which may be said to be still in its infancy, it may not be uninteresting to the members to state, as briefly as possible, a few of the leading facts connected with the works of the St. Petersburg Water Company, which as has been before stated, supply the main part of the city south of the Neva, and which are now of very considerable extent.

About four years ago this company very largely extended its mains, laying down something like 50 miles of additional piping, and increasing its pumping power by the addition of three pumping engines of 100 horse power each, with the necessary boilers. These engines were constructed by Messrs John Cockeril & Co., of Seraing, Belgium, whose tender it may be worth noting, was in this instance about 40 per cent. under the lowest English offer.

The contract for providing, laying, and jointing the pipes, and the greater part of the rest of the work was secured by R. Laidlaw & Son, and in the carrying out of which some rather curious experience was gained.

The pumping station is placed about three miles higher up the river than the works of the New Company on the Wassili-Ostroff, and before the river breaks up into its several branches. The engine-house is situated about 300 yards from the river, and at the end of a short canal, which was constructed for Catherine the Great, and was used for the gondolas and pleasure boats of that famous Empress, but is now given over to the possession and purposes of the Water Company.

One part of our contract was to lay and joint two lines of 36 inch inlet pipes, from a short distance out into the river, up the bed of this canal, and connect them with the straining wells and suction pipes of the pumps. To accomplish this, the canal, in which there was a depth of about 7 feet of water, had of course to be pumped dry; and the pipes having been got in and jointed, after great difficulty in piling, and digging a trench in the soft material composing the bottom, a temporary dam was thrown across the upper end of the canal, and over the pipes; and, to save pumping night and day with the steam centrifugal pumps, the water was allowed to gather over the pipes in the portion thus completed, the steam pump having been removed to keep the upper end of the pipes dry, to enable the connections to be made. It may be imagined, therefore, what was the surprise of the workmen, who, on coming one morning to commence work, saw what appeared to them to be some long sea serpent in the canal, but which turned out to be neither more nor less than these two lines of 36″ pipes floating on the surface of the water; and it was with no little difficulty that they were convinced of this, or that something like a miracle had not taken place. Even some of the local engineers—who in justice, it must be remembered, have not so much practice as many of our marine friends here in calculating displacements—could hardly be convinced that the pipes were really afloat. A very simple calculation, however, served to show that each 12 feet length of pipe, which weighed 32 cwt., had a floating capacity or displacement of about 58 cwt., or 26 cwt. above the dead weight of the pipe; and the water, acting on the long line of pipes, which were empty, raised them to the surface, the joints yielding sufficiently to allow of this. Fortunately, as the water was not very high in the canal, the joints were not much strained, and the matter was easily cured by admitting the water into the inside of the pipes, when they quietly settled down into their former position. These inlet pipes being simply conduits, and always full of water, will have no opportunity of repeating the escapade again.

One of the greatest difficulties that we encountered in the course of our operations, was the laying and jointing of several miles of 30 inch and 24 inch pipes in the vicinity of the pumping station. The substratum of this district, in certain parts at all events, is peculiarly soft, as on cutting through about 4 feet of crust, the remaining portion of the 7 feet depth of trench was found to be simply a species of thin mud, which would neither pump nor shovel, and had to be got out by hand buckets; but as it came in from the sides and rose up in the bottom almost as fast as it was taken out, it soon undermined the hard crust, and it was not unusual to see large portions of the street, almost from side to side, collapse or sink down to a very considerable extent. The great difficulty was of course with the joint holes, every one of which had to be closely sheet-piled on both sides, before a joint could be got sufficiently dry to be run up. The process was a very slow one, for although there were three or four gangs, with from seventy to eighty men in each, not more than one or two pipes were put in daily by each gang, clearly showing that the work could not possibly be finished at that rate in one season, or in the time allowed. In these circumstances, and as necessity is the mother of invention, I decided on having a number of portable cofferdams constructed, of $\frac{3}{16}''$ sheet iron. Each dam or box was about 6 feet × 3 feet × 8 or 9 feet deep, open on one side and on the top and bottom, and stiffened by gusset stays and angle-irons at the top; one of these was inserted on each side of the faucet, the sharp edge of the plates sinking readily into the soft ground, so that with a few strokes of the mallet they were got down into position; the box being close and tight prevented the mud from coming in, and the joint was easily got ready for running up. The boxes were easily drawn by the pipe winch, and shifted to the next joint, the result being that each gang could now put in with comparative ease from eight to ten pipes per day.

There is one other point only that I wish to refer to—namely, the canal crossings, of which there are 34 in all in this Company's system, 11 being in our contract. Some of these are of considerable extent, such as those under the Foutanka Canal, which is over 100 feet wide and 7 feet deep. The main is carried under this canal by a syphon formed of 18 inch spigot and faucet pipes having ordinary lead and yarn joints. The crossings are generally made in winter, when the thick coating of ice forms an excellent platform to work from. The pipes are jointed up on the ice, on a cradle formed of planks of wood, and with a double bend at each end, to bring the mouth of the syphon above the surface of the water. The quay walls of the canals are lighter than the main quays, and more easily removed, and the ice having been cut across from side to side, and a trench dredged in the bottom by the bag and spoon, the cradle with the syphon is lifted by four or five crab winches, and steadily lowered into the bed of the canal; the bends are then connected to the mains on the bank, a valve being placed at each end of the syphon; and the water being applied, and a gauge put on with the valves shut, the pressure was found in each case to remain for a considerable time, proving that the syphons or the joints had received no damage in the process.

In conclusion, I have much pleasure in adding briefly a few interesting particulars, which have been very kindly furnished to me by Mr Michael Altouhoff, the very able resident engineer of the Company, and whom I have had much satisfaction in proposing as a member of this Institution to night.

The Company was started and the works commenced in the year 1859, and the water was first supplied to the city in 1863. The principal feature of the works is a large octagon brick tower, 154 feet high, and 56 feet across the octagon; on the top of this tower is a water tank, of a capacity equal to about half-an-hour's supply; and inside this tower the four vertical pumping engines made by James Aitken & Co. are erected. The tower took three years to build, and cost 400,000 roubles. or over £60,000.

There are 9 pumping engines in all, 4 vertical and 5 horizontal, and are each capable of pumping the following quantities per second —viz., 2 engines pump each 4½ cubic feet per second, 2 do. 4¼ cubic feet, 2, 5¾ cubic feet, and 3, 6½ cubic feet per second; the average quantity of water pumped daily being about 5,000,000 *vedros*, or about 13½ millions gallons, being at the rate of 27 gallons per head per day of the inhabitants. There are 18 boilers which supply these engines with steam, the fuel used being either wood or coal, as economy dictates.

The average pressure of water in the city mains is from 40 to 55 pounds per square inch, and the loss of pressure from friction in the pipes at a considerable distance from the tower is about 20 lbs.

The Company has 210 *versts*, or 140 miles, of main pipes, from 30 inches diameter to 2½ inches. The number of inhabitants within the area of supply is about 500,000, and the number of houses supplied is nearly 3500. One-third of the houses are supplied by meter, and two-thirds by agreement.

The greatest number of inhabitants in any one house or *dom* (except the far-famed Winter Palace) is 3000, and the average may be taken at 150.

The water is paid for by meter or by agreement, as follows:— For shareholders, 7 *copecks* per 100 *vedros*—equal to 9½d per 1000 gallons; for non-shareholders, 12½ per cent. more. If by agreement, the annual charges are 24 *copecks* per square *sajene* of floorage of dwelling houses if the water is into the house—equal to 9d for 49 square feet; if the water is only in the yard, the price charged is 19 *copecks* per square *sajene*, or rather over 7d for 49 square feet.

There is also a charge, for each water closet, of 2 *roubles* 70 *copecks*, or 8s 6d; and the same charge for each bath; and half this charge, or 4s 3d, for each horse.

There are 1100 fire hydrants, all of the kind known as ball hydrants, and fixed as shown on Plate XVIII.; the mean distance between the hydrants is 230 yards.

There are 9 fire towers in this part of the city, from the top of each of which watch is constantly kept.

The capital of the Company is 1,500,000 *roubles*, or £235,000, in 15,000 shares; and obligations or bonds to the extent of 3,000,000 *roubles*, or £470,000, bearing interest at 5 per cent.

The average dividend paid to shareholders is 11½ per cent.

The total capital of the Company, including obligations, is fully £700,000.

The discussion of this paper took place on the 18th May, 1880.

Mr James M. Gale said the Messrs Laidlaw had executed the new water works at St. Petersburg under some very great difficulties. From its northern climate, the season for outdoor work was excessively short; and then the nature of the subsoil in which they had to work was such that it could neither be removed by shovel, nor pumped out. He was of opinion that the expedients adopted by Mr Thomson, in order to get the joints made, were very good. It must have been very alarming to have half a street falling in when making joints at a depth of six or eight feet below the surface. He could not understand how Peter the Great chose such a spot for his capital, and why he had not gone a few miles further up the Neva for a site, where he probably would have got firmer ground for it to stand upon. He rather liked the pumping engines that were illustrated in the drawings. They were single cylinder engines, uncoupled, and could be worked independently of each other. They were placed horizontally, and they had been so put down because of the soft running mud under them, in order to spread the weight of the engine over as large an area as possible. The same difficulty had presented itself to him when erecting pumping engines on a bed of mud, some 30 feet or 35 feet thick, near the Clyde, above Glasgow. This bed, which was covered with a hard crust, came in at the level of high water or thereabout, and extended all over the upper part of the banks of the Clyde for some miles above the Albert Bridge. In addition to the difficulty the mud offered, he had likewise to contend with the fact that there had been two or three seams of coal worked out under it by the late Mr Harvey, who was proprietor of the lands. Following the same train of reasoning adopted by Mr Thomson, he had decided that the engines should be horizontal, although he was of opinion that under other circumstances they should have been the ordinary kind, the peculiarity of the subsoil being sufficient reason for adopting that class of engine. Their West-thorn engines were coupled, because it was intended that if ever they supplied the full quantity of water that might be required, they would need five engines, and those two would form an instalment of that number. Mr Thomson, however, had designed two engines, which were quite distinct, the one being able to be worked while the other was at rest. There was a variety of matters in the paper deserving of consideration, although he was not prepared with remarks upon them. In particular, Mr Thomson had fully detailed in his paper the manner in which he dealt with the pipes which were put under rivers and canals in St. Petersburg, he had shown considerable invention in his grappling with the extreme severity of the climate, and had told them how he got upon those rivers and canals when they were frozen to a depth of three or four feet, how he used the ice as a platform, from which he lowered his pipes to the bed of the river; thus utilising naturally adverse circumstances, and turning them into facilities to lay the pipes. Mr Thomson had drawn attention to a joint which was shown by Fig. 1, Plate XX., but came to the conclusion that it was not possible to make a real flexible joint under water. He (Mr Gale) had also come to that conclusion having had to execute a similar piece of work; and therefore he thought the right thing would be to have a pipe which would be very nearly rigid. As a suction

33

pipe it might do, or as a simple conduit, as had been done in some places, and if there was a little leakage, it would not be of much consequence. He thought they were all very much indebted to Mr Thomson for the care with which his paper had been prepared and presented to them.

Mr R. BRUCE BELL could not but admire the carrying out of such an important work. He had been "mudlarking" all his life, and he must say that mud was the most troublesome enemy the engineer had to contend with. Neither rock nor sand nor gravel was to be feared like mud, so that the work of laying water pipes on mud was a matter of no small difficulty. In reference to the facilities afforded by the frozen surface of water to carry out engineering works in winter, he had had experience of this in Russia, when constructing a large repairing dock in the Winterhaven of Riga, at the mouth of the Dwina, some years ago, the whole of the surveys and soundings for which were made in the winter upon the ice. The soundings were taken by boring holes in the ice, through which the sounding poles were lowered. The piling was all carried out upon the ice, which served as a natural platform upon which the piling machines were set, and the piles driven through the holes opened out for them, the thickness of ice being from three to four feet. He understood Mr Thomson to say that he thought this was the first case of water works pumping direct to higher parts of a town, without having a supply reservoir; but he knew of two previous instances—the Monte Videan Water Works, and the Ottawa Water Works. In the case of the Monte Video Works, he had been consulted by the late Mr Proudfoot as to the safety of this, and gave his opinion that with a proper hydraulic safety valve, in case of a burst to take off the shock and to put on the strain on a weighted valve, they could carry out their works very well without a reservoir. He would like to ask Mr Thomson if there was no valve in the St. Petersburg works to shut the connection and take off the water in case of a burst?

Mr JAMES M. GALE said the valve referred to by Mr Thomson was not a safety valve simply. He thought the manner in which that valve worked was such that a piston moved as the pressure decreased, and that controlled a throttle valve, and so the strokes of the engine were reduced to a very few per hour during the dead hours of the night. It was a very nice contrivance for the purpose. The only difficulty would be that it might get out of order, and the consequences might be rather serious. Another thing that had occurred to him was that the engines that that valve controlled could not be working with any great amount of economy of fuel.

Mr Ralph Moore said he remembered that Mr M'Kean had pointed out to him one of the engines that stood when the water had got so great. He mentioned that a brother of his in San Francisco had constructed many miles of water pipes there without having a delivery into any reservoir. The pipes did not carry beyond 1000 feet of pressure, although they were led over wonderful depths and heights. There was very little metal in them, the 4 feet pipes being only sheet iron three-sixteenths thick. He believed they sent a lot of saw-dust down with the first water to fill up the joints.

Mr Gale said that the greater part of the Glasgow Water Works engines pumped into reservoirs.

Mr Charles Bell, of Glasgow, and formerly of St. Petersburg, said he could corroborate what had been stated with reference to the admirable character of the water works erected in St. Petersburg by the Messrs Laidlaw, and also with regard to the difficulties with which they had to contend. He had often seen the men working in the streets, and observed that they could not get more than three feet of their pipes laid without their excavations being filled up with water. He corroborated the fact of their working during the winter season, with the ice upon the rivers and canals, of which they made a very grand natural platform, and which could not have been available unless in winter. The pipes had now been laid down some years, and only in the first early spring there had been a little annoyance from leakage, yet this was inconsiderable when it was remembered the great disadvantages under which the pipes were laid owing to the muddy subsoil. The engines were most admirable pieces of workmanship, and much admired by the inhabitants of St. Petersburg, and he had paid them a visit to see how splendidly they worked, and was very much pleased with the condition in which this monument to the energy and skill of the Messrs Laidlaw had been erected. Of course, as stated in the paper, there were three pumping stations —on Williams Island, the Citadel Island, and on the mainland. There they had a very much better footing; but on the Wassili-Ostroff, or island surrounded by water, they could not go down more than three or four feet without being flooded. Those works had made an entire revolution in the mode of supplying water to the inhabitants of St. Petersburg, and in consequence of the water being conveyed through those pipes, as it now was, some thousands of men had been deprived of their work of carrying water in small buckets on their backs up four, five, and even six flights of stairs, so that when they saw a few of the pipes leaking it led to a certain amount of rejoicing amongst them, as they imagined that they would soon get back their usual work! In that, however, they had been grievously disappointed.

Mr C. C. Lindsay said that the laying of pipes under water without cofferdams was attended with many difficulties, one of the greatest being the joint, which must be flexible and tight. The method of jointing and laying adopted for the Wassili-Ostroff suction pipe was very simple and effective. In the case of submerged pipes subject to pressure, where absolute tightness was a necessity, he considered that it was desirable to have a joint which would be rendered tight by the water-pressure, and described a joint, illustrated by a sketch (Fig. 2, Plate XX.), which he thought might in many cases answer the purpose. Differing from other water joints—which had the axis of the joint coincident with the centre of the pipe, and which could not be turned through a large angle—this joint had its axis at right angles to the centre of the pipe and was capable of being turned through any angle in the plane of the joint. It consisted of a junction formed by a brass ring (in halves) bolted to a flanged bend on the end of a pipe length, and enclosing the end of a bend on the other pipe length; the watertight brass and iron bearings being angular and turned so that the pressure would cause the faces to bear hard against one another. A somewhat similar joint had been used for steam pipes by the Messrs Wöhrmann of Riga. In some cases the loss of head caused by friction at the bends might be objectionable. He thought the joint might be used in many cases for submerged pipes subject to pressure, as the pipes could be laid without cofferdams, and the joint was flexible through a large angle, possessed great facility for jointing and laying, and would be perfectly watertight under pressure. Mr Thomson had described the invention of his regulator very modestly; but, there could be no doubt that it was a mechanical refinement of great merit, and it was by such inventions that the steam engine and machinery generally had attained their present state of economy and efficiency. No better test of its value could be made than by comparing it with the gigantic and costly brick water tower of the old St. Petersburg Water Works, seeing that each were intended to serve almost the same purpose. Taken altogether, he thought Mr Thomson's paper a valuable addition to the Transactions of the Institution.

Mr John Thomson said, the site of St. Petersburg being quite level, there was no elevated ground in the vicinity on which a reservoir could be placed, the necessary pressure had therefore to be obtained, either by means of a water tower and tank, as at the works of the St. Petersburg Water Company, or by a stand pipe and tower as was at first proposed for the stations of the St. Petersburg New Water Works, or by pumping direct into the mains, through a pressure air vessel, as described. He knew of some water works where the water was pumped direct into the mains, the supply pipes being filled from the rising main, but in each case there was an escape through an open stand pipe, or an overflow for the surplus water into a reservoir. In the St. Petersburg New Water Works, the only outlet for the surplus water was through the loaded valves AA (Plate XIX) placed between the suction air vessel B and the pressure air vessels PP, the speed of the engines and delivery of the pumps being regulated as nearly as possible to the consumption of water at any hour of the day, by the action of the regulating valve (Fig. 3, Plate XX.) This valve, which is acted on by pressure from the mains, through the small accumulator was also a perfect safety valve, as, should a burst take place by which the pressure in the mains was reduced, the valve instantly fell and shut off the steam at once, preventing "racing" of the engines or shock of any kind. In starting the engines at first, the escape valves between the air vessels were not fixed, and there not being sufficient outlet for the water pumped, the pressure rose in the pipes and lifted the valve, shutting off the steam on the opposite side and stopped the engines, the valve being arranged so that it shuts off the steam, when the pressure in the mains gets too high, or when it disappears altogether. Should the air vessel burst, as he had seen occur in other water works, the pressure was gone and the valve dropped and shut off the steam, so that it was a thorough regulator in every way. In this case the consumption of water was very little at the first, and therefore they had provided those loaded valves between the suction and pressure air vessels. These were 8-inch spring-loaded valves, and they rose when more water was being pumped than was being drawn off by the consumption in the town, and allowed the water to pass back again into the suction air vessel. It was really the large air vessel that acted as a cushion and kept the pressure steady in the mains. At first they kept the scour valves open in different parts of the system, but latterly they were entirely shut, so that the only escape was through the loaded valves. The index of the pressure gauge was perfectly steady, not more than a pound of variation of pressure being indicated at any time. These valves, with the steam regulating valve, served the purpose of the weighted valve referred to by Mr Bruce Bell. The peculiarity in this case was, that the whole area of supply being perfectly level, no outlet into a reservoir could be provided, so that the pressure in the mains was equal throughout the whole system, and in this respect he understood it differed from Monte Video. Since these engines were erected he had seen notices in the engineering journals of water works where somewhat similar arrangements for regulating the speed of the engines were adopted, but they all had some outlet or escape into a reservoir. At first they feared there would be a considerable accumulation of air in the mains, but on trying the fire hose, even at the extreme end of the system, it discharged a perfectly steady jet of water from the nozzle, which was a pretty good test, and showed that there was not much air in the pipes. The highest houses in the district were perfectly supplied with water, and had a steady constant pressure day and night. If a fire took place and water was freely drawn, the pressure fell and the engines simply moved a little faster. The whole arrangements had worked very satisfactorily since they started, and were, he believed, peculiar in that they had no outlet either by stand pipe, tank, or reservoir. He quite agreed with Mr Gale that engines regulated by a valve in this manner would not be very economical in working, that is, if they depended wholly on the regulating valve, but as the consumption of water during the different periods of the day and night was pretty regular, the engineer in charge had no difficulty in setting the expansion valve to the cut off necessary for the average speed required. The function of the regulating valve in ordinary circumstances was simply to correct slight variation in the pressure that might occur through any irregularity in the consumption. He was sorry they had not yet had an opportunity of testing the engines fully in regard to their economical working, as hitherto the consumption of water had been comparatively small in proportion to the pumping power; the engines had therefore to be driven very slow, and the steam had to be cut off at an unusually high grade of expansion, the maximum speed hitherto having been from twelve to thirteen revolutions per minute and the cut-off from an eighth to a tenth of the stroke; even at this speed, however, the returns of the duty obtained were very fair, showing clearly, in his opinion, that with a more favourable speed and a fuller development of power the duty performed would be very good. He rather liked the flexible joint referred to by Mr Lindsay; it was a purely metallic joint depending on the internal pressure to keep it tight, and it could be turned through a large angle, and might therefore be used in positions where joints with their axis coincident with the centre of the pipe was not admissible, but it was not suitable for a straight length of main, and the sharp angles of the bends were objectionable. He thought it could not be relied on for a submerged water main under pressure, as the metal surfaces could not easily be made tight, especially in joints of large diameter, and he was quite satisfied that the pressure within would not keep the faces together or the joint tight if there was the least twist in the pipe, or any unevenness or irregularity in the bed on which it was laid. He therefore adhered to the conclusion he had arrived at, that the joints of a submerged water main, to be thoroughly reliable must be very nearly rigid, and should be made without any perishable packing whatever, in which opinion he was glad to be supported by a gentleman of so great experience as Mr Gale, and who had recently executed an extensive work of this kind in carrying a large water main across the bed of the Clyde in a most substantial and satisfactory manner. He was glad they had a gentleman present who had been long resident in St. Petersburg and was well acquainted with the nature of the ground and the difficulties they had to contend with in carrying out their contract there. He referred to Mr Charles Bell, who had borne testimony to the substantial nature of the New Water Works, especially of the pumping engines and of the favourable opinion entertained of them by the inhabitants. He was much gratified by Mr Bell's remarks, as being thoroughly acquainted with the place and people Mr Bell was well qualified to speak on the subject. He omitted to mention in the paper that the capital of the St. Petersburg New Water Works Company was £200,000 in 10,000 shares of £20 each, and about £110,000 in debenture bonds bearing interest at 6 per cent. Assuming that one-third (or say 250,000) of the population of St. Petersburg was resident within the area of supply of this company, the capital expenditure was thus 25s per head of the inhabitants. The number of inhabitants resident within the area of supply of the St.

Petersburg Water Company on the south or great side of the Neva, was about 500,000, and the capital expenditure was therefore a little over 28s per head in that district of the city.

Mr R. B. BELL said that in the Ottawa Water Works any extra water flowed back into the aqueduct again. They had an unlimited supply of water, and the work was done by turbines driven by the Falls above the town, from which there was a special canal to feed them. They had no stand-pipe.

Mr THOMSON said that if the engines were working at full power he had no doubt that the regulating valve would preserve the pressure and the speed of the engines in proportion to the draw of water. When the engines are working in full power he believed the regulating valve would work with perfect delicacy; even now without escape valve the pressure was quite steady.

The PRESIDENT, in moving a cordial vote of thanks to Mr Thomson for his paper, said the paper contained very valuable information for the hydraulic engineer, and would be most serviceable to any of them whose lot it might be to construct such works.

On Patent Fuel Feeders.

By Mr WILLIAM CLAPPERTON.

Received and Read 20th April, 1880.

(SEE PLATES XXI. AND XXII.)

In the session of 1873-74, I read a paper on the economy of making coke, which is detailed in Vol. XVII. of the Institution's "Transactions," thinking I thereby would induce our coke makers here to adopt the economical system pursued by their competitors on the Continent; but, so far as I am aware, the Continental system has not been adopted in this country, except at Shorncliffe, near Sheffield. Whether the process is still carried on there, I am unable to say.

What I propose bringing before the notice of the members to-night is on a cognate subject—namely, the saving of fuel, as illustrated by the various methods in which it is introduced into or under boilers, but more especially descriptive of Mr M'Millan's patent for that purpose.

While in the course of my remarks I will have to refer to several mechanical fuel feeders, I wish to do so in such a way as to preclude, as far as possible, any discussion on the comparative merits of the different systems I may refer to, as my feeling has been that, as an Institution, we cannot legitimately sit as judges on competing systems. At the same time, I admit, the criticism of anything contained in the paper is open to all.

I think I can truly hazard the remark, that till very lately all the fuel feeders brought before the public have had the green fuel introduced in by the ordinary furnace door, or some door equivalent, each patentee using the machinery he considered best to accomplish the end he had in view.

The first apparatus I saw was at Hogarth's cotton mill in Aberdeen, in the year 1838—this was for coal feeding; and the last, till very recently, was at Guinness' brewery in Dublin, for peat feeding. Both, however, were fired at the front of furnace door, to which the special appliances of each maker were fixed.

What I take as the desideratum to be aimed at is this—such a thorough combustion of the fuel and its gases, that the maximum of heat is evolved in the furnace, and the minimum of smoke emitted from the chimney. This has in some measure been obtained by specially made boilers, and careful alternate firing; but so much depended on the fireman, that the results aimed at, though attainable, were not got very often.

Of various systems of fuel feeders, I may mention those of Jukes by Whitworth, Smith's, Dillwyn Smith's, Haworth & Horsfall's, Sinclair's, Auld's, Frisby's, and the one under more immediate review to-night—M'Millan's. With the exception of Frisby's and M'Millan's, in all the other systems named the fuel is admitted by the ordinary furnace door or its equivalent; and although every precaution is taken to keep the atmospheric air from passing in with the fuel, it is not always successful.

Nearly all the systems have contrivances more or less elaborate for working the fuel from the front to back end of furnace bars, where the partially burnt coal falls down into a space before the bridge, and when consumed so far as the system will allow, is drawn out to the front, through a door in the brickwork under back end of bars. Some of these apparatus are so contrived, that if anything goes wrong with the gearing, the firing can be continued in the old ordinary way. It is a great drawback if this is otherwise. Then again, in all these systems, small dross is required to be used, as uniform as possible. In Dillwyn Smith's, and other stokers on a similar principle, the coal is broken or ground in the hoppers over the furnace mouth.

In Frisby's and M'Millan's systems, the process of supplying the fuel is different from all the others mentioned, inasmuch as the fuel is put into the fire from below, and through a space provided in the grate bars, each fresh charge displacing and pushing up the one immediately preceding it, allowing the green coal to partially coke, during which process the gases find their way up through the live coal and are thoroughly ignited. It will therefore be apparent that, the combustion being slow, a greater saving in fuel is the result than from the other systems.

Frisby's plan differs from that of M'Millan by having the grate bars fixed in a circular plate similar to a railway turntable, this plate being capable of being turned round, so as to bring the different sections of bars more under the influence of the draught; but, owing to its form, it can only be used *under* a boiler, not in flues of Cornish boilers, as M'Millan's can. Both plans, however, have this decided dvantage, that they do not require the coal broken or ground to any particular size.

I shall now endeavour to describe more minutely the merits of M'Millan's system of patent fuel feeder, which is shown in Figs. 1 & 2, Plate XXI., the feeder for which is represented as applied to a common boiler, having the fire underneath it, shown in plan, side and end elevations, the feeding apparatus being self-acting. In plan and side elevation the box A, containing the green coal, is shown on outside of boiler, ready to receive its charge, while the space provided, B, in grate bars, is closed at bottom by the plate C, thus preventing the fuel from falling down. The gearing for moving the box and plate is shown at D, but is better seen and will be more fully explained when we come to Plate XXII., where it is shown on a larger scale.

Connected with the plate C is a lever E, having a projecting catch F which enters into a slot G in box A. The working of the apparatus is as follows. After box A has received its charge the apparatus is put in motion and the box is moved in under the bars, the catch F entering into slot G, so that both box and plate goes in until the box A comes exactly under the opening B in grate bars, then the loose bottom of A is raised by the self-acting gearing, forcing the green coal up underneath and amongst the live coal already in the furnace, after which the box is withdrawn, bringing plate C with it until lever E touches a projection, thus relieving the catch F when the plate remains to support the coal in the furnace till box A returns and the operation is repeated.

Figs. 1 & 2, Plate XXII., are drawings of a similar apparatus applied to a furnace for the revivification of animal charcoal, the motive power being by hand. As similar letters refer to similar parts, they require little explanation. I would, however, just remark, that in such a narrow furnace Frisby's apparatus could not be used at all, thus showing the greater adaptability of M'Millan's for general purposes. I may mention that in the first one tried in Greenock the requisite heat was got up in four hours against seven by the old mode of firing.

Fig. 5 shows the application to a steamboat boiler of the ordinary hay-stalk type with four furnaces. In this case the place C is made to join between the boxes, consequently moving along with them. The motive power is a pair of small steam engines placed either as shown in drawing or in any other convenient position. By the arrangement shown, while two of the boxes are under the grate bars delivering green coal into the furnaces, the other two are outside getting filled, thus working alternately. Fig. 7 need not be further described than that it shows in one sheet the feeder applied under a still, brewers' coppers, soap boiler, or other similar furnaces. For boilers on board steam boats, as applied under an egg-ended, or in the flues of a Lancashire boiler, and end views of the feeding apparatus. Although this apparatus is shown as working only one boiler, the shafts can be prolonged so that any number of boilers can have their fuel feeding apparatus wrought simultaneously and mechanically. In this case, however, all the boilers would require to have their fronts in a line. Fig. 1, Plate XXII., shows the feeding gearing. The driving is done by belt on three pullies O, working two bevel pinions into a bevel wheel Q, arranged so that as the belt is on either of the outside pulleys the motion is reversed. At end of shaft D[1] there are three spur wheels, two of them having clutches at back, the loose ones being wrought by lever and ball H. The shaft R works the box A in and out; the shaft S works up the loose bottom of A, when it is exactly under opening B in grate bars. The action is accomplished by the bevel wheels T, which bring the action to a stand till A is filled, by a paul falling into a recess U, which being released by throwing the lever H toward the right hand, sets shaft R in motion, thus sending A underneath the boiler. The shaft S is then set in motion, the whole process reversed and repeated. As before mentioned the shafts R and S can be prolonged so as to work any number of boilers with one set of gearing.

In conclusion, so far as I have been able to ascertain, the cost of the other systems named varies from £175, with brick work added, to £100 with brick work also. That of M'Millan's is from £40 to £60 per furnace and no brick work required.

M'Millan's system can be applied to all sizes and description of fire-places, from the smallest fire to the largest furnace, even to kitchen ranges and such like. The matter lies entirely on what can be got out in evaporation from a given quantity of fuel. So far as M'Millan has been able to ascertain up to this time, as the results of the various proofs taken at his own works and elsewhere, he counts on a gain of 20 per cent. in favour of his system over the ordinary mode of firing, and that, combined with its price, I think is worth the attention of the members of this Institute.

The discussion of this paper took place on May 18th, 1880.

The PRESIDENT (Mr Mansel) said that the paper which ought next to engage their attention had a melancholy interest for them all. But the previous day he had read in the newspapers the announcement of the death of the author. Mr Clapperton had been in a failing state of health for some time, and had died suddenly on Saturday afternoon. Under these circumstances, a discussion and expression of opinion on the paper might seem rather out of place;

but as there were other interests involved, if any one had remarks to offer upon the subject of the paper they would be glad to hear them.

Mr W. R. M. THOMSON thought they were all much indebted to Mr Clapperton for bringing this important subject before them, as the feeding of fuel from below to steam boiler and other combustion furnaces had not received the attention it deserved from engineers. He thought this mode of feeding fuel automatically to furnaces up through apertures, from under the grate bars, would engage far more attention, and might yet be the mode of feeding furnaces of the future, thus preventing the necessity for, or opening of large doors, and all the evils attending these and top green firing. Small inspecting and cleaning doors would alone be required in this new mode of feeding furnaces, and perfect combustion of the gaseous, solid, or liquid fuel would be obtained from the more perfect regulation of the feeding in of the fuel and air from below, with a better and undisturbed draught within the furnace.

Mr JOHN MILLER, in response to the President, said he had no special remarks to make on the paper, but if there was any particular part of it that had not been fully explained he would be very glad to answer any question. He might state that the plan advocated in the paper had been applied in several places. It had lately been applied to a char kiln furnace for a Sugar Refinery Company at Greenock with considerable success, and this is one of the worst forms of furnace the apparatus could be applied to, the fire grate being 7 feet 6 inches long by 21½ inches wide. At the beginning it was found that the heat was much too great for the purpose it was applied to, but by reducing the air spaces in the bars they got up a uniform heat throughout the furnace and that with a saving of somewhat like 13 per cent. That was a fortnight ago, and the following week they had saved 16⅔ per cent. of fuel. There were still some little alterations to make for spreading the fuel better over the furnace, and so enable them to do without opening the doors at all, unless in cleaning the fires; and which it was expected would result in a saving of over 20 per cent. of fuel. With furnaces of the ordinary form a saving of 25 per cent. has already been obtained.

Mr JOHN MAYER directed attention to the fact that the late Dr Neil Arnott, some years before his death, devised an exceedingly interesting fire grate, in which he took advantage of this same principle of feeding in the fuel from below. By this means the fuel was always moving up so that the surface of the fire was constantly fresh and devoid of the smoke usually seen in a freshly fed fire. He did not know if the grate had come into common use; but the idea of the paper was a carrying into practice the same principle.

Mr J. M. GALE asked how they got rid of the clinker when feeding from below.

Mr JOHN MILLER answered that they did not entirely get clear of them, but the fuel was not so ready to clinker in that way of feeding, because it was charred in the hopper before being fed up into the body of the fire and broke up more readily. Of course the clinker had to be drawn out in the usual way at the furnace doors in cleaning the fires.

Mr RALPH MOORE said the question of the consumption of smoke was merely a question of boilers. If they fired slow it would prevent smoke. There was no difficulty in that, but if they had few boilers and forced the fires the smoke would not be consumed. He held that the self-feeding furnace was a great improvement, if it did nothing else than ease the hard toil of men. What a lamentable state of matters it was, that they were still firing at furnace doors by manual labour, in an atmosphere of 160°. This would be put an end to if they could get an apparatus like this to work.

Mr R. B. BELL remarked that he thought the Government should turn its attention to the feeding of boiler fires, for by so doing it would promote much good.

The PRESIDENT said that no doubt this system of feeding coal from below was a practical way. If the arrangement advocated in the paper was inexpensive it must have a great future.

The PRESIDENT then formally thanked Mr Miller for his attendance and explanations.

Note received from Messrs J. & J. M'Millan. 2nd June, 1880.

Referring to Mr Clapperton's paper on "Patent Fuel Feeders," in which he particularly calls attention to our patent fuel feeding apparatus, and of which he has given a description of the mechanical working of the apparatus as applied to various furnaces, but as the results are not fully explained we have pleasure in submitting the following particulars respecting the objects aimed at in fixing upon this construction of furnace and mode of firing, with their results.

1st.—Prevention of Smoke.

By feeding the fuel from under the fire-grate into a hopper in the centre of the furuace, raising the red fuel on the surface through which the gases from the green fuel must pass and become ignited, smoke is not allowed to form.

2nd.—Saving in Fuel.

No cold air being admitted into the furnace except through the grate bars where it becomes heated, less fuel is required to create an equal amount of heat in the furnace. And by the system of charring the fuel in the hopper and extracting the gases before it is fed into the centre of the fire, the utmost virtue is secured from the coal and at once made heat-producing. Thus the charred coal, when in its turn by each succeeding charge, comes to the surface of the fire and distributes itself over the bars, the gases passing through it instantly become flame, throwing off an intense heat which freely diffuses itself for the purpose required, there being no green fuel on the surface to protract its course, hence the saving obtained of from 20 per cent. to 25 per cent. of fuel.

3rd.—Durability to Boilers and Furnaces.

The system of admitting cold air at the doors and bridges of furnaces for the purpose of igniting the gases over the fire, has been fraught with disappointments, for while it to a certain extent diminishes the black smoke when attended to by a careful fireman, it is well known that the heat in the furnace is thereby reduced, consequently the same results cannot be attained without consuming a greater amount of fuel. The great object, however, in preventing cold air from entering the furnace is to avoid the contraction of the plates of boilers and other vessels that it comes in contact with, and thereby obviate to a great extent the destruction of property by rents which, perhaps slowly still surely, take place in the metal. The method of firing by this apparatus not only secures a uniform heat in the furnace, but as the greatest heat is always on the surface of the fire where it is best utilised, the furnace bars are comparatively cool, thus securing the durability of the furnaces as well as of boilers and other vessels to which they are applied.

4th.—Command of Heating Power with Easier Labour.

The red fuel being always on the surface of the fire, combustion is complete. The amount of heat required is quite under the control of the fireman, and, determined by the number of feeds he may put into the furnace and the use of the damper. Besides, it has been found that a considerable increase of heating power can be obtained at pleasure over the best hand firing. It will be obvious from the construction of our fuel feeding apparatus that the furnace doors, although always accessible, are kept perfectly close except when cleaning the fires, consequently the stock-room is kept comparatively cool, and the fireman is not subjected to the excessive scorching heats from the open doors; besides, as the clinker does not so readily adhere to the bars and brickwork, the labour in cleaning fires is reduced, as well as that in stoking, one feed of the apparatus being equal to two by hand.

Notwithstanding the dimensions given upon the plates of the size and position of the apertures, they may be varied to suit circumstances.

On the St. Helier's Harbour Works.

By Mr Imrie Bell, M.Inst.C.E., London.

Received 20th April, and Read 27th April, 1880.

(SEE PLATES XXIII., XXIV., AND XXV.)

The port of St. Helier, in the island of Jersey, is situated in the bight of a bay closed by the headlands of Noirmont Point and La Rocque, and, lying on the south side of the island, it is protected from all winds except westerly, from north-west to south-west, during the prevalence of which winds the full swell of the Atlantic comes with all its force into the bay. The existing harbour was designed by the late Mr James Walker, and is a tidal harbour, entirely dry at low water; so that passenger steamers, unless they arrive at a high state of the tide, have to moor outside, and discharge the passengers into small boats in the open bay—a most inconvenient and sometimes dangerous arrangement; and this operation has to be repeated as frequently in embarking to leave the port.

Under these circumstances, the government of the island, called "The States," took into consideration, in the year 1867, the necessity of providing better harbour accommodation. After considerable discussion, it was arranged to advertise in England and France for competitive designs for a harbour, with sheltered berths for vessels drawing 13 feet, lying about during all states of the tide and weather; and the result was that forty-two designs were submitted, which were made over by The States to their harbour committee, with instructions to consider and report upon the whole question.

The committee, after mature deliberation, and investigation of the plans and estimates, during which they called in an independent engineer to aid them in comparing the quantities and prices with the various estimates, finally decided upon awarding the first premium to Sir John Coode, who shortly afterwards received instructions to make the necessary arrangements for carrying out the works; which were ultimately commenced under the superintendence of the author in 1872, from a modified design from the one submitted for competition.

DESCRIPTION OF WORK

The site of the harbour (Fig. 1, Plate XXIII.), is upon a flat shore thickly studded with high rugged rocks, composed principally of hard, close-grained syenite, extending a long distance out to sea, and exposed to the full force of the Atlantic. The height of ordinary spring tides is 32 feet, and extraordinary equinoctial springs 40 feet.

The works consist of two separate arms, situated on either side of the small roads.

The western arm, forming the Hermitage Breakwater, commences from the south curtain of Elizabeth Castle, a fortress built upon a large isolated patch of rocks, distant from the mainland a little over two-thirds of a mile, and is continued over the Crow rock, which is quarried down to level of surface of breakwater, out to the Hermitage rock, which it was decided to leave intact, as this is the rock where the hermit-saint Helier is said to have lived in ancient times, and after whom the town of St. Helier derives its name. The breakwater is carried out from seaward side of the Hermitage rock in a southerly direction, to the Platte rock, where it terminates with an elbow 170 feet long. The total length of the breakwater is 2665 feet, by 36 feet wide at top, with sides battered to 1 in 12; the height at outer end is 60 feet, with 20 feet of water at low water, ordinary spring tides.

The eastern arm, forming the landing pier, with approach, principally for the accommodation of steam vessels, commences from a place named Point de Pas, and is carried in a south-westerly direction for a distance of nearly 1700 feet; it then turns in a west-north-westerly direction for about 1700 feet, finishing with a slight cant of 300 feet, making the total length 3700 feet. The land portion, or approach, is 48 feet wide at the level of the roadway, surmounted by a parapet wall 13 feet 6 inches above high water ordinary spring tides. The roadway of pier is 48 feet in width, provided with a double line of railway, and has besides a raised promenade 17 feet 6 inches wide, protected by a parapet wall on side facing the sea. There are three landing stages, with platforms at levels suitable to the different states of the tide, for the accommodation of steamers, and the convenience of passengers landing and embarking, which are accessible by flights of stairs. A slipway 20 feet wide is also provided for the use of small boats and the landing of cattle; the depth of water varies from 12 to 18 feet at low water, ordinary spring tides.

ESTIMATES.

Sir John Coode, in his original competitive design, estimated that the total cost would be £282,500; but of course that sum cannot be taken in reference to the works as carried out by the decision of the authorities, which plan was very much altered and enlarged from the original design, and by the time the plans were finally arranged and the works commenced the prices of labour and material had increased from 20 to 30 per cent. The actual estimate of the cost of the entire structure, as made out from the working plans by Sir John Coode and the author, at the request of the authorities, showed a total amount of £379,000.

In 1877, a short time previous to the suspension of the works, the author was again instructed to report upon the actual cost of the work completed, and also to make a separate detailed estimate of the cost which the execution of the entire harbour works would entail, the result of which showed the total cost to be £395,899, which sum includes damage done to the works by the sea during the storms of three successive winters, amounting in all to £6800, or about 1¾ per cent. on the estimate, thus leaving excess over original estimate to be about 2½ per cent. These figures were based upon actual cost of work executed, and including engineering plant and all charges; so that had the whole work been allowed to proceed to its termination, it would have been completed for a sum within £400,000, certainly a moderate amount for an undertaking of such magnitude. Sir John Coode, in his report to the Insular Government, recommended them to carry out the remainder of the work in solid concrete masonry, similar to that of the seaward portion of the breakwater, which had resisted the fury of all the storms so successfully; but the extra cost of this prevented the entertainment of the proposal, and unfortunately, owing to party dissensions amongst the members of the States, the party under whose auspices these works were originated being in a minority, and also to financial difficulties, it was decided to proceed no further with the works under their existing form, and to take into consideration the advisability of substituting something of a less expensive description, with the result that, after three years of unprofitable discussion upon all sorts of projects, the works are now standing as they were left in 1877, when the author handed them over to the States.

Situated as these works are, exposed to the full range of the Atlantic, and in a tideway which rises to 30 and 40 feet, the history of works constructed in similar situations would lead one to anticipate great casualties. But the author is happy to have it to record that in the case of the western arm of the breakwater, after the adoption of the plan of building in solid work, no mishap of any kind occurred, and after three years' exposure in their unfinished state, they remain intact as they were left by him in 1877.

But, in the case of the eastern arm, which, having less exposure, was built of a less solid description of work, this arm of the work suffered from the effects of severe storms during three successive winters in the years 1874, 1875, and 1876. The severity of the storms of these years was curiously enough recorded by the sea itself at the opposite end of the island, at the foot of the rock upon which the author constructed the Corbière Lighthouse. The shore between the rock on which the lighthouse stands and the mainland was very rough and rocky, upon which a half-tide causeway was built. At the foot of the rock there was a deep gorge or gulley, and during these storms a large block of rock about two tons in weight was carried by the force of the sea up the gorge and thrown over the causeway. The breaches in the work occurred in every case where the work was unfinished or in an unprotected state. The authorities decided in the summer of 1876 to delay the construction of the landing pier until the Hermitage Breakwater was extended further out. The work at the end of the landing pier was then in two lifts or levels to suit the arrangements for carrying on the work continuously during high and low water. The author received instructions to protect the rubble filling between the longitudinal walls of this unfinished length with a covering of concrete about two feet thick. He objected to carry out these instructions and strenuously urged that he should be allowed to construct the whole of the unfinished portion of the work out to end of foundations already laid up to surface level, and finish the extreme end with a nearly vertical scar end built with solid blocks from wall to wall, similar to what he had previously successfully carried out at the breakwater, but he was overruled, and after a lengthened correspondence he was instructed to protect the rubble filling in the slopes, and on the level between the upper and lower slopes by a concrete skin of from two to three feet thick, which was done.

During the winter gales of the same year the breach occurred at this place, evidently caused by the hydrostatic pressure from the great height of the sea bursting up the concrete skin of slope, and thus gaining an entrance into the space between the longitudinal walls, and the result was that the harbour wall, the weaker of the two, was burst out, the breach extending up to cross wall marked on Plan A (see Fig. 1, Plate XXIII.), about 100 yards, where the fall of the tide prevented further damage being done. On examination it was found that although the cross wall was intact, many of the upper blocks beyond it in the masonry of the harbour wall were forced out, leaving an entrance into the next division or compartment, which would have inevitably allowed another length of wall to be forced out had the tide not receded. This portion of the wall was, previous to the next rise of tide, protected by a breastwork of railway metals, fixed vertically and overlapping one another, bolted and chained to the face of the wall—which acted most successfully in protecting it, and preventing further damage to the work, until the weather moderated and allowed of the wall being built up with masonry.

There appears to be no doubt that the solid section of masonry would ensure the greatest security in carrying out the work, but whether it is the only safe plan that could be adopted is a question worthy of consideration, as it entails a very greatly increased expenditure. The author considered, after careful reflection upon the nature of the breach previously described, that a structure hearted with rubble could be made sufficiently strong to resist the power of the heaviest sea by building it in completely separate compartments, and not carrying out the longitudinal main walls in a continuous length, so that each compartment or division of the structure would be complete in itself, consisting of its four walls of masonry filled in with rubble and protected with a covering of concrete, so that in the event of one of these sections being breached by a storm, the others would remain unaffected; or otherwise, to build the main walls with large blocks without mortar, and and fill up between with dry rubble hearting. Under either of these plans the author was confident that the works could be completed at his estimate. He also proposed an alternative plan, at the request of the Harbour Committee, for building the pier with soiid masonry, on lines modified from the original design, which would have given ample accommodation for the present requirements, yet so arranged that it could be extended when required. This plan, the author felt confident, could be completed at a cost of £450,000, including the amount already expended; but the party in power having determined that the works should be stopped, the proposal was not agreed to.

DESCRIPTION OF CONSTRUCTION.—HERMITAGE BREAKWATER.

The commencement of the Hermitage Breakwater was made in April, 1872, upon a small piece of ground under the castle rock a few feet above high water level, containing only about nine hundred square yards, by the erection of a shed for the storage of cement and blacksmiths' and carpenters' shops which absorbed nearly all the ground available above high water. During the time this was going on blasting operations were begun upon the Crow rock, and between this rock and the Castle rock the breakwater sea wall was lined out and its construction commenced. The rock was roughly quarried into level benches, upon which the mould frames were fixed in position and securely bolted to the rock, when they were filled with concrete and covered over with stout canvas and weighted with railway metals, which were secured with chains lewised into the rock; this was both laborious and costly work, but could not be avoided, as the work in this wall had to be pushed on as quickly as possible in order to have this portion completed above high water level before the winter's rough weather set in, as the protection of the workyard, which was then under way, depended entirely upon it. The reclamation of the foreshore below high water level was at the same time being proceeded with; its superficial area was over 8000 square yards, varying in height from eight to twenty feet, the material being procured from the quarrying of the upper part of the Crow rock, which it was necessary to remove to the leve of the top of the breakwater. The large quantity of stone quarried from this rock was more than sufficient for all the requirements, temporary and permanent, of the work between the Castle and the Hermitage rocks, which included the concrete, masonry, and rubble hearting in the breakwater, the building yard and stacking depot, with the whole of the filling up of reclaimed ground up to eight feet above high water spring tides, and the building of temporary harbour with quays, which was required in order to provide shelter to the vessels arriving with cement, coals, and other materials, and to accelerate their unloading. Upon the completion of these operations the block building floors, stores, offices, and other buildings were gone on with, along with the laying down of railways for general traffic and the foundations for the stone crushing and concrete mixing machinery. The construction of the breakwater from the Crow rock to the Hermitage was the next portion of the main work proceeded with; the space between these rocks, 400 feet in length, was called Hell's Gate from its exposed position and the fury with which the waves rushed through it during any other than very calm weather, and in consequence much anxiety and trouble was experienced in the construction of this section of the work. It was found to be utterly impossible to build the concrete blocks in situ though tried several times, and on some occasions with the loss of the frames which were wrenched from their position and carried bodily away, though they were bolted, chained, and lewised in every possible way. In some instances where the frames remained rigid the water gradually forced itself through some joint, and by the continued action of the sea the whole of the cement and the finer portion of the sand was washed out, and upon the tide receding the frame was found to contain only the broken stone and large shingle, so that the work was necessarily delayed for a short time until the railway could be laid to this point for the transport of the concrete blocks from the building yard on trucks which, on arrival, were lifted off by means of a pair of sheer legs and set in the position required, the legs being moved forward with the progress of the work. This arrangement facilitated the working considerably and enabled the building to be carried on much more rapidly, though occasionally the railway was displaced and the sheer legs thrown down, but this only occurred in exceptionally boisterous weather, and was easily restored when the wind and sea moderated sufficiently to allow of the work being resumed. The breakwater in this section consisted of two longitudinal walls connected together at short distances by cross walls bonded into them, the compartments between were filled in with rubble hearting up to about 11 inches from the top of the masonry in the walls, when the whole was covered over with concrete and finished with a barrel-shaped surface to allow the water to run off. (Plate

XXIII.) The continuation of the breakwater seaward from the Hermitage rock was the point where the real difficulties of the work commenced, owing to the very strong tidal currents in addition to the heavy seas that had to be contended with. The same mode of construction was continued as previously described, but the progress was much slower owing to the power of the sea, which came nearly end on and scoured out the rubble hearting, thus endangering the stability of the side walls; this was partly met by concreting over the hearting in ten feet lifts, but was not entirely satisfactory, and it was determined to build the remainder of the breakwater in solid concrete masonry with the hearting blocks composed of cement concrete in the proportion of 15 to 1, while that of the face blocks was 8 to 1 of cement. The first idea for lifting and setting these blocks was to have a staging carried upon wrought-iron piles, but the author had experienced so much trouble with various experimental appliances, which all proved unsatisfactory in their capability of withstanding the power of the sea, that it appeared to be imperative that whatever plan might ultimately be adopted the lift must be from either the top of the breakwater or from the deck of a pontoon or barge; one plan suggested was to construct large blocks on shore and transport and place them in position by means of floating shears in a manner similar to that adopted and described by Mr B. Stoney, M. Inst. C.E., in his very valuable paper upon harbour and marine works, but this plan, though admirably adapted to the work it was designed for by Mr Stoney, could not possibly have been used on these works, owing to the uncertainty of the sea and the strength of the currents. After mature deliberation and numerous trials with blocks and bags of various sizes of concrete, lowered and set by means of derricks and tipping machines on barges, it was finally decided to construct the foundations with large concrete blocks weighing about 100 tons, lowered into position by means of barges fitted with steam winches, up to a height of six feet three inches above low water ordinary spring tides, and the superstructure from that level up to the top with concrete blocks weighing about 12 tons, to be set in place by an overhanging travelling crane or titan, which for practical purposes may be considered as an improvement upon the combined plans of Messrs Stoney & Parkes, and which acted most successfully up to the time that the works were suspended. The amount of progress being pretty steady at an average rate of one foot lineal of breakwater per day, equal to 85 cubic yards, and in favourable summer weather the work proceeded easily at the rate of 127 cubic yards per day, or 1½ lineal feet, costing nearly £60 per foot including plant and all other charges over whole length of the breakwater, but of course a considerable portion of this was above low water. The cost of the work executed in solid masonary with the height of breakwater at 60 feet, including 20 feet below level of low water, was, including everything, a little over £100 per lineal foot.

WORKYARD AND DEPOT.

It is a matter of vital importance in works such as these, in order to obtain an economical as well as a successful result, that great care and attention should, at the outset, be bestowed in devising a general plan of procedure, and in organizing a proper working system, leaving details to be worked out as circumstances require from time to time, during the progress of the work; and as the material of which this work had to be constructed was nearly entirely concrete, the author, in devising his arrangements, considered that the central point of the system should be the concrete mixer. In deciding upon its position, three important points had to be considered: 1st, that it should be in easy and direct communication with the temporary harbour quay where the materials arrived and were unloaded; 2nd, that its position should be so situated that the railways for conveying the materials should not interfere with those required for conveying the concrete to building floors; 3rd, that it should be adjacent to cement shed and mechanics' shops, in order that its engine power might be used where required, and also where the coal and water supply would be available for all purposes.

The yard and depot being formed upon reclaimed ground, required special arrangements in regard to levels, as it was necessary to have the concrete mixer raised considerably above the level of the building floor for the purpose of conveying and tipping the concrete into the mould frames, and at the same time have it fixed so as to economise to the fullest extent the labour in lifting the material into the mixer, and allow of the gravel and sand being stored below the level of the railways. These difficulties were overcome by adopting the level of the top of the breakwater as the medium level, and determining upon the levels for the machines and branch lines of railways to conform to this level, so that there should only be one lift of all the materials in their required proportions into the concrete mixer.

The main line of railway was formed practically level throughout its entire length, laid to a gauge of 3 feet, which gauge was adhered to in all the lines for the cranes and rolling stock. It commenced (Fig. 1, Plate XXIII.) on quay of temporary harbour at X; a siding branched off to gravel and sand depot, and continued past coal store A, where there was a second siding for cement; it then continued along by stone depot for supply of stone-crushing machine at B, in front of mechanics' shop and stores. and curved round the end of the block building yard, continuing in a straight line and passing between the sea wall of breakwater and the building and stacking floors, at the side of which there was left a platform for tipping the rubble stones to be used in the block building; a crossing fixed a little beyond the Crow rock joined the line again at a short distance beyond the locomotive shed F, thus completing the circle. The straight line continued along the top of the breakwater, with sidings, as shown, out to G, where a line branched off past the buildings in which the diver's rooms and stores were situated down an incline built with rubble and cement mortar to the low water foreshore quarries, where it branched off to suit the situation of the rocks which were being quarried,—the main line continuing in the straight, and lengthened as the work progressed.

CONCRETE BLOCKMAKING.

The materials used were broken stone, shingle, fine gravel, and Portland cement. The stone was quarried from the rocks adjacent to the works, and consisted of a very dense syenite, 13½ feet to the ton, and traversed by broad bands of trap rock. The shingle and gravel were procured from a bay about 5 miles distant, and were brought by barges. The Portland cement was supplied from England by the Burham Co., the Wouldham Co., and Messrs Peters Brothers, under the usual conditions and tests as to quality

The machinery for the stone crushing and concrete mixing was placed in the following order: 1st, one of Blake's patent stone crushers—size of space for reception of stone to be crushed was 15 inches by 9 inches; 2nd, the steam engine for driving the stone crusher; a chain barrel with jib, worked by lever and friction wheels, for lifting the materials up to the hopper of the concrete mixing machine, which was fixed 3rd in the line of order.

The stone quarried above and below high water was divided into three classes:—1st, picked rectangular pieces, which were hammer dressed, for the purpose of placing across the holes left in the concrete blocks for lifting bars, to ensure a solid bearing for the T heads of the bars; 2nd, the large irregular shaped pieces interspersed in the mass concrete blocks--these two classes were taken to the platform above the building floor; 3rd, the smaller pieces of stone were tipped on space in front of stone crusher, and broken into sizes suitable for the concrete mixer. The shingle and fine gravel were unloaded at the quay from the barges into trucks by a portable 2½ ton steam crane, and taken to the store, where they were tipped. The cement was also unloaded in a similar manner from the vessels alongside the quay into waggons, which were then shunted on to the siding at the end of the cement shed, and hauled up by means of a wire rope—passed over a series of guide pulleys, and wound round the cylinder of the concrete mixer—along a line of rails fixed to the wall at back of cement shed, and tipped over and placed in tiers. This operation did not occupy much time, and was carried out after ordinary working hours, when the concrete mixing machine was not in use.

The concrete mixing was pursued in the following manner. The tipping skip, capable of containing a charge of about one-third of a cubic yard of concrete material, was run on a light trolly over an 18-inch gauge railway into the gravel depot, where it was supplied with its regulated quantity of gravel. It was then pushed under the shoot from the stone crusher, where it received its proportion of broken stone, when it was wheeled round the curve, under the main roads, past the shoot of the cement hopper, where the proportion of cement was added, on to position under hoist, whence it was lifted by crane and slewed round exactly over the hopper of the concrete mixer, into which the contents were delivered, and the skip lowered again on to the trolly, taken back to the gravel depot, and the operation repeated. There were two trollies with tipping boxes used, and passed each other half way on a loop in the railway. Upon the reception of the material in the hopper of the mixer, the man in charge immediately turned on the water, which was delivered through a perforated pipe extending across the breadth of the hopper, in a sufficient quantity, regulated by the man's experience. The mass, after being mixed by longitudinal blades fixed upon the shaft, and turned over a series of times in the cylinder, was delivered by a shoot into side-tipping trucks and run upon a line of 18-inch railway, branching out fan shape into three lines corresponding to the three rows of mould frames fixed on the building yard floor, and on the top of which the railways, consisting of short lengths of rails secured to 3-inch planks, were laid. The road was extended along with the frames, as the latter were filled till one row of blocks was completed, the second row was then commenced, and so on. The frames could be removed within two to three days after depositing the concrete, and the blocks themselves lifted and removed on the fifth day. The weight of these blocks varied from 7 to 12 tons each. The blocks were lifted by an overhead steam traveller or Goliath (see Fig. 17, Plate XXIV.). The attachment for lifting them consisted of a sling chain with two T-headed lifting rods, which passed through the blocks. They were carried from building floor to the stacking yard, where they were carefully placed in tiers and numbered, in conformity with the different positions that they were destined to occupy in the permanent work. The details of the mould frames, &c., are shown on Plate XXV.

In reference to the art of concrete block building, the author has been much struck by the want of attention paid to the art of producing a fair and finished surface in the exposed faces of the blocks, as exemplified in many of the large engineering works in course of construction in the metropolis and elsewhere, where the exposed faces of the concrete present a rough, honeycombed appearance, with the marks of the joints of the timber planks forming the moulds in which the blocks have been formed, or the frames inside of which they have been built *in situ*, in place of showing a fair and smooth surface.

The author has given this matter much consideration, and the result of his experience is that in concrete building it is perfectly easy, with a little attention, not only to produce a fair surface, but to form mouldings and panels, and even tracery and ornament, and at the same time make this face work as durable and solid as any part of the block. There are two reasons why little attention has hitherto been paid to this art—one is carelessness or indifference to appearance, the other is that most engineers who have attempted it have done so by rendering or grouting, both most objectionable and dangerous modes of effecting the object; and which, even if successful for a time, is simply veneering, and is subject at any time to decay, the failure generally occurring after wet and frosty weather, which has naturally caused a want of confidence, and stopped a repetition.

The plan which the author has followed, and with complete success and at an inappreciable increase of cost, by which a smooth, uniform, and equal coloured face can be obtained (and if wanted the colour of the blocks might be slightly varied by different coloured sand), and which, both above and below low water, has stood successfully the test of eight years' exposure to frost and heat and storm and rain. This plan is simply to have a smooth planed board for the face of the mould painted previous to commencing the work with a mucilage of soap, and to line inside with a finer concrete or mortar as the work proceeds, so that the mixture placed close to the face boards is carried up with that contained in the body of the block, the whole forming one homogeneous mass, and ensuring that the setting process of the whole mass shall progress simultaneously; and in fact this face, like the skin of cast-iron, is actually the strongest portion of the block

FOUNDATION.

In the first section of the work, the foundation being above low water, there was not any serious obstacle to delay the prosecution of the work. The rock was blasted or quarried to a comparatively level bed; or, where it rose irregularly and approached the vertical, the mould frame was cut and fitted to the shape of the rock, and securely bolted to it, and then filled in with the concrete to the level of the superstructure.

In the foundations below the level of low water, very great difficulty was experienced, more especially between the levels of a few feet above and below low water, owing to the very strong eddies and currents, which varied considerably with the state of the wind and tide. The mode first tried was, after the divers in dresses had been down and cleared the rocks of seaweed, to lower concrete in bags into place by means of skips from barges (see Fig. 3, Plate XXIV.), and from a tipping trolly traversing upon rails laid across the deck of a barge. When the bag inside of the trolly was filled with concrete, the trolly was started with block and tackle to give it a slight impetus, which carried it across the barge, and caused the bag to be tipped over the side of the barge. This latter plan required careful adjustment, as upon the first trial the trolly was very nearly carried over with the bag of concrete. The surface of the bags thus deposited was very irregular, and quite unfit for the reception of the upper work. This was obviated by fixing a frame the entire breadth of the foundation, and 10 feet in length, strengthened and stiffened with railway metals; the sides being about 18 inches deep, formed of 3-inch planks, projecting about one foot below low water, and continued with a crinoline of canvas down under water to the level of surface of the bags of concrete. At each corner sharp-pointed iron uprights were set, formed of pieces of permanent way metals driven down to the required level, to which the sides of frame were firmly secured. The concrete, which had been previously prepared, was then thrown into this frame from barges moored in close proximity, as well as from the shore end, and the whole completed and protected with canvas on top, and weighted with rails and stones, all of which had to be done before the tide rose. This was tolerably satisfactory work in calm weather, but with the slightest sea on it was impracticable, so that this plan proved tedious, and the rate of progress slow and consequently expensive.

After this a trial was made with a larger barge having a well in the centre through which a wrought-iron rectangular box, with folding bottom in two halves, holding a bag of concrete, about 14 tons in weight, was lowered (see Fig. 1, Plate XXIV.); but there was still the disadvantage and loss of time in levelling the surface of bags at or about low water level. During the time that these methods were in operation the author was experimenting upon lifting various sized blocks, by means of the large barge fitted with a staging carrying a double set of three sheaved blocks, with two ordinary winches, by means of which he succeeded in lifting and lowering into position blocks of over 70 tons carried below the barge, the lifting gear passing down through the well, the result of which proved so favourable that Sir John Coode was induced to give up entirely his idea of using staging for the foundations. The special machinery for carrying out the work upon this plan consisted of 1st, for the foundation work, a steam tug constructed by Messrs James Taylor & Co., a steam barge, made upon the works, capable of carrying 250 tons, fitted with powerful steam winches and Napier's patent self-holding brake, made by Messrs Chaplin in Glasgow; a barge for concrete bags, capable of carrying over 200 tons, made on the works 2nd, for the superstructure, a titan, or steam traveller, capable of carrying and placing blocks weighing 18 tons in position, with an overhang of 50 feet. The design was an improvement by

Sir John Coode on one used on the Kurrachee works, designed by Messrs Parkes & Price, Mems. Inst. C.E., which was, as stated by Mr Parkes to the anthor, the first machine of the kind used for such work. Sir John Coode's improvements consisted, first, in making the horizontal jib to radiate, which was an indispensable condition where the breadth of the work was 40 feet; second, in the engine and lowering gear being arranged at the back end of machine, so as to assist in acting as a counterbalance, there being simply a light carriage traversing between the girders forming the horizontal jib which carried the chain with sheave blocks for lifting and carrying the concrete block, instead of the engine and crab having to travel along the jib; third, in the arrangement of the tension bars over head, which allowed of the whole being made of a lighter and consequently less expensive mode of construction. This machine was made by Messrs Stothert & Pitt of Bath, who also constructed the one for Mr Parkes.

This arrangement for the construction of the breakwater was maintained throughout, and there seemed to be nothing further required as the work was carried on continuously without any break or loss of time. The foundation was principally on rock, but where sand or clay was found it was removed by a bag dredge fixed to a barge and worked by steam, aided by divers with siebes dresses, and when the site of the foundation was thoroughly cleared bags of concrete varying in size from 1 to 14 tons were lowered so as to form a comparatively level bed, which was then accurately made up with small broken stone and placed by the divers (Plate XXIII.) for the reception of the large concrete blocks. In order to insure the surface being level throughout, a short piece of railway metal sharpened at one end was driven into the bags of concrete about 20 feet ahead of finished foundation, so as to take a firm hold. A length of rail was then lowered upright down through the well of the barge and fished on to the end of the short piece and securely held in a vertical position and driven down by a light ram from the deck of the barge to the required depth, under the direction of an assistant with a spirit level from the shore. The long rail was then unfished and hauled up on the barge. This operation was repeated at the opposite corner at the same distance from the end of the work, when two long permanent way rails were stretched from end of completed foundation on to head of each of the short lengths on either side, which covered a length of 20 feet of breakwater. This space was then filled in with small stone to the height of the top rails, the surplus being removed by the divers drawing a rail along the tops of the longitudinal rails, leaving a uniform level bed of broken stone varying from 6 to 15 inches in thickness. The steam barge with the concrete block 22 feet × 10 feet × from five to eight feet, suspended from the winches by two 3¾ inch round bars with T heads, was brought into position and moored by four hawsers at bow and stern to chain moorings, two at either end, in plan forming a St. Andrew's cross. The concrete block was then slowly lowered till about three feet above the level of its bed, when it was drawn close against face of block previously laid by two shore lines attached to it, and upon a signal from the divers below that all was right the brake was released and the block settled down on to its bed. Small bags of concrete were then laid along the ends of the blocks to protect and retain the broken stone upon which the blocks rested. This, however, did not prove a satisfactory means of protection, as the perfect adjustment of the bags could not be insured, and it occurred to the author that if a bag of liquid concrete could be placed under the edge of block it would be more effectual, which was tried in the following manner :—A long bolster-shaped bag was loosely filled with concrete and lowered immediately previous to the block and laid by the divers in line of the outside of the block, so as to allow the block to bear upon eight or nine inches of the breadth of the bag, which was a few inches higher than the bed of broken stone, so that when the block was lowered it pressed upon the concrete which, in its soft state, yielded sufficiently to allow of the block bearing firmly upon the bed of broken stone, thus insuring a solid bed and at the same time securing complete protection from the danger of the broken stone being washed from under the ends of the block. This method proved most satisfactory, and was continued throughout the laying of the foundations.

The brake used on board the barge, for lowering the blocks, was Napier's patent. It acted admirably, and instantly arrested the descent of the block, with a very gentle pressure on the lever. These brakes are made either perfectly self-holding, or else aided by the addition of a small weight fixed on the handle when required to support the load.

The large foundation blocks were carried up to a height of 6 feet 3 inches above low water ordinary spring tides, and, of course, were set without mortar. Two blocks, 22 feet long, formed the entire breadth of the foundation of the breakwater, and the number of blocks in height varied according to the depth of water.

The superstructure was built in solid masonry, consisting of concrete blocks varying in weight from 5 to 14 tons each, set in Portland cement mortar by means of the titan or steam traveller (Fig. 2, Plate XXIII.), which, when not at work, was securely fixed in its place in front of the Hermitage rock by means of chains and eyebolts lewised into the rock. Previous to commencing the work of block setting, the titan was travelled out to the end of the finished portion of the breakwater, and blocked up; the truck with concrete block was then run under it, and the little carriage with lifting tackle, traversing on horizontal jib, brought over the block and the hooks attached to the eyes of lifting bars, when the concrete block was slightly raised from the truck and run out to the end of the jib, the extreme overhang of which was 46 feet from top edge of breakwater, and lowered nearly to the level required, when it was slewed round in the direction wanted, and finally set in its bed. In working this machine only two men were employed, one at the engine, where the levers were so arranged that the block to be set could be lifted, traversed in or out, slewed to either side of the breakwater, and lowered into place without the engineman changing his position; the second man at out end of the jib giving the engineman whistle calls for all the different movements.

PROPORTION OF MATERIALS.

The concrete blocks were arranged under three classes, the proportions of the materials varying according to the position that the block was to occupy in the work. No. 1 blocks, from 5 to 14 tons in weight, to be used in the face work, were made in the proportion of eight parts shingle and gravel to one part of Portland cement. They could be lifted from the building floor, and removed and stacked three days after they had been made.

No. 2 blocks, from 5 to 11 tons in weight, to be set in the hearting of superstructure, composed of fifteen parts of shingle and gravel to one part of Portland cement. These blocks could be lifted from the building floor, removed by the Hercules, and stacked six days after they had been made.

No. 3 blocks, from 70 to 100 tons in weight, for setting under low water in the foundation courses, made in the proportion of twelve parts of shingle to one of Portland cement. These required to remain six weeks before they were strong enough to bear lifting and removal from the floor upon which they were made. This floor or platform was submerged each tide, so that each block that was commenced had to be finished and covered over with canvas and weighted with rails and stone before the return of the tide.

No. 1 Block, proportion 8 to 1.

	C.	Q.	LB.				
Machine-broken stones not larger than 2 inches cube,	12	2	16	at 2/3,	£0	1	5
Machine-broken stones not larger than ¼ inch cube,	6	2	24	,, 2/6,	0	0	10
Coarse sand and fine gravel,	6	2	24	,, 3/0,	0	1	0
Rubble stone placed by hand through the mass,	2	0	24	,, 1/4,	0	0	2
Portland cement,	3	1	14	,, 46/,	0	7	9
Labour and superintendence, including water, fuel, &c.,					0	3	3
Cost of concrete block per cubic yard,					£0	14	5
Setting blocks in place, including mortar, water, fuel, &c.,					0	2	10
Total cost of concrete masonry per cubic yard,					£0	17	3

No. 2 Block, proportions 15 to 1.

	C.	Q.	LB.				
Machine-broken stone not larger than 2 inches cube, ...	10	1	2	at 2/3,	£0	1	2
Machine-broken stone not larger than ½ inch cube, ...	9	2	17	„ 2/6,	0	1	3
Coarse sand and fine gravel, . . .	7	0	4	„ 3/0,	0	1	1
Portland cement, ...	1	3	19	„ 46/,	0	4	5
Labour and superintendence, including water, fuel, &c.,					0	3	3
Cost of concrete block per cubic yard, . .					£0	11	2
Setting blocks in place, including mortar, water, fuel, &c.,					0	2	10
Total cost of concrete masonry per cubic yard,					£0	14	0

No. 3 Block, proportion 12 to 1.

	C.	Q.	LB.				
Machine broken stone not larger than 2 inches cube, ...	12	2	16	at 2/3,	£0	1	5
Machine broken stone not larger than ½ inch cube, ...	8	1	16	„ 2/6,	0	1	1
Coarse sand and fine gravel, . . .	6	2	16	„ 3/,	0	1	3
Portland cement, ...	2	1	10	„ 46/,	0	5	2
Labour and superintendence, including water, fuel, &c.,					0	2	6
Cost of concrete block per cubic yard, . .					£0	11	5
Setting blocks in place by barge, including divers, fuel, &c.,					0	1	6
Total cost of concrete masonry under water per cubic yd., .					£0	12	11

The water used in mixing the concrete was fresh, and the quantity used averaged 4½ cubic feet per cubic yard of concrete, the sand and shingle being in a moist state.

EASTERN ARM.

DESCRIPTION OF CONSTRUCTION OF THE LANDING PIER.

The site for the approach to the landing pier, including the work-yard and depot, had partly to be reclaimed from the sea, and the remainder had to be quarried out of the high slope facing the sea, which consisted of rock similar to that at the Hermitage but with broader bands of trap rock running through it. The area of the foreshore reclaimed was upwards of 17,000 superficial yards, protected by a massive sea wall built of rough granite in Portland cement mortar. The two main points which had to be considered in devising the working arrangements were, first, to fix the levels of the platform for the various machines connected with the concrete block making in such manner as to work into each other with the least possible amount of manual labour, having the stores of granite and cement in the immediate vicinity; second, to adjust these heights so as to enable the high level railway, which was of necessity above the level of the machines, to join in with the incline from the quarries to the landing pier. The level of the top of the pier was adopted for the level of the workyard, and the main lines of railway with sidings (Plate XXIII.), commenced from the side of the Victoria Harbour, and passed through the yard, having the block building floor and stacking ground on the one side, and the machine shops and delivery shoots from the concrete mixer and stone crusher on the opposite side; it was then continued on a curve round the approach on to the landing pier, along which it was extended as the work proceeded. For the convenience of access to the platform, a loop high level line was formed up an incline in rear of the machine shops to the level of the top of the stone crushing machines; it then curved into the line leading from the quarries to the main line on to the landing pier. The concrete mixing floor, with sand depot and shoot from cement store, were all on one platform under the stone crushers, which allowed of the stone being delivered through shoots, thereby saving manual labour.

The work was commenced on this side by the removal of the high rocks, by blasting, on the site of the root or shore end of the landing pier, the material being utilised in filling up the sloping foreshore to form the workyard. Along with this the construction of the sea wall, cement shed, and machine shops was proceeded with, and the opening out of quarry at South Hill, which was to supply the whole of the stone for building and hearting required for the pier works. The gradient of the main line from quarry was 1 in 24, with a level bench about the middle to join in to the line from cement shed. The waggons were made side and end tipping, to carry two tons, with heavier ones for the conveyance of the large concrete blocks and heavy pieces of rock for hearting, which were constructed to carry from 10 to 16 tons. The haulage was effected by means of locomotives, and the shunting by horses. The explosives used were Hall's and Harvey's blasting powder and Krebb's lithofracteur. The rock-boring was mainly carried out with the Ingersoll rock drill, which worked most satisfactorily, the work performed being both cheaper and quicker than by hand. The notes from careful observation gave the following results:—Ingersoll drill, working 10 hours per day, bored a hole 2¾ of an inch diameter, and 16 feet deep, at a cost of 1/6 per foot, including percentage for first cost of machine; whilst the result by manual labour for same size of hole, and working for a similar number of hours, was 4 feet 6 inches deep, at a cost of 3/5 per foot. A little difficulty was experienced at the outset in working the drill, which was of the ordinary chisel shape. It frequently jammed in working, especially where the rock was shaken. The author, after trials of various shaped drills, found the most suitable description to be one with cross section at cutting edge of a St. George's cross, or, as it were, two chisels crossing each other vertically; the diameter of the body of the drill being kept parallel for a couple of inches from the cutting edges, which steadied the drill and kept it working in a circular hole, whereas the ordinary chisel-shaped drill would cut gradually into an oval-shaped hole and finally get jammed. The drills were made entirely of steel, and as they decreased in length by wear, they worked in for the shorter lengths of the set.

The stone, when quarried, was separated into heaps, the picked lot being taken to the stone crusher and block-making yard, the remainder, suitable for hearting, being filled into trucks and run down the incline, along the pier, and tipped into position between the side walls.

CONCRETE MIXING.

The concrete mixer was fixed at a level sufficiently high to allow of the concrete being delivered from the shoot into small tipping trollies. On a level with the top of the mixer was placed a platform with lines of railway, 18-inch gauge, led to the delivery shoots of the stone crushers, and to the gravel depot. The latter situated under the high level railway from which the sand and gravel were tipped. The cement was delivered from a shoot fixed close to the receiving hopper of the concrete mixer, the water supply being obtained from a cistern placed above it, so that the whole of the materials required for the concrete were manipulated from this intermediate level; the connection of the lines of rails being made by means of a triangle instead of a turntable, was found to be more economical, both in regard to time and labour. The concrete mixer, with cement and water supply, were at one end of the base line, and the gravel depot at the other end, with the strong crushing machines at the apex.

The process of mixing was as follows. A trolly, made to contain a charge of two-thirds of a cubic yard, with the bottom hinged so as to open in two halves, on which a tubular bottomless measure for the cement was placed upright, was first brought under the shoot of the stone crusher, where it received its proportion of broken stone, after which it was shoved along the rails to the sand depot, where it received its quantum of sand and gravel; and then run over the shoot of the concrete mixer, where the tube was filled with cement and drawn out, leaving its solid core of cement standing up through the broken stone and sand. A cord being pulled by the attendant, which released the bottom of trolly, and the charge was deposited into the hopper of the cylindrical concrete mixer. Water was added from a perforated pipe extending across the top of hopper, and the door of hopper pulled up, and the whole was delivered into the mixer, where it was turned over till the ingredients were all thoroughly incorporated together and discharged into the trucks below. Three men were required for the mixing — one at the crusher, one at the sand depot, and one at the concrete mixer. The quantity made was at the rate of 6 cubic yards per hour.

CONCRETE BLOCK MAKING.

The concrete block making pit was made on a line parallel with the shops and stores. The floor being about 3 feet 8 inches below the level of the yard, to allow the railroads to pass clear over the tops of the frames in which the blocks were made. The stacking floor was placed adjoining and parallel to this pit, separated by a line of railway upon which the blocks were conveyed to the works; and over both floors a Hercules or steam traveller traversed on rails laid on the outside of floors, 60 feet apart. The floor of building pit provided space for three rows of frames for making the concrete blocks. Above the level of the top of the frames was placed a pair of heavy permanent way rails, about 3 inches apart, stretching across the pit every 12 feet, and secured to the side walls, to support a light portable railway, for transporting the small tipping trollies for filling the frames. The railway was formed of light rails, fastened to narrow planks, retained in correct gauge by flat iron bars. The planks were in 12 feet lengths, corresponding to the spaces between the heavy permanent way metals, and were laid over the row of block frames in course of construction at the time. The line of rails from concrete mixer crossed above the building floor at right angles, having three turntables, one in line with each row of blocks, for turning the trolly on to the line where it was required.

The mould frames were in four pieces, each piece forming a side, and were framed together and screwed up tight and placed in position on the building floor. Two holes were left in each block for the purpose of allowing the T-headed lifting bars to pass through the block when it required to be lifted and removed These holes were formed by placing two tapered pieces of wood in the position wanted, equidistant from the centre of the block. The concrete was then tipped into the frame, and on the following day the pieces of wood were withdrawn, leaving holes of similar size in the block. At the delivery end of the concrete mixer a man was stationed, whose duty it was to attend to the delivery of the concrete into the side tipping trollies, which were made to tip on either side, and contained about two-thirds of a cubic yard. When the trolly was filled, he closed the bottom of the mixer by means of a lever, at the same time giving a signal to the man above, who delivered a fresh charge into the mixer, while he pushed the full trolly clear of the siding, and returned with an empty trolly to the mixer, another man taking the trolly with concrete along to the turntable opposite the line of rails required, and thence on to the mould frame, into which the contents were tipped, and the empty trolly returned to the siding again; and so on continuously. After the moulds were filled with concrete, a straight edge was passed over the top, to strike it to a uniform level with the top of the mould frame, and the block was then marked with the date of making. The sides of frame were loosened and removed on the third day. The blocks were lifted after the fifth day by the steam traveller, and piled one above another in the stacking yard, in such a manner that the letters painted on the blocks and divisions where they were stacked corresponded with the plan and stock book, in which the position was noted that they were permanently to occupy in the work, which prevented confusion, and enabled the foreman to assure himself of having a sufficient number of blocks of the letter required stacked in the yard in advance of his setting work.

EASTERN ARM.—BUILDING OF PIER.

The pier consisted of two longitudinal side walls, with cross walls bonded into them at intervals, the interior being filled with granite rubble and quarry rubbish, similar to the manner of work described in the first portion of the breakwater. The work was proceeded with in two lifts, to suit high and low water levels, which allowed of its being carried on full swing, independent of the state of the tide. The lifting and placing of the blocks in position was done by means of sheer legs made with one leg shorter than the other, equal to the height of the course, the long leg being in advance of the block to be set. The side guys from head of sheers were fitted with block and tackle, so that they could be luffed or swung to either side by means of ropes passed down the legs; and the chain for lifting or lowering the blocks passed from the concrete blocks up through a sheave block, attached to the apex of the sheer legs (see Fig. 3, Plate XXV.), and down through a guide block fixed to the foot of sheer leg along to the winch, which was secured to the masonry of the wall and worked by manual labour. The concrete blocks for setting were taken from the stacking yard on trucks capable of carrying 16 tons by a locomotive to the head of the incline, where they were attached to chain of steam winch, and run down the incline opposite the place where they were required, when they were lifted off the trucks and set in position. The railways down these inclines gave a good deal of trouble at first, from the effect of the sea, especially during stormy weather, but this was ultimately overcome by making the road in lengths of a rail each. The rails were rivetted to sleepers composed of short pieces of bridge rails reversed, and the lengths fished together and bolted. The ends of the sleepers were secured in position by chains to side walls of the pier, by bolts lewised into the masonry. This was found to act satisfactorily, and it served the double purpose of securing the railway and at the same time acting as a network which kept the rubble hearting in place between the walls. It was only during exceptional storms that trouble from this arrangement was experienced, when the rails, chains, lewis bolts, and rubble hearting were all carried away to long distances from the pier, and the whole work was delayed for two or three tides. This form of road was easily laid as the work proceeded. The extension was made by joining on a length of rails, and packing them up in lifts of hand laid stones, the space between being made up from stone tipped from side and end tipping waggons.

The foundations were formed in a very similar manner to those described in the first portion of the Hermitage Breakwater. The rock was cleared of seaweed and other impediments, and concrete in situ brought up to a height previously determined upon to suit the various levels of benches for receiving the masonry of the superstructure. The cross walls were formed partly with blocks and partly with concrete in situ, in heights corresponding to that of the rubble hearting, and thoroughly bonded into the masonry of the side walls, and when the work was carried up to the top course the inside rubble hearting was protected from the action of the sea by a covering of concrete from 15 to 18 inches in thickness.

During very calm weather the work was pushed on through the night. A very effectual mode of lighting the foundation work was obtained by the use of a naptha and oil lamp designed by Mr R. Lavender and made by Messrs Milne & Sons, Edinburgh, with some alterations, including a conical reflector which the author found desirable to have made. The power of illumination was such that a newspaper could be easily read on a dark night at sixty yards distance, horizontally from the lamp, and about 20 feet below its level, the steam required for the draught of the lamp was obtained from the boiler of steam hoist used at the top of the incline by a pipe ½ inch diameter, and the cost of the oil consumed was slightly over one penny per hour. The arrangement of the lamp is such that the combustion of mineral oils of a heavy specific gravity produces a very luminous flame by the aid of a draught of air, produced either by steam or a very high chimney; the former is preferable, giving the clearest light with the least smoke. The lantern is practically air tight, except underneath, where the air enters in a way designed so as to cause it to impinge both on the inside and outside of the annular flame. This lamp gives little trouble after the wick is carefully trimmed and lighted, and is well suited for night out-of-door work even during high winds.

The plant and machinery upon these works were of the most approved and hand-labour-saving nature The special plant was made in England, and cost about £10,000. The ordinary plant, which consisted of railway rolling stock, boats, barges, concrete and sand tipping machines, derricks and lifting gear, &c., was designed by the author, and made upon the works.

Mr J. C. Coode, Assoc. Mem Inst. C.E., was the principal assistant engineer, and Mr R. K. Gibson, the accountant and treasurer, with the usual staff of foremen, clerks, and time keepers, &c. The whole of the work from the commencement was carried out under the personal superintendence of the author, without contractors.

The discussion of this paper took place on May 18th, 1880.

Mr R. BRUCE BELL said he had seen the place and witnessed the work, and knew the history of it, which illustrated the great mischief that opposing parties in a State can do when the one in power is bent upon upsetting the arrangements of its predecessors. This great work, after being half completed, was now at a dead stand. The island of Jersey, and the other Channel Islands, had each their own States and their own laws, as was the case with the Isle of Man; and those States could levy taxes and carry out public works upon their own responsibility, so that it was merely a matter of borrowing money, and finding sufficient to pay the interest thereon. Jersey was a very rich island, and, as one instance of its wealth, the value of the annual export of potatoes alone amounted to £300,000, so that it was a great discredit to them to have stopped this useful and necessary work, a work which had been well designed and well carried out. It was a pity that it should have been allowed to stop, after sinking such an amount of money; and which, had it been allowed to go on, would by this time have made St. Helier the best port in the Channel Islands. The sinking of these concrete blocks of 100 tons weight in such an exposed position, in such a tideway, was a daring feat of engineering. The roll of the sea there was severe, not to speak of the tide, which rose from 30 to 40 feet in six hours' time, so that it would at once be seen that there were difficulties of no mean order to contend with. Considering that the work stood out in the open sea, and was raised to a height of 60 feet, in a depth of 10 fathoms water, the cost certainly appeared moderate; for £300 per yard run was only £150 per lineal yard of cope for each wall. He had endeavoured to compare this with the cost of similar works, but found that engineers had been chary in giving costs. The Dover breakwater, 65 feet high, built in 7½ fathoms water, he found was stated in a paper at a discussion in the Institution of Civil Engineers to have cost £1245 per lineal yard of breakwater, or £622 per yard cope. The breadth, however, is 80 feet, or double that of the Jersey work, so that for the same cubic contents the price may be taken at £311 per yard of cope. The Aberdeen breakwater, also built in an exposed ocean, but only 44 feet, or two-thirds of the height, he found was stated to have cost £216 per lineal yard, or £108 per yard of cope. In similar works built without cofferdams in a protected seaway, he had an instance of a work built 14 years since by Mr Miller and himself. The sea pier of the Albert Harbour at Greenock, which was 36 feet in height besides foundations, cost £70 per lineal yard of cope; so that the cost of these Jersey works, taking the comparative contents of exposure, contrasted favourably with works of a similar description, and reflected great credit both upon Sir John Coode, the consulting engineer and designer of the work, and upon the resident engineer who constructed it; and it was to be hoped that the parties in the island would reconcile their differences and set themselves to complete this great undertaking.

Mr James M. Gale said that the invention of Portland cement in its recent application to work of this kind, had given the engineer a new power. A piece of work like this could not have been attempted twenty-five years ago. He believed the first application of this cement in large concrete blocks was by Mr B. Stoney, in connection with harbour works at Dublin. It was used, mixed with sand only, at Port Said, and since that it had been used largely in such works. In this case they had used Portland cement, with sand and broken stones, to form the blocks. The proportions were given, and he thought them very remarkable. It must have taken a great deal of faith to mix thirteen parts of broken stone and sand with one of Portland cement, for some of those large interior blocks. They seem to have done very well, and that at a very small price—not above the tenth of the price of ashlar, and cheaper than most rubble could be quarried.

There were most valuable particulars given of the cost of the concrete blocks — which he thought one of the most valuable parts of the paper—showing the remarkably small price at which this work had been executed. This Portland cement was going to alter very materially some of the larger engineering works for the future. There was a very similar work, described in one of the engineering newspapers, at the Isle of Man, and which he believed was also designed by Sir John Coode, which was carried out in somewhat the same way as this. Looking at one of the diagrams of the pier, he said it appeared to him that Sir John Coode must have been very confident of his outside work when he proposed, in such an exposed situation, to build two walls and pack in loose rubble between; for one of the most destructive forces was a heavy sea striking a wall, where the air, being compressed, would blow the structure to pieces. He had no doubt that the outer wall was practically sea and water-tight, having been so well built with those blocks of concrete. It appeared to him marvellous, for it could not have been done so well with dressed ashlar.

Mr R. BRUCE BELL quite agreed with Mr Gale as to the necessity for extremely careful building outside work when hearted in such a manner. This hearting was evidently the cause of the trouble with that pier. The whole of that pier, so far as it went, was founded at low water. He had seen some very serious cases of walls constructed with open rubble work below and close ashlar work above. They might imagine the effect of a wave 10 feet high rising within such a wall, which would, on falling, leave nothing but air in its place, so that the return wave, as there was nothing to let the air out, burst the whole thing up at once. Mr Bell in his paper mentioned that when the injury took place to the eastern arm in that way, about 100 yards of cross wall were damaged, and that more would have been injured had not the storm given way; and that then he protected it by putting a solid breastwork of railway metals fixed upright against the face of the wall and overlapping one another firmly secured with chains and lewis bolts; and after the weather moderated the wall was built up solid. The reason for putting in these cross walls, he supposed, was to break it up into separate spaces, so that if one happened to be damaged there would be no harm done to the others.

Mr Ralph Moore inquired what was the size of the blocks used at Wick Harbour?

The President believed that some of them were about 120 tons in weight.

Mr R. Bruce Bell said that he understood that the concrete in Wick Harbour had been built *in situ.* The strength of these blocks at Jersey was shown by some smaller blocks that he had seen which had been raised up by the waves and thrown right over the pier, without being smashed to pieces; and they appeared to have been made of the proportions of 12 of sand and gravel to one of cement. The old idea of concrete was, the more cement the better. In fact when Mr D. Miller read his paper, on "Structures in the Sea without Cofferdams," before the Institution of Civil Engineers, in 1864, one of our leading engineers said that the proper way to make concrete would be to put in plenty of cement and little or no sand. That was now proved to have been a mistaken idea. It was found that if they mixed the sand and the cement well together, and distributed the stones properly a first-rate concrete was made in the proportions already indicated. Concrete was composed of stones and gravel, with cementing material made of lime or cement and sand, which when mixed became mortar; and good mortar was produced by one of cement to two of sand, and that was what held the stones together; so that in talking of 12 to 1 they talked of 10 parts of stone and gravel to 1 of cement and 2 of sand. That meant 10 parts of stone to one part of mortar; and if they could distribute the mortar so as to bind these stones together, that was all that was required to produce good concrete. A mode frequently adopted to economise cement was to make a concrete with small stones, and while this was soft to squeeze big stones into the heart of the mass.

Mr J. M. Gale thought in mixing concrete two things were to be considered. If they wished to make a large block that would stand handling, suitable for use in making a breakwater, they must make it of such proportions that the cement would be close enough together to hold its parts fast. But when they made concrete to keep water out they had a very different state of matters. It was known that a heap of stones taken from an ordinary stone breaking machine had somewhere between 50 and 60 per cent. of void or spaces. Now, if that was to be made watertight these spaces must be filled with cement mortar. He could not make a watertight concrete otherwise than by mixing one part of cement with one part of sand, and the most broken stones that he could work in was 3¾ parts. Of course in building a structure like that described in the paper, the concrete did not need to be watertight, and therefore they could put in an enormous quantity of stone, and make a block at so small a price.

Mr John Mayer drew attention to the melancholy interest attaching to the discussion of this paper, from the fact that the late Mr Clapperton—who had been so suddenly cut off a few days before—had, as manager to Messrs Chaplin & Co., materially assisted, with his practical knowledge, in adapting some special machinery for use in the construction of the St. Helier's Works.

Mr Johnston was of opinion that if concrete blocks could be made a little heavier they would probably better withstand the effects of the waves. He believed that if the specific gravity of the blocks used in the Wick Harbour had been greater the waves would not have had the same effect upon them; but if that could not be accomplished he thought it would be better to bolt them together, so that the blocks might be heavier weighted and better able to resist heavy storms.

Mr C. C. Lindsay stated that the concrete blocks used in constructing the Wick Breakwater were bolted together with vertical wrought-iron bars, but even that method was found to be insufficient. A mass of about 1300 tons, bolted together in this way, had been displaced entire by the force of the waves.

The President said that the blocks used in this harbour, being of dense syenite, were of greater specific gravity than those of old red sandstone, of which Wick Harbour was made.

Mr JOHN MAYER said he thought it would be at least 3 of specific gravity altogether.

Mr R. B. BELL said there was no doubt the heavier the blocks were made the better. They were made, he understood, from the hard syenite and trap rock found upon the island, which was a very heavy rock.

Mr GALE thought it could not be more than two of specific gravity—they could only get 120 lbs. to the foot.

Mr W. R. M. THOMSON said the blocks might each be built on launching stages as large as a house in this new cement work, without joints, and having the tops made air-tight and removable, they could easily be floated out and lowered into position, and then filled in firmly with stones or concrete from hopper barges, and save much of the expense and evils connected with the transport and securing of the smaller blocks.

The PRESIDENT was of opinion that this had been the plan adopted by Mr Moffat at Ardrossan.

Mr R. B. BELL said that Mr Moffat had carried out that mode of building very successfully at Ardrossan with brickwork, and he understood the same system had been tried at Dundee, but the blocks being made of porous concrete, they could not be got to float.

Mr IMRIE BELL, in reply, stated that in the discussion the question of proportion of the materials used in the concrete had not been very clearly described, as in the blocks described of 8 to 1 it was meant that there were 8 parts of all kinds of material to 1 part of cement—*i.e.*, 6 of broken stone, 2 of sand, 1 of cement. These proportions, he considered, after very careful consideration, could not be reduced if first-class cement concrete, sufficient for exposed face of harbour or sea work walls, were required. Of course these proportions could be varied if shingle containing a proportion of sand were used in the place of clean broken stone. The details of the blocks made in the proportion of 15 to 1 could be seen in the table of proportions of materials. He might, however, add that the blocks were decidedly porous, as might have been expected. The reason the author was led to adopt this proportion was simply economy. After careful study and experiment he found that the blocks thus composed could bear lifting from the building floor six days after they were made, which proved they were amply strong for the purpose they were required—namely, to take the place of loose rubble hearting between the two side walls of breakwater when it was determined to build the whole in solid masonry. He agreed so far with Mr Johnston that the heavier the block the better it would stand the action of the sea, but this only stood when the weight could be increased without increasing the exposed surface to the resistance of the sea—namely, by increasing its breadth—which for many reasons cannot always be done. In answer to Mr Gale, he stated that the stone used was a very dense syenite, traversed by broad bands of trap, averaging 166 lbs. to the foot. In conclusion he also stated, as an instance of the force of the sea during the gale which caused the breach previously described, that the railway metals, which were less than six inches above the surface of the breakwater, and firmly fixed down to the solid masonry, without the intervention of sleepers, were twisted and thrown out of line so much as to stop the traffic on the roads, and had to be lifted and renewed. The sea wall in landing pier, which withstood the effect of the gale, was now standing intact, though it had been left exposed to the gales of three succeeding winters, one of which even exceeded in intensity the gale which caused the damage to the inner or harbour wall. He might also be allowed to state that Sir John Coode, in designing this harbour wall, considered that, owing to the outlying rocks, and the diminished depth of water, the wave stroke to which this arm would be subjected would be of a less trying character than at the breakwater. Further, having regard to the length of the inner arm and the fact of its object being simply to afford the means of the approach to the outer or landing pier portion, it was an important consideration in determining the mode of construction to arrange the structure so as to incur the least possible expenditure, more especially as this inner arm would, upon the completion of the outer portion, be entirely protected from the effects of heavy seas. Many members of the Legislature of the

Islands, and other amateur engineers, suggested various plans during the construction of the works which they considered better than the one being built, one of which appeared to the author plausible, and which was brought to his notice by the late Deputy Simon, a member of the Government. The idea was to dredge a channel or canal from the deep water in the small roads up to the existing harbour entrance. After a careful consideration of the exposed situation, combined with a range of tide of 40 feet and with strong currents, in addition to there only being about three months in the year during which dredging operations could be carried out, he was of opinion that such a scheme was not practicable; and upon further reflection his opinion remained unchanged. He further believed that the only drawback to Jersey becoming one of the most favourite and fashionable watering places was the landing and embarking of passengers at all states of the tide and weather, and this must be accomplished at St. Helier as it is the capital of the island, and has all the necessary accommodations on land for the shipping frequenting the port. There could be no doubt, if the harbour was completed with such facilities, that the prosperity of the whole island would be vastly increased, and a spurt would be given to the building trade which would favourably affect all other trades, and tend most materially to the prosperity of that most lovely little island.

The President then moved a hearty vote of thanks to Mr Imrie Bell for his very excellent and exhaustive paper—a paper which those who had to do with these matters would be glad to refer to, as one of great value to them.

27TH APRIL, 1880.

The PRESIDENT (Mr Mansel), begged to express his deep sense of the kindness and courtesy he had received from all the members of this Institution during his term of office, and for the generous way in which they had assisted him in the proper transaction of the business of the Institution. When he took office, two years ago, the first matter that came before him was the difficulty of providing accommodation for the future meetings and business of the Institution, seeing that they had been warned, like their friends the Philosophical Society, that they would require to give up the occupancy of their present premises in the Corporation Buildings. Various steps were taken to meet this difficulty, but no offer was received which did not involve increased expense and more restricted accommodation and a chance of having in a few years to go again in search of accommodation, so that the proposal, brought forward by Mr Millar, the Secretary, to build in a position adjacent to this hall, gave them great relief, because it seemed to be a scheme within the power of the Institution, and more especially when taken up in conjunction with the Philosophical Society, could be carried out very efficiently. It was at first proposed that they should be landlord and the other society their tenants; but he was glad that this had not been carried out, but that they had agreed to become joint proprietors, equally interested in responsibility and privileges. He dared say that many of them had had an opportunity of seeing the new building, and he was glad to know that it was likely to turn out a great success. Everybody connected with its erection seemed well satisfied with it; and he had no doubt the joint proprietorship had removed a great source of trouble, and possibly dispute, between the two bodies. As it was, the joint committee of their Institution and the Philosophical Society had all along acted most harmoniously, and he had no doubt this would be corroborated by the other members of their Council who had acted on the works committee—viz., Messrs Jamieson and Bruce Bell. In their labours they had been greatly assisted by the members of the Philosophical Society on the committee—viz., Dr Wallace, and Messrs John Honeyman and Archibald Robertson. He ought also to mention their worthy Secretary, Mr W. J. Millar, who had taken great care and pains in the work, besides attending and writing the minutes of their meetings, and otherwise co-operating with the committee. They also had the assistance of Mr John Mann, who had agreed to act as the joint-treasurer during the building operations, so that the whole business had proceeded in the most satisfactory way. In a short time they would be able to take possession of the building, and next session they would commence their business therein. No doubt they would have been better of having had more money to spend, but they had endeavoured to keep everything as moderate as possible. As Mr Gale had remarked in proposing the adoption of the Accounts, this was the first time they had been the recipients of a legacy. The late Mr Robert Napier with his native benevolence, had allotted part of his means to benevolent objects, and the trustees of that fund had very kindly considered the claims of their Institution and the Philosophical Society, and awarded each £100 out of the fund. He might also mention that these trustees had awarded the handsome sum of £500 to the Mechanics' Institution, to assist to clear it of difficulties in which it had been involved by its building in Bath Street. He trusted that this would be the beginning of extended usefulness to this old Institution, under its new constitution, which assigned a share in its management to a nominee of the Institution of Engineers and Shipbuilders. Turn now to the more important business of the evening. One of the awkward duties sometimes laid upon a President in institutions of this kind, was that of finding a suitable successor. Mr Bruce Bell, he knew, was in a great strait when he nominated him to the office; but in the present instance there was not the least difficulty in finding a suitable successor. There was a gentleman amongst their number who had been often looked to, to fill the President's chair, but, as they could well understand, from business engagements had always refused. Now, however, he had time at his command for such an important office. The gentleman he referred to was Mr John L. K. Jamieson, who was well known as one of the most eminent of our marine engineers, and therefore he had pleasure in proposing that he be elected President for the ensuing two sessions.

This motion was seconded by Mr ANDREW BROWN, and unanimously adopted.

Mr R. BRUCE BELL said, notwithstanding Mr Mansel's remarks, he had pleasure in saying that they had not had a more painstaking or better President than he. He therefore proposed a hearty vote of thanks to their retiring President.

The vote was carried by acclamation.

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

TWENTY-THIRD SESSION, 1879-80.

MINUTES OF PROCEEDINGS.

THE FIRST GENERAL MEETING of the TWENTY-THIRD SESSION of the Institution was held in the Hall, 2 Dalhousie Street, on Tuesday, the 28th October, 1879, at 7·30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The Minute of Annual General Meeting of 29th April, and the Minutes of Special Meetings of 20th May and 9th September, 1879, were read and approved, and signed by the President.

The following candidates for admission to the Institution were elected:—

AS MEMBERS:—

Mr R. S. NEWALL, F.R.S., F.R.A.S., &c., Ferndene, Gateshead-on-Tyne.

Mr JAMES TAIT, Civil Engineer, Wishaw.

Mr JOHN YOUNG, Ironfounder, Glasgow.

AS GRADUATES:—

Mr JONATHAN L. DEAN, Pupil Civil Engineer, Glasgow.

Mr DONALD M'TAGGART, Foreman Engineer, Glasgow.

Mr WILLIAM WILLOX, M.A., Pupil Civil Engineer, Glasgow.

The Institution Medal, awarded to Mr CHAS. C. LINDSAY, for his Paper on "The Design and Construction of Partick Bridge," read during Session 1877-78, was presented, The Marine Engineering Medal, awarded to Mr JAMES HOWDEN, for his Paper on "The Action of the Screw Propeller," read during Session 1877-78, was presented.

The President delivered his Introductory Address, and, on the motion of Mr GEO. RUSSELL, a cordial vote of thanks was awarded the President for his address.

It was agreed to adjourn the further discussion of Mr JAMES HOWDEN'S Paper on "The Reaction of the Screw Propeller" to next General Meeting.

Mr JOHN TURNBULL, Jun., read his Paper on "A New and Perfect Compound Action Piston Packing." A discussion followed, and was carried to next General Meeting.

THE SECOND GENERAL MEETING of the TWENTY-THIRD SESSION of the Institution was held in the Hall, 2 Dalhousie Street, on Tuesday, the 25th November, 1879, at 7.30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The Minute of General Meeting of 28th October, 1879, was read and approved, and signed by the President.

The following candidates for admission to the Institution were elected :—

AS MEMBERS :—

Mr JOHN FRASER, Superintendent Engineer, Messrs P. Henderson & Co., Glasgow.

Mr ROBERT HADFIELD, Steel Founder, Sheffield.

Mr A. P. HENDERSON, Mechanical Engineer, Glasgow.

Mr JOHN L. HENDERSON, Marine Engineer, Partick.

AS GRADUATES:—

Mr ALEX. BROWN DOBBIE, Apprentice Mechanical Engineer, Glasgow.
Mr ALEX. R. PATON, Apprentice Engineer, Partick.
Mr CHARLES G. RUSSELL, Apprentice Civil Engineer, Glasgow.
Mr ROBERT RUSSELL, Draughtsman, Crosshill

The discussion of Mr JAMES HOWDEN'S Paper, on "The Reaction of the Screw Propeller," was resumed, Mr J. M. Gale occupying the chair whilst the President made some remarks, illustrated by diagrams, upon the paper. The chair having been re-occupied by the President, the discussion was afterwards terminated, and a vote of thanks awarded Mr Howden for his paper.

The discussion of Mr JOHN TURNBULL, Jun.'s Paper on "A New and Perfect Compound Action Piston Packing," was resumed and terminated, and a vote of thanks awarded Mr Turnbull for his paper.

A Paper on "The Introduction of the Compound Engine, and the Economical Advantage of High Pressure Steam; with Description of the System introduced by the late J. M. Rowan," by Mr FREDERICK J. ROWAN, was read, discussion of which was adjourned to next General Meeting.

THE THIRD GENERAL MEETING of the TWENTY-THIRD SESSION of the Institution was held in the Hall, 2 Dalhousie Street, on Tuesday, the 23rd December, 1879, at 7.30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The Minute of General Meeting of 25th November, 1879, was read and approved, and signed by the President.

The following candidates for admission to the Institution were elected;—

AS MEMBERS :—

Mr WILLIAM T. COURTIER DUTTON, Underwriters' Surveyor, Glasgow.

Mr JOHN G. KINGHORN, Mechanical Engineer, Rockferry, Cheshire.

The discussion of Mr F. J. ROWAN'S Paper, on "The Introduction of the Compound Engine, and the Economical Advantages of High-Pressure Steam; with Description of the System introduced by the late J. M. Rowan," was continued, and, in order to give full opportunity for Members to discuss the subjects treated of, was adjourned to next General Meeting.

A Paper on "Considerations in the Construction of Marine Boilers," by Mr JOSIAH M'GREGOR, C.E., was read; but owing to the lateness of the hour, the discussion was left over till next General Meeting.

THE FOURTH GENERAL MEETING of the TWENTY-THIRD SESSION of the Institution was held in the Hall, 2 Dalhousie Street, on Tuesday, the 27th January, 1880, at 7.30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The Minute of General Meeting of 23rd December, 1879, was read and approved, and signed by the President.

The following candidates for admission to the Institution were elected:—

AS MEMBERS :—

Mr ALEXANDER FINDLAY, Mechanical Engineer, Glasgow.

Mr WILLIAM MURDOCH, Engineer, Glasgow,

AS GRADUATES :—

Mr Robert Kerr, Pupil Civil Engineer, Glasgow.

Mr George Scott M'Ritchie, Draughtsman, Maryhill.

Mr James Morton, Apprentice Mechanical Engineer, Glasgow.

Mr Hermann Pape, Improver, Glasgow.

Mr James S. Porter, Apprentice Engineer, Glasgow.

Mr H. Sherlock, Apprentice Engineer, Glasgow.

In accordance with the order of Business as stated on the Notice of Meeting, the discussion of the Papers on "Boiler Construction," by Mr F. J. Rowan and Mr Josiah M'Gregor, fell to be taken up.

It was, however, unanimously agreed, with the consent of the Authors of the Papers to be discussed, that it would be advisable to take up the reading of Mr Day's Paper, on "The Forth and Tay Bridges," as this matter had a very special interest at the present time. Mr Day then read his Paper, on "The proposed Bridges for carrying the North British Railway across the Firth of Forth, with some Remarks on the Structure and Cause of the Fall of the Tay Bridge." On account of the lateness of the hour the discussion was held over till next General Meeting, when it was arranged that this should be the first business of the evening.

The Fifth General Meeting of the Twenty-third Session of the Institution was held in the Hall, 2 Dalhousie Street, on Tuesday, 24th February, 1880, at 7.30 P.M.

Mr Robert Mansel, President, in the Chair.

The Minute of General Meeting of 27th January, 1880, was read, approved, and signed by the President.

The following candidates for admission to the Institution were elected :—

AS MEMBERS :—

Mr William N. Bain, Mechanical Engineer, Hong Kong.
Mr James Lang, Mechanical Engineer, Glasgow.

AS GRADUATES :—

Mr George Almond, Apprentice Civil Engineer, Bolton-le-Moors.
Mr Neil M'Kechnie, Student Engineer, Glasgow.
Mr Robert Miller, Apprentice E gineer, Glasgow.
Mr James Fitzroy Mitchell, Apprentice Engineer, Glasgow.

In answer to a question as to the visit by some of the Members to the Tay Bridge, the Secretary stated that these gentlemen in no way represented the Institution, as a deputation or otherwise, but had simply gone in a private capacity for their own information.

The discussion of Mr Day's Paper "The proposed Bridges for carrying the North British Railway across the Firth of Forth, with some Remarks on the Structure and Cause of the Fall of the Tay Bridge," was then proceeded with; but not being terminated, it was decided to hold a Special Meeting on 9th March, for this and other business.

An Extraordinary General Meeting of the Institution of Engineers and Shipbuilders in Scotland was held in the Rooms, 2 Dalhousie Street, Glasgow, on 9th March, 1880, at 7 o'clock p.m.

Present—Messrs Robert Mansel, Ralph Moore, David Campbell, J. G. Fairweather, J. M. Gale, Wm. Murdoch, D. C. Glen, St. J. V. Day, Wm. N. Bain, John Robertson, Geo. Russell, Peter Stewart, Andrew Barclay, John Thomson.

Mr Robert Mansel, President, in the Chair.

The Secretary read the notice calling the meeting, and the

President moved the following Resolution, the tenor whereof is set forth at length in the notice, viz. :—

"That the liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments to the Society, viz. :—in the case of a Member, by the payment of £20; and in the case of an Associate, by the payment of £15,—and in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money, as well as future Annual Subscriptions."

The motion was seconded by Mr David Campbell. The Meeting unanimously agreed to adopt the Resolution, and it was declared by the Chairman to have been unanimously carried.

Thereafter the Meeting was resolved into a Special Meeting, for the purpose of resuming the discussion of Mr St. John Vincent Day's Paper, on "The proposed Bridges for carrying the North British Railway across the Firth of Forth, with some Remarks on the Structure and Cause of the Fall of the Tay Bridge." And the adjourned discussion of Mr F. J. Rowan's Paper, on "The Introduction of the Compound Engine, and the Economical Advantage of High-Pressure Steam; with Description of the System introduced by the late J. M. Rowan;" and the discussion of Mr Josiah M'Gregor's Paper on "Considerations in the Construction of Marine Boilers."

The discussion of Mr Day's paper was then resumed and terminated, and a vote of thanks awarded Mr Day for his paper. A vote of thanks was also awarded Mr Barclay for bringing forward his design for a Forth Bridge. On account of the lateness of the hour, the discussion of the other papers was deferred till next General Meeting.

An Extraordinary General Meeting of the Institution of Engineers and Shipbuilders in Scotland, was held in the Rooms, 2 Dalhousie Street, Glasgow, on Tuesday, 23rd March, 1880, at 7·30 o'clock, P.M.

Present--Messrs Robert Mansel, John Thomson, James Howden, George Russell, John Henderson, Jun., James M. Blair, Peter Stewart, William Clapperton, H. C. Lobnitz, David Halley, John Robertson, James M. Thomson, and Thomas Kennedy.

Mr Robert Mansel, President, in the Chair.

The Notice calling the Meeting, and specifying the terms of the Resolution aftermentioned, was read by the Secretary.

The President moved that the Meeting confirm the Special Resolution passed at the Extraordinary General Meeting of the Institution, held on the 9th day of March current, and which Resolution is to the following effect, viz.:—

"That the liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments to the Society, viz.:—in the case of a Member, by the payment of £20; and in the case of an Associate, by the payment of £15,—and in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money, as well as future Annual Subscriptions."

The motion was seconded by Mr James Howden. The Meeting unanimously confirmed the Resolution, and the Chairman declared the motion to have been unanimously carried.

Thereafter the Meeting was resolved into an Ordinary General Meeting, for the disposal of the business as set forth on the Notice. The Minutes of General Meeting of 24th February, and of Special Meeting of 9th March, 1880, were read and approved, and signed by the President.

The following candidates for admission to the Institution were elected:—

AS MEMBERS :—

Mr IMRIE BELL, Civil Engineer, London.
Mr JAMES BRAND, Civil Engineer, Glasgow.
Mr HUGH SHAW DUNN, Mining Engineer, Kilmarnock.
Mr FREDERICK KREBS, Mechanical Engineer, Japan.
Mr ALLISON LENNOX, Mechanical Engineer, Glasgow.
Mr F. G. HOLMES, Civil Engineer, Glasgow.

AS GRADUATES :—

Mr ALEX. BOWIE, Draughtsman, Glasgow.
Mr J. PATTERSON, Jun., Assistant Draughtsman, Glasgow.
Mr ROBERT M. SHORT, Ship Draughtsman, Partick.

Mr ANDREW MACLEAN and Mr DAVID KINGHORN were appointed Auditors of Annual Accounts for present Session.

The adjourned discussions of Mr F. J. ROWAN'S paper "On the Introduction of the Compound Engine, and the Economical Advantage of High Pressure Steam; with Description of the System introduced by the late J. M. Rowan;" and of Mr JOSIAH M'GREGOR'S paper "On Considerations in the Construction of Marine Boilers," were resumed and terminated, and a vote of thanks awarded the authors of the papers.

Mr THOMAS KENNEDY read his paper "On Experiments on the Strength of Branch Pipes." A discussion followed. It was agreed that a Special Meeting should be held on the 20th April, for the purpose of continuing the discussion of Mr Kennedy's paper, for the reading of Mr JOHN THOMSON'S paper "On the St. Petersburg Water Works," and other business.

Messrs J. & J. THOMSON exhibited and explained Batchelor's Mechanical Diagram of the Steam Engine. A vote of thanks was awarded the Messrs Thomson for bringing the invention before the Meeting.

A SPECIAL MEETING of the Institution of Engineers and Shipbuilders in Scotland was held in the Rooms, No. 2 Dalhousie Street, Glasgow, on Tuesday, the 20th April, 1880, at 7.30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The discussion of Mr THOMAS KENNEDY'S paper "On Experiments on the Strength of Branch Pipes" was resumed and terminated.

Mr JOHN THOMSON read his paper "On the St. Petersburg Water Works."

Mr WILLIAM CLAPPERTON read his paper "On Fuel Feeders."

The discussion of these papers was carried to next General Meeting.

THE ANNUAL GENERAL MEETING of the Institution of Engineers and Shipbuilders in Scotland was held in the Hall, 2 Dalhousie Street, Glasgow, on Tuesday, the 27th April, 1880, at 7.30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The Minutes of Extraordinary General Meeting, and of Ordinary General Meeting of 23rd March, and of Special Meeting of 20th April, 1880, were read and approved, and signed by the President.

The TREASURER'S Annual Financial Statement, duly audited, was laid before the meeting and received.

A vote of thanks was awarded to the Treasurer and Auditors.

The PRESIDENT intimated that the Council had been unable to recommend the Award of Medals for papers read during Session 1878-79.

The Election of Office-Bearers to fill up vacancies caused by retiring Members of Council then took place.

Mr J. L. K. JAMIESON was unanimously elected President.

Mr RALPH MOORE was unanimously elected a Vice-President.

The following gentlemen, by a majority of votes, were elected Councillors:—Messrs A. C. KIRK, C. C. LINDSAY, S. G. G. COPESTAKE, WALTER MACFARLANE, H. R. ROBSON.

On the motion of Mr R. Bruce Bell a cordial vote of thanks was awarded Mr Mansel on retiring from the President's office.

The discussion of the following papers, viz.:—"On the St. Petersburg Water Works," by Mr JOHN THOMSON; "On Fuel Feeders," by Mr WILLIAM CLAPPERTON, was adjourned to Special Meeting to be called for Tuesday, the 18th of May.

A paper "On the St. Helier's Harbour Works," by Mr IMRIE BELL, C.E., was read by the Secretary, the discussion of which was also adjourned to Special Meeting of 18th May.

A SPECIAL MEETING of the Institution of Engineers and Shipbuilders in Scotland was held in the Hall, 2 Dalhousie Street, on Tuesday, the 18th May, 1880, at 7.30 P.M.

Mr ROBERT MANSEL, President, in the Chair.

The discussion of the following papers, read at previous General Meetings took place, viz.:—

"On the St. Petersburg Water Works," by Mr JOHN THOMSON.

"On Fuel Feeders," by Mr WILLIAM CLAPPERTON; and

"On the St. Helier's Harbour Works," by Mr IMRIE BELL, C.E.

Votes of thanks were awarded Mr John Thomson and Mr Imrie Bell for their papers, and to Mr John Miller of Messrs J. & J. M'Millan, for his explanations as to the working of their Fuel Feeder referred to in Mr Clapperton's paper. The decease of Mr Clapperton, having occurred since the reading of the paper, was fitly referred to by the President prior to the opening of the discussion.

TREASURER'S STATEMENT—1879-80.

GENERAL FUND.

Dr.

To Balance in Union Bank at close of Session 1878-9,				£222	16	0
Subscriptions received :						
Session 1879-80, ..	£498	10	0			
Arrears of Previous Sessions,	88	10	0			
	£587	0	0			
Deduct Entry Money transferred to Building Fund, ..	8	0	0			
				579	0	0
Dividends on Preference Stock, London and North-Western Railway, for half-year, ...				7	14	4
Interest on Capital lent to New Buildings Account,				7	14	4
Donation from Local Committee Inst. Mechanical Engineers, Glasgow Meeting, 1879, ...				35	13	9
Sales of Transactions, ...				4	4	6
				£857	2	11

Cr.

By Rent of Rooms, ...	£100	0	0			
Less Taxes deducted, ...	3	6	8			
				£96	13	4
Printing, ...				141	12	0
Lithography, ...				93	5	3
Institution Medal (Session 1877-78), ...				10	0	0
Salary to Secretary, ...				100	0	0
Commission for Collecting Arrears of Subscriptions, viz. :—						
For Session 1879-80, ...	£308	0	0			
For Previous Sessions, ...	87	0	0			
	£395	0	0 at 5 °/ₒ	19	15	0
Salary to Sub-Librarian, ...				25	0	0
Binding Books for Library, &c., ...				6	5	0
Police and Poor Rates and Property Taxes, ...				16	5	2½
Postages, ...				41	18	7½
Delivery of Annual Volumes, ...				2	5	3
Coal, Gas, Cleaning, &c., ...				0	17	11
Stationery, &c., ...				5	3	4
Petty Cash, ...				3	13	4
Cash advanced to New Buildings Account,				140	5	9
Bank Interest, ...				0	5	5
Balance in Union Bank, ...				153	17	6
				£857	2	11

MARINE ENGINEERING MEDAL FUND.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Balance in Union Bank at close of Session 1878-79, ...	£92	4	4	*By* Cash for Medal (Session 1877-78), ...	£10	0	0
Dividends on Debenture Stock, Glasgow Corporation Water Works, ...	1	3	8	Cash advanced to New Buildings Account, ...	90	0	0
Dividends on Preference Stock, London and North-Western Railway, for half year, ...	4	8	2	Balance in Union Bank, ...	2	9	8
Interest on Capital lent to New Buildings Account,	4	8	2				
Bank Interest, ...	0	5	4				
	£102	9	8		£102	9	8

RAILWAY ENGINEERING MEDAL FUND.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Balance in Union Bank at close of Session 1878-79, ...	£66	6	1	*By* Cash advanced to New Buildings Account, ...	£60	0	0
Dividends on Debenture Stock, Glasgow Corporation Water Works, ...	0	15	7	Balance in Union Bank, ...	12	9	0
Dividends on Preference Stock, London and North-Western Railway, for half year, ...	2	11	3				
Interest on Capital lent to New Buildings Account,	2	11	2				
Bank Interest, ...	0	4	11				
	£72	9	0		£72	9	0

NEW BUILDINGS ACCOUNT.

Dr.

To Amounts received to meet Expenses on New Buildings, viz. :—		
Cash from Building Fund, ...	£327 0 0	
,, General Fund, ...	140 5 9	
,, Marine Engineering Medal Fund, ...	90 0 0	
,, Railway Engineering Medal Fund, ...	60 0 0	
		£617 5 9
Capital from General Fund, ...	£402 9 10	
,, Marine Engineering Medal Fund,...	231 11 2	
,, Railway Engineering Medal Fund,	133 13 3	
		767 14 3
Cash received from Building Fund to meet Interest on Loans, ...		14 13 8
		£1399 13 8

Cr.

By Price of Ground, ...	£600 0 0	
Paid to Contractors, ...	785 0 0	
		£1385 0 0
Interest on Loans, viz.:—		
To General Fund, ...	£7 14 4	
,, Marine Engineering Medal Fund,	4 8 2	
,, Railway ,, ,,	2 11 2	
		14 13 8
		£1399 13 8

BUILDING FUND.

Dr.

To Balance in Union Bank at close of Session 1878-79, ...	£327 12 9
Entry Money, ...	8 0 0
Dividends on Debenture Stock, Glasgow Corporation Water Works, ...	17 12 5
Legacy per Robert Napier's Trustees, ...	100 0 0
Bank Interest, ...	0 18 6
	£454 3 8

Cr.

By Cash advanced to New Buildings Account, ..	£327 0 0
Cash to New Buildings A/c to meet interest on loans,	14 13 8
Balance in Union Bank, ...	112 10 0
	£454 3 8

Glasgow, *20th April, 1880.*—We have examined the foregoing Annual Financial Statement of Treasurer, the Accounts of the Marine and Railway Engineering Medal Funds, the Building Fund, and the New Buildings Account, and find the same duly vouched and correct, the Amounts in Bank being as stated.

(Signed) Andw. MACLEAN, } Auditors.
D. KINGHORN, }

SUBSCRIPTION ACCOUNT.

Dr.

To Subscriptions due as per Roll :—			
Arrears due at close of last Session, ...		£282 15 0	
Deduct since placed on Suspense list,		74 15 0	
			£208 0 0
Session 1879-80 :—			
329 Members	at £1 10 0 —	£493 10 0	
6 New Members	,, 2 10 0 —	15 0 0	
4 ,,	,, 2 0 0 —	8 0 0	
9 ,,	,, 1 10 0 —	13 10 0	
32 Associates	,, 1 0 0 —	32 0 0	
115 Graduates	,, 0 10 0 —	57 10 0	
			619 10 0
			£827 10 0

Cr.

By Subscriptions received, as per Cash Book :			
Arrears of Sessions previous to Session 1879-80, ...			£88 10 0
Session 1879-80 :—			
268 Members	at £1 10 0 —	£402 0 0	
6 New Members	,, 2 10 0 —	15 0 0	
4 ,,	,, 2 0 0 —	8 0 0	
6 ,,	,, 1 10 0 —	9 0 0	
28 Associates	,, 1 0 0 —	28 0 0	
73 Graduates	,, 0 10 0 —	36 10 0	
			498 10 0
Arrears due for Session 1879-80, ...		£121 0 0	
Arrears due for previous Sessions,		119 10 0	
			240 10 0
			£827 10 0

BANK ACCOUNT.

Dr.

To Balances at close of Session 1878-79 :—	
General Fund, ...	£222 16 0
Marine Engineering Medal Fund, ...	92 4 4
Railway Engineering Medal Fund, ...	66 6 1
Building Fund, ...	327 12 9
Amounts lodged, Session 1879-80, ...	1081 3 8
Interest, Session 1879-80, ...	1 3 4
	£1791 6 2

Cr.

By Amounts Drawn, Session 1879-80, ...	£1510 0 0
Balance in Union Bank, ...	281 6 2
	£1791 6 2

CAPITAL ACCOUNT.

GENERAL FUND.

Loan to New Buildings Account (formerly Lond. and N.-W. Ry. Preference Stock),	£402 9 10	
Do. Cash drawn from Union Bank, ...	140 5 9	
Cash in Union Bank, ...	153 17 6	
		£696 13 1

MARINE ENGINEERING MEDAL FUND.

Loan to New Buildings Account (formerly Lond. and N.-W. Ry. Preference Stock),	£231 11 2	
Do. Cash drawn from Union Bank, ...	90 0 0	
Glasgow Corporation Water Works Debenture Stock, ...	30 0 0	
Cash in Union Bank, ...	2 9 8	
		354 0 10

RAILWAY ENGINEERING MEDAL FUND.

Loan to New Buildings Account (formerly Lond. and N.-W. Ry. Preference Stock),	£133 13 3	
Do. Cash drawn from Union Bank, ...	60 0 0	
Glasgow Corporation Water Works Debenture Stock, ...	20 0 0	
Cash in Union Bank, ...	12 9 0	
		226 2 3

BUILDING FUND.

Glasgow Corporation Water Works Debenture Stock, ...	£450 0 0	
New Buildings Account, amount drawn from Bank, ...	327 0 0	
Cash in Union Bank, ...	112 10 0	
		889 10 0

ARREARS OF SUBSCRIPTIONS.

Arrears due for Session 1879-80, ...	£121 0 0	
Do. previous Sessions, ...	119 10 0	
		240 10 0
		£2406 16 2

DONATIONS.

On Mechanical and Physical Properties of the Copper Tin Alloys. United States Report. From Prof. R. H. Thurston, M.E. C.E , &c.

Set of Photographs, illustrative of Quarrying operations at Furnace Quarries. From Messrs Wm. Sim & Co.

Photograph of Steam Crane. From George Russell, Esq.

University College Calendar, Session 1879-80, and General Library Catalogue, University College, London. Presented by the Council.

On The Latest Improvements in Marine Engines and Boilers, by John R. Ravenhill. From the Author.

The Solar Spectrum in 1877-78, by Professor C. Piazzi Smyth, F.R.S.S.L. and E. From the Author.

Modern Review, No. I. From the Publishers.

Revue de Droit International, &c. From the Publishers.

Report of British Association, Sheffield Meeting. 1879. Presented by the Council.

Friction and Lubrication, by Prof. R. H. Thurston, A.M., C.E., &c, From the Author.

On the Liability of Employers, by Lord Shand. From the Author.

Winding and Over-winding at Mines, by C. M. Percy. From the Author.

The Mechanical Theory of Heat, by Professor R. Clausius. Translated by W. R. Browne. From the Publishers.

Transactions, Engineers' Society of Western Pennsylvania. From the Society.

On the Mechanical Transmission of Sound by Wires, and on Simple Forms of Microphone Receivers, by W. J. Millar, C.E. From the Author.

Prehistoric Iron and Steel, by St. John Vincent Day, C.E. From the Author.

Gunpowder Manufacture, by James A. C. Hay, C.E. From the Author.

Spon's Engineers' and Contractors' Illustrated Book of Prices, and Engineers' Directory, 1880-81. From the Publishers.

The River Tyne, its History and Resources. From the Tyne Improvement Commissioners.

Separat-Abdruck aus den Annalen der Physik und Chemie. From Professor R. Clausius.

On the Variation due to Orthogonal Strains in the Elastic Limit in Metals, and on its Practical Value and More Important Applications, by Professor R. H. Thurston, M.E., C.E. From the Author.

Publications received periodically in exchange for Institution Transactions:—

Annales Industrielles.
Annales de la Propriété Industrielle.
Colliery Guardian.
Engineer.
Engineering.
Iron.
Iron and Coal Trades' Review
Marine Engineering News.
Mining Journal.
Nature.
Revue Industrielle.

The INSTITUTION exchanges Transactions with the following Societies:—

Institution of Civil Engineers.
Institution of Civil Engineers of Ireland.
Institution of Mechanical Engineers.
Institution of Naval Architects.
Institute of Mining and Mechanical Engineers.
Institute of Mining, Civil, and Mechanical Engineers.
South Wales Institute of Engineers.
Society of Engineers.
Iron and Steel Institute.
Philosophical Society of Glasgow.
Royal Scottish Society of Arts.
Royal Dublin Society.
Liverpool Polytechnic Society.
Literary and Philosophical Society of Manchester.
Patent Office, London.
Society of Arts.
Association of Employers, Foremen, and Draughtsmen, Manchester.
American Society of Civil Engineers.
Smithsonian Institution, U.S.A.
Stevens Institute of Technology, U.S.A.
Royal Society of Tasmania.
Royal Academy of Sciences, Lisbon.
Royal Society of Victoria.
Société des Ingénieurs Civils de France.
Société Industrielle de Mulhouse.
Société d'Encouragement pour l'Industrie Nationale.
Société des Anciens Elèves des Ecôles Nationales d'Arts et Métiers.
Société des Sciences Physiques et Naturelles de Bordeaux.
Austrian Engineers' and Architects' Society, Vienna.
Geological Survey of Canada.
Engineers and Architects' Society of Naples.

LIST

OF

HONORARY MEMBERS, MEMBERS, ASSOCIATES, AND GRADUATES

OF THE

Institution of Engineers and Shipbuilders in Scotland,

(INCORPORATED,)

Session 1879-80.

HONORARY MEMBERS.

JAMES PRESCOTT JOULE, LL.D., F.R.S., 12 Wardle Road, Sale, near Manchester.

Professor CHARLES PIAZZI SMYTH, F.R.SS.L. and E., Astronomer-Royal for Scotland, 15 Royal Terrace, Edinburgh.

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

Professor R. CLAUSIUS, the University, Bonn, Prussia.

Sir JOSEPH WHITWORTH, Bart., C.E., LL.D., F.R.S., Manchester.

Professor JOHN TYNDALL, D.C.L., LL.D., F.R.S., &c., Royal Institution, London.

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

MEMBERS.

DATE OF ELECTION.			
1867, Apr. 24:	Thomas	Adams,	Ant and Bee Works, West Gorton, Manchester.
1859, Jan. 19:	James	*Aitken, jun.,	Shipbuilder, Whiteinch.
1860, Dec, 26:	William	Aiton,	Caesygidal, Dyffryn, by Carnarvon, North Wales.
Original:	William	Alexander,	23 India Street, Glasgow.
Original:	Alexander	Allan,	Glen House, The Valley, Scarborough.
1872, Feb. 27:	A. B.	Allan, C.E.,	Burgh Surveyor, Burgh Chambers, Govan.
1869, Jan. 20:	William	Allan,	Sunderland Engine Works, Sunderland.
1864, Dec. 21:	James B.	Alliott,	The Park, Nottingham.
1877, Dec. 18:	William M.	Alston,	24 Burnbank Gardens, Glasgow.
1880, Apr. 27:	Michael	Altouhoff, C.E.,	26 Fagaradney Prospect, St. Petersburg, Russia.
1860, Nov. 28:	Robert	Angus,	Lugar Ironworks, Cumnock.
1875, Dec. 21:	Thos A.	Arroll,	18 Blythswood Square, Glasgow.
Original:	David	Auld,	23 Duncan Street, Calton. Glasgow.
1880, Feb. 24:	William N.	Bain,	East Point, Hong Kong, China.
1873, Apr. 22:	H. W.	Ball,	Cranstonhill Engine Works, Glasgow.
1858, Dec 22:	Andrew	Barclay, F.R.A.S.,	Caledonian Foundry, Kilmarnock.
1876, Jan. 25:	James	Barr,	London Road Iron Works, Glasgow.

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

1868, Apr. 22:	Edward	Barrow,	Directeur du Veritas, 188 Rue Royale, Bruxelles.
1875, Jan. 26:	Charles	Bell,	4 Clifton Place, Glasgow.
	David	*Bell,	Shipbuilder, Yoker.
1868, Feb. 12:	Edward M.	Bell,	TinplateWorks,Coatbridge.
1880, Mar. 23:	Imrie	Bell, C.E.,	1 Victoria Street, Westminster, London, S.W.
Original:	R. Bruce	Bell, C.E. (*Past President*),	203 St. Vincent Street, Glasgow.
1877, Jan. 23:	Ernest	Benedict, C.E.,	2 Manchester Square, London.
	Neil	*Black,	18 Neptune St., Liverpool.
1866, Dec. 26:	Edward	Blackmore,	Eagle Foundry, Greenock.
1864, Oct. 26:	Thomas	Blackwood,	Shipbuilder, Port-Glasgow.
1869, Feb. 17:	Geo. M'L.	Blair,	127 Trongate, Glasgow.
1867, Mar. 27:	James M.	Blair,	2 Cecil Place, Paisley Road, Glasgow.
1874, Jan. 27:	Howard	Bowser,	13 Royal Crescent, W., Glasgow.
1880, Mar. 23:	James	Brand, C.E.,	109 Bath Street, Glasgow.
1865, Apr. 26:	Walter	*Brock,	Engine Works, Dumbarton.
1859, Feb. 16:	Andrew	*Brown,	London Works, Renfrew.
1858, Mar. 17:	James	Brownlee,	23 Burnbank Gardens, Glasgow.
1877, Oct. 30:	Robert	Bruce,	16 St. Enoch Sq., Glasgow.
1876, Jan. 25:	Charles E.	Bulmer,	c/o D. Rollo, jun., Engineer & Shipbuilder, 10 Fulton St., Liverpool.
1860, Dec. 26:	James C.	Bunten,	100 Cheapside St.,Glasgow.
1866, Apr. 26:	Amedee	Buquet, C.E.,	13 Boulevard des Batignolles, Paris.
	Andrew	*Burns,	Hilton of Burley, Milnathort.
1878, Oct. 29:	Edward B.	Caird,	8 Scotland St., Glasgow.
1878, Dec. 17:	James	Caldwell,	130 Elliot Street, Glasgow.

1875, Dec. 21:	J. C.	Cameron,	343 Paisley Road, Glasgow.
1870, Nov. 22:	David	Campbell,	151 Eglinton St., Glasgow.
1868, Dec. 23:	David	Carmichael,	Ward Foundry, Dundee.
1859, Nov. 23:	Peter	Carmichael,	Dens Works, Dundee.
1862, Jan. 8:	John	Carrick,	6 Park Quadrant, Glasgow.
1859, Oct. 26:	Robert	Cassels,	168 St. Vincent St., Glasgow.
1867, Jan. 30:	Albert	Castel,	3 Lombard Court, London, E.C.
1864, Dec. 21:	William	Clapperton,	Consulting Engineer, 7 Corunna Street, Glasgow.
1875, Oct. 26:	W. J.	Clark,	Southwick, near Sunderland.
1860, Apr. 11:	James	Clinkskill,	1 Holland Place, Glasgow.
1871, Apr. 18:	Jose Maria	da Conceicao,	Rio de Janiero, c/o D. Rowan, 231 Elliot St., Glasgow.
	Charles	*Connell,	Whiteinch.
Original:	Robert	Cook,	Woodbine Cottage, Pollokshields.
1864, Feb. 17:	James	Copeland,	16 Pultney St., Glasgow.
1864, Jan. 20:	William R.	Copland, C.E.,	146 W. Regent St., Glasgow.
1868, Mar. 11:	S. G. G.	Copestake,	Glasgow Locomotive Works, Little Govan, Glasgow.
1871, Jan. 17:	Antonio	Costa,	Fundicion de la Patria, Valparaiso.
1866, Nov. 28:	M'Taggart	Cowan, C.E.,	109 Bath Street, Glasgow.
1868, Apr. 22:	David	Cowan, C.E.,	Mt. Gerald House, Falkirk.
1861, Dec. 11:	William	Cowan,	Great North of Scotland Railway, Aberdeen.
1877, Mar. 20:	John	Crawford,	108 Derby Road, Bootle, Liverpool.
1876, Nov. 21:	David	Croll,	17 Sutherland Terrace, Hillhead.
1866, Dec. 26:	James L.	Cunliff,	Inch Works, Port-Glasgow.
1872, Nov. 26:	David	Cunningham,	C.E., Harbour Chambers, Dundee.
1869, Jan. 20:	James	Currie,	16 Bernard Street, Leith.

1861, Dec. 11:	Thomas	*Davison,	248 Bath Street, Glasgow.
1864, Feb. 17:	St. J. V.	Day, C.E.,	115 St. Vincent St., Glasgow.
1869, Feb. 17:	James	Deas, C.E.,	Engineer, Clyde Trust, 16 Robertson St., Glasgow.
1866, Feb. 14:	A. C. H.	Dekke,	Shipb'der, Bergen, Norway.
	Peter	*Denny,	Helenslee, Dumbarton.
1873, Feb. 18:	William	Denny,	Leven Shipy'd, Dumbarton.
1878, Mar. 19:	Frank W.	Dick,	405 Eglinton Street, Glasgow.
1878, Jan. 22:	James S.	Dixon,	19 Elmbank Crescent, Glasgow.
1871, Jan. 17:	William	Dobson,	Shipbuilder, Joy Lodge, Low Walker-on-Tyne
1864, Jan. 20:	James	Donald,	Abbey Works, Paisley.
1869, Dec. 21:	James	Donald,	Engineer, Johnstone.
1876, Jan. 25:	James	Donaldson,	Fulbar Street, Renfrew.
1863, Nov. 25:	Robert	Douglas,	Dunnikier Foundry, Kirkcaldy.
1876, Oct. 24:	Patrick E.	Dove,	8 Hamilton Park Terrace, Hillhead.
1864, Oct. 26:	Robert	*Duncan,	(*Past President*) Shipbuilder, Port-Glasgow.
1873, Apr. 22:	Robert	Dundas, C.E.,	3 Germiston Street, Glasgow.
1869, Nov. 23:	David Jno.	Dunlop,	Inch Works, Port Glasgow.
1877, Jan. 23:	John G.	Dunlop,	115 King Edward Road, South Hackney, London.
1880, Mar. 23:	Hugh S.	Dunn,	Earlston Villa, Caprington, Kilmarnock.
1879, Dec. 23:	Wm. T. Courtier	Dutton	30 Gordon St., Glasgow.
1876, Oct. 24:	Jo. Marshall	Easton,	70 James Watt St., Glasgow.
1865, Oct. 23:	Mortimer	Evans, C.E.,	97 W. Regent St., Glasgow.
1875, Oct. 26:	James G.	Fairweather, C.E., F.S.A.,	12 Buccleuch Pl., George Sq., Edinburgh.

	John	*Ferguson,	Shipbuilder, Whiteinch.
1878, Mar. 19:	John	Ferguson, jun.,	Shipbuilder, Leith.
1861, Dec. 11:	William	Ferrie,	Monkland Ironworks, Calderbank.
1874, Feb. 24:	Immer	Fielden,	47 Queen's Square, Belfast.
1880, Jan. 27:	Alexander	Findlay,	c/o Messrs James Goodwin & Co., Motherwell.
1876, Oct. 24:	Charles	Forman, C.E.,	160 Hope Street, Glasgow.
Original:	William	Forrest,	77 Renfield St., Glasgow.
1872, Nov. 26:	Thomas	Forrest, M.E.,	Dumfries Ironworks, Dumfries.
1870, Jan. 18:	William	Foulis,	Engineer, Corporation Gas Works, 42 Virginia St., Glasgow.
1862, Nov. 26:	Alexander	Fullarton,	Vulcan Works, Paisley.
1879, Nov. 25:	John	Frazer,	4 Kingston Place, Paisley Road, Glasgow.
1858, Nov. 24:	James M.	Gale, C.E.,	(*Past President*) Engineer, Corporation Water Works, 23 Miller St., Glasgow.
1862, Jan. 8:	Andrew	Galloway, C.E.,	St. Enoch Station, Glasgow.
1873, Dec. 23:	Bernard	Gatow,	Veritas Office, 29 Waterloo Street, Glasgow.
1875 Mar. 23:	William	Gibb, M.E.,	Messrs Palmer & Co., Jarrow-on-Tyne.
1859, Nov. 23:	Archibald	*Gilchrist,	11 Sandyford Pl., Glasgow.
1878, Oct. 29:	James	Gilchrist,	8 Derby Terrace, Glasgow.
1859, Dec. 21:	David C.	Glen,	14 Annfield Place, Glasgow.
1868, Nov. 25:	Thomas	Goldie,	Post Office, Cape Town, Cape of Good Hope.
1864, Feb. 17:	James	Goodwin,	Ironfounder, Ardrossan.
1866, Mar. 28:	Gilbert S.	Goodwin,	Alexandra Buildings, James Street, Liverpool.

1868, Mar. 11:	Joseph	Goodfellow,	83 Taylor Street, Glasgow.
1858, Dec. 22:	Henry	*Gourlay,	Dundee Foundry, Dundee.
	Edwin	*Graham,	Messrs Osbourne, Graham, & Co., Hylton, Sunderland.
1858, Mar. 12:	George	Graham, C.E.,	Engineer, Caledonian Railway, Glasgow
1876, Jan. 25:	Thomas M.	Grant,	Townholm Engine Works, Kilmarnock
1869, Feb. 17:	Alex. D.	Gray,	Lilybank Boiler Works, Eglinton Street, Glasgow.
1871, Mar. 28:	Thomas	Gray,	Chapel Colliery, Newmains.
1861, Dec. 11:	Archibald	Gray,	Glengarnock Iron Works, Glengarnock.
1862, Jan. 8:	James	Gray,	Parkhead Colliery, Old Cumnock, Ayrshire
1867, Nov. 27:	James	Grier,	29 Waterloo St., Glasgow.
1870, Feb. 22:	P. B. W.	Gross, M.E.,	4 Albion Place, Cumberland Road, Bristol.
1879, Nov. 25:	Robert	Hadfield,	Heda Foundry, Attercliffe, Sheffield.
1872, Feb. 27:	A. A.	Haddin, C.E.,	137 West Regent Street, Glasgow.
1876, Oct. 24:	David	Halley,	21 Berkeley Ter., Glasgow.
	James	*Hamilton,	15 Royal Crescent, Glasgow.
1873, Mar. 18:	James	Hamilton, jn.,	5 Parkgrove Terr , Glasgow.
	John	*Hamilton,	2 Granby Terrace. Hillhead.
1875, Feb. 23:	J. B.	Hamond,	The Victoria Engineering Company, Victoria Works, Stockport.
1866, Dec. 26:	James B	Handyside,	19 Burnbank Gardens, Glasgow.
1876, Feb. 22:	Walter	Hannah,	Board of Trade Surveyor, 7 York Street, Glasgow.

1878, Mar. 19:	Timothy	Harrington,	61 Gracechurch Street, London, E.C.
1875, Jan. 26:	Peter T.	Harris,	19 West St. (S.S.), Glasgow.
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.
1873, Jan. 21:	John	Henderson, jun.,	Meadowside, Partick.
1879, Nov. 25:	John L.	Henderson,	3 Minard Terrace, Partick.
1878, Dec. 17:	William	Henderson,	Meadowside, Partick.
1875, Jan. 26:	William	Henderson,	Bishop Street, Anderston, Glasgow.
1870, May 31:	Richard	Henigan, C.E.,	Alma Terrace, Avenue Road, Southampton.
1877, Feb. 20:	George	Herriot,	7 York Street, Glasgow.
	Laurence	*Hill, C.E.,	59 St. Vincent St., Glasgow.
1880, Mar. 23:	F. G.	Holmes, C.E.,	103 Bath Street, Glasgow.
1874, Mar. 24:	John A.	Hope,	24 Bath Street, Glasgow.
1864, Apr. 13:	Thomas R.	Horton,	Rose Cottage, Smith Street, Hillhead.
Original:	James	Howden,	8 Scotland Street, Glasgow.
Original:	Edmund	*Hunt,	87 St. Vincent St., Glasgow.
1860, Nov. 28:	James	Hunter,	Coltness Iron Works, by Newmains.
1857, Dec. 23:	John	Hunter,	Dalmellington Iron Works, near Ayr.
1877, Feb. 20:	P. S.	Hyslop,	Public Works Department, Cape Town, S'th Africa.
	Anthony	*Inglis,	64 Warroch Street, Glasgow.
Original:	John	*Inglis,	64 Warroch Street, Glasgow.
1861, May 1:	John	Inglis, junr.,	Point House Shipyard, Glasgow.

1872, Nov 26:	Josh. Hyde	Irwin, M.E.,	11 Aubery Ter., Sunderland.
1879, Jan. 21:	Thos. F.	Irwin,	Inman Steamship Coy., Liverpool.
1875, Dec. 21:	William	Jackson,	Govan Engine Works, Govan.
1872, Oct. 22:	William	Jacks,	39 St. Vincent Pl., Glasgow.
	Geo. W.	*Jaffrey,	17 Robertson St., Greenock.
1867, Dec. 26:	John L. K.	Jamieson,	9 Crown Terr., Dowanhill, Glasgow.
1879, Feb. 25:	David	Johnstone,	7 Carmichael St., Govan.
1870, Dec. 20:	David	Jones,	Highland Rlwy., Inverness.
1872, Mar. 26:	Ebenezer	Kemp,	Linthouse Engine Works, Govan.
1875, Nov. 23:	William	Kemp,	Mechanical Engineer, Ellen St. Engineering Works, Govan.
1878, Mar. 19:	Hugh	Kennedy,	Redclyffe, Partickhill.
1877, Jan. 23:	Jno.	Kennedy,	Bond Court Chambers, Walbrook, London, E.C.
1876, Feb. 22:	Thomas	Kennedy,	Water Meter Works, Kilmarnock.
1876, Oct. 24:	Andrew	Kerr, C.E.,	Warrnambool, Victoria, Australia.
1876, Mar. 21:	John G.	Kincaid,	Clyde Foundry, Greenock.
	David	Kinghorn,	172 Lancefield St., Glasgow.
1879, Dec. 23:	John G.	Kinghorn,	2 Alexandra Terrace, Rock Ferry, Cheshire.
1864, Oct. 26:	Alex. C.	Kirk,	Govan Park, Govan Road.
Original:	David	*Kirkaldy,	Testing and Experimenting Works, Southwark St., London, S.E.
1880, Mar. 23:	Frederick	Krebs,	M.B.M.S.S. Co., Tokio, Japan.
1875, Oct. 26:	William	Laing,	72 Gt. Clyde St., Glasgow.

1858, Apr. 14:	David	Laidlaw,	147 E. Milton St., Glasgow.
1862, Nov. 26:	Robert	Laidlaw,	147 E. Milton St., Glasgow.
1880, Feb. 24:	James	Lang,	Superintendent Engineer, Kobe, Japan.
1864, Oct. 26:	George	Lauder, C.E.,	c/o Messrs Carnegie & Co., Coke Works, nr. Larimer Station, Pa., United States of America.
Original:	James G.	*Lawrie,	(*Past President*), 2 Westbourne Terrace, Glasgow.
	Andrew	*Leckie, Surveyor,	Commercial Buildings, West Hartlepool.
1880, Mar. 23:	Allison	Lennox,	131 W. Regent St., Glasgow.
1878, Mar. 19:	John	Lennox,	131 W. Regent St., Glasgow.
1875, Feb. 23:	Robert	Liddell,	1 Stanley Pl., Uddingston.
1876, Oct. 24:	Charles C.	Lindsay, C.E.,	203 St. Vincent St., Glasgow.
1862, Apr. 2:	H. C.	Lobnitz,	Renfrew.
1865, Dec. 20:	John L.	Lumsden,	Fairfield Shipyard, Govan.
	James	*Lyall,	13A Exchange Buildings, Liverpool.
1873, Jan. 21:	James M.	Lyon, M.E.,	Singapore, c/o Messrs Londen Bros., 111 Bothwell Street, Glasgow.
1862, Oct. 29:	John	M'Andrew,	17 Park St. East, Glasgow.
1858, Feb. 17:	David	M'Call, C.E.,	160 Hope Street, Glasgow.
1876, Oct. 24:	James Wilson	M'Carter,	78 Foyle St., Londonderry.
1874, Mar 24:	Hector	MacColl,	Messrs James Jack & Co., Engineers, Liverpool.
	Hugh	*MacColl,	Manager, Wear Dock Yard, Sunderland.
1878, Oct. 29:	James G.	M'Culloch,	Marine Board Dept., Adelaide, Australia.
1871, Jan. 17:	David	M'Culloch,	Vulcan Works, Kilmarnock.
1857, Dec. 23:	J. I.	M'Derment,	39 Sandgate Street, Ayr.

Original:	Walter	MacFarlane,	Possil Park, Glasgow.
	Andrew	*M'Geachan,	Newark Shipbuilding Yard, Port-Glasgow.
1879, Mar. 25:	Josiah	M'Gregor, C.E.,	4 Cavendish Park, Barrow-in-Furness.
Original:	James	M'Ilwham,	100 Cheapside Street, Glasgow.
1880, Apr. 27:	Wm. Rae	M'Kaig,	17 Water St., Liverpool.
1858, Apr. 14:	John	Mackenzie, M.E.,	Ashgrove Villa, Ibroxholm.
1873, Jan. 21:	J.B.Affleck,	M'Kinnell,	Palmerston Foundry, Dumfries.
1876, Dec. 19:	R. B.	MacKinnon,	Tube Works, Washington Street, Glasgow.
1859, Dec. 21:	Robert	M'Laren,	22 Canal St., S.S., Glasgow.
	Andrew	*M'Lean,	Whiteinch House, White inch.
1858, Nov. 24:	Walter	M'Lellan.	127 Trongate, Glasgow.
	John	*M'Millan,	Shipbuilder, Dumbarton.
	William	*MacMillan,	19 Elgin Terrace, Partick.
Original:	William	M'Nab,	3 Eastfield Ter.,Rutherglen.
Original:	Andrew	M'Onie,	1 Scotland Street, Glasgow.
1864, Oct. 26:	Robert	*Mansel (*President*),	Shipbuilder,Whiteinch.
1867, Oct. 30:	John	Mather,	London and South-Western Rlwy., Nine Elms Works, London, S.W.
1875, Dec. 21:	George	Mathewson,	Bothwell Works, Dunfermline.
1876, Jan. 25:	William W.	May.	3 Sandbank Place, Dumbarton Road, Partick.
1861, Dec. 11:	Daniel	Miller, C.E.,	203 St.VincentSt.,Glasgow.
	James	*Miller,	Kelvin Forge, Partick.
1875, Oct. 26:	Leighton	Mills,	Principal Board of Trade Officer, N. E. District, Tynemouth.

Original:	James B.	Mirrlees,	45 Scotland St., Glasgow.
1857, Dec. 23:	John	Moffat, C.E.,	Ardrossan.
1876, Mar 21:	James	Mollison,	Lloyd's Register, 36 Oswald Street, Glasgow.
1869, Dec. 21:	John	Montgomerie,	Caledonian Railway Works, Perth.
1864, Jan. 21:	William	Moore, C.E.,	49 W. George St., Glasgow.
1862, Nov. 26:	Ralph	Moore, C.E.,	Croft Villa, Rutherglen.
1878, Apr. 23:	Robert H.	Moore,	Parkhead Forge, Glasgow.
1868, Feb. 12:	Alexander	Morton,	32 Windsor Ter., Glasgow.
1864, Feb. 17:	Hugh	Muir,	345 Bath Crescent, Glasgow.
Original:	Mathw. A.	Muir,	100 Cheapside Street, Glasgow.
1870, Mar. 22:	Wm. T.	Mumford,	36 Oswald Street, Glasgow.
Original:	James	Murdoch,	Shipbuilder, Port-Glasgow.
1880, Jan, 27:	William	Murdoch,	77 S. Portland St., Glasgow.
1874, Mar. 24:	Richard	Murray,	160 Hope Street, Glasgow.
1877, Jan. 23:	Robert	Murray,	25A Coltman Street, Hull.
1857, Dec. 23:	John	*Napier,	23 Portman Sq., London.
1864, Feb. 17:	G. M.	Neilson,	Burnfoot House, Ardrossan.
Original:	Walter	Neilson,	172 West George Street, Glasgow.
Original:	Walter M.	Neilson,	(*Past President*), Queen's Hill, Kirkcudbrightshire.
1858, Jan. 20:	William	Neilson,	92 W. Regent St., Glasgow.
1869, Nov. 23:	Theod. L.	Neish,	Broughty Ferry, by Dundee,
1879, Oct. 28:	R. S.	Newall, F.R.S., F.R.A.S., &c.,	Ferndene, Gateshead on-Tyne.
	Benjamin	*Nicholson,	Shipbuilder, Annan.
	Hugh	*Niven,	Old Kilpatrick.
1876, Dec. 19:	Richard	Niven, C.E.,	Dalnottar House, Old Kilpatrick.
1876, Jan. 25:	Thomas Ogilvie	Niven, C.E.,	115 Wellington Street, Glasgow.

1861, Dec. 11: John	Norman,	16 Pulteney St., Glasgow.
1873, Dec. 23: Lewis	Olrick, C.E.,	27 Leadenhall St., London.
1860, Nov. 28: John W.	Ormiston,	Shotts Iron Works, by Wishaw.
1867, Apr. 24: T. R.	Oswald,	The Southampton Shipbuilding & Engineering Works, Southampton.
1864, Oct. 26: John	Page, C.E.,	39 Arlington Street, Glasgow.
1876, Apr. 25: William	Parker,	2 White Lion Court, Cornhill, London.
1877, Apr. 24: Andrew	Paul,	Levenford Works, Dumbarton.
1866, Dec. 26: William	Pearce,	Fairfield Shipyard, Govan.
1868, Dec. 23: Eugène	Perignon, C.E.,	105 Rue Faubourg, St. Honoré, Paris.
John	*Price,	Rose Villa, Gateshead Road, Jarrow-on-Tyne.
1875, Dec. 21: Matthew	Prior,	56 Ellesmere Rd., Sheffield.
1877, Nov. 20: F. P.	Purvis,	14 Strathleven Place, Dumbarton.
1868, Dec. 23: Henry M.	Rait,	155 Fenchurch St., London.
1873, Apr. 22: Richard	Ramage,	Shipbuilder, Leith.
1866, Dec. 26: Daniel	Rankin,	Eagle Foundry, Greenock.
1872, Oct. 22: David	Rankine,	75 West Nile Street, Glasgow.
1876, Dec. 19: Robert	Rankin,	35 Paisley Road, Glasgow.
1876, Oct. 24: Thomas E.	Rawlinson, C.E.,	Britannia Lodge, 2 Lyon's Road, Southport.
1868, Mar. 11: James	Reid,	Locomotive Works, Springburn.
1869, Mar. 17: James	Reid,	Shipbuilder, Port-Glasgow.

	John	*Reid,	Shipbuilder, Port-Glasgow.
1880, Apr. 27:	John	Rennie,	Kiangnan Arsenal, Shanghai, China.
1876, Oct. 24:	Duncan	Robertson,	30 Gordon Street, Glasgow.
Original:	James	Robertson,	Stanley St., Kinning Park, Glasgow.
1873, Jan. 21:	John	Robertson,	Grange Knowe, Pollokshields.
1873, Apr. 22:	M. W.	Robertson,	Avon Steel Works, Duke Street, Glasgow.
1867, Nov. 27:	Stewart	Robertson,	Barrow Shipbuilding Co., Barrow-in-Furness, Lancashire.
1863, Nov. 25:	William	Robertson,	C.E., 123 St. Vincent Street, Glasgow.
Original:	Hazltn. R.	*Robson,	(*Past President*), 14 Royal Cres., Glasgow.
1877, Feb. 20:	Jno. Macdonald	Ross,	11 Queen's Cres., Glasgow.
1861, Dec. 11:	Richard G.	Ross,	21 Greenhead St., Glasgow.
1870, Jan. 18:	Alexander	Ross, C.E.,	Alva.
Original:	David	*Rowan,	(*Past President*), 231 Elliot Street, Glasgow.
1876, Oct. 24:	Alfred	Rumball, C.E.,	23 Parliamentary Street, Westminster, S.W.
1863, Mar. 4:	George	Russell,	Engineer, Motherwell.
1877, Oct. 30:	Alexander	Russell,	100 Cheapside St., Glasgow.
1859, Dec. 21:	Thomas	*Russell,	Albyn Lodge, Bridge of Allan.
1876, Oct. 24:	Peter	Samson,	Board of Trade Offices, Downing Street, London, S.W.
1872, Jan. 30:	James E.	Scott,	Shipbuilder, Eldon Street, Greenock.
1860, Nov. 28:	Thos. B.	*Seath,	42 Broomielaw, Glasgow.

1875, Jan. 26:	Alexander	Shanks,	Belgrade, Ayton Road, Pollokshields.
1858, Nov. 24:	William	Simons,	Renfrew.
1862, Jan. 22:	Alexander	Simpson, C.E.,	175 Hope Street, Glasgow.
1871, Mar. 28:	Hugh	Smellie,	Belmont Grange Terrace, Kilmarnock.
Original:	Alexander	Smith,	57 Cook Street, Glasgow.
1869, Mar. 17:	David S.	Smith,	Hellenic Steam Navigation Co., Syra, Greece.
1859, Jan. 19:	George	Smith,	Kennedy Street, Parliamentary Road, Glasgow.
1861, Dec. 11:	Hugh	Smith,	9 Kelvinside Terrace, N., Glasgow.
1874, Oct. 27:	Hugh	Smith,	57 Cook Street, Glasgow.
1873, Nov. 25:	Henry B.	Smith, C.E.,	Canadian Pacific Ry. Office, Prince Arthur's Landing, Lake Superior, Canada.
1878, May 14:	James	Smith,	40 Margaret St., Greenock.
Original:	William	Smith,	57 Cook Street, Glasgow.
1870, Feb. 22:	Edward	Snowball,	Engineer, Hyde Park Locomotive Works, Springburn.
Original:	Robert	*Steele,	Shipbuilder, Greenock.
	William	*Steele,	Shipbuilder, Greenock.
	John	*Stephen,	Linthouse, Govan.
1859, Jan. 19:	David Y.	Stewart,	3 Provan Place, Glasgow.
1867, Jan. 30:	Duncan	Stewart,	47 Summer Street, Glasgow.
1874, Oct. 27:	Peter	Stewart,	53 Renfield Street, Glasgow.
1866, Nov. 28:	James	Stirling,	Loco. Engineer, S. Eastern Ry., Ashford, Kent.
Original:	Patrick	Stirling,	The Great Northern Railway, Doncaster.
1874, Nov. 23:	Edward	Strong,	c/o Kent Cottage, Queen's Cres., Southsea, Hants.
1877, Jan. 23:	James	Syme,	358 Paisley Road (West), Govan.

1879, Oct. 28: James Tait, C.E., Wishaw.
1879, Mar. 25: Stavely Taylor, 13A Exchange Buildings, Liverpool.
1873, Dec. 23: E. L. Tessier, Veritas Office, 29 Waterloo Street, Glasgow.
1874, Nov. 24: Prof. James Thomson, F.R.S.S.L. & E., LL.D., C.E., Oakfield House, University Avenue, Glasgow.
1868, Feb. 12: James M. Thomson, 36 Finnieston St., Glasgow.
1868, May 20: John Thomson, 36 Finnieston St., Glasgow.
1876, Feb. 22: John Thomson, 147 E. Milton St., Glasgow.
1875, Jan. 26: Robert S. Thomson, 19 Windsor St., Glasgow.
1864, Feb. 17: W. R. M. Thomson, 96 Buchanan St., Glasgow.
1878, May 14: W. B. Thompson, Tay View, Broughty Ferry.
1878, Oct. 29: Cornelius Thompson, 17 Albyn Place, Aberdeen.
Original: Thomas C. Thorburn, 35 Hamilton Square, Birkenhead.
1874, Oct. 27 Prof. R. H. Thurston, M.E., C.E., Steven's Institute of Technology, Hoboken, N. Jersey, U.S.A.
1875, Nov. 23: John Turnbull, jun., Consulting Engineer, 184 Buchanan St., Glasgow.
1876, Nov. 21: Alexander Turnbull, 5 Gartocher Ter., Shettleston.
1876, Jan. 25: Henry Turner, Managing Engineer, Canada Works, Birkenhead.
1880, Apr. 27: John Tweedy, Neptune Works, Newcastle-on Tyne.

1865, Apr. 26: W. W. Urquhart, Blackness Foundry, Dundee.

1872, Mar. 26: Henry Hay Wake, Engineer, River Wear Commission, Sunderland.
1872, Nov. 26: Nicholas Watts, C.E., 34 Porchester Square, London, W.
1875, Mar. 23: G. L. Watson, 108 W. Regent St., Glasgow.

1864, Mar. 16:	W. R.	Watson,	16 Woodlands Ter., Glasgow.
1872, Nov. 26:	Middlemost	Wawn,	64 Fawcett St., Sunderland.
1865, Apr. 26:	William	Weems,	Engineer, Johnstone.
	John	*Weild,	Underwriter, Exchange, Glasgow.
1874, Dec. 22:	George	Weir, M.E.,	18 Millbrae Cres., Langside.
1874, Dec. 22:	James	Weir, M.E.,	Silver Bank, Cambuslang.
1869, Feb. 17:	Thomas M.	Welsh,	63 St. Vincent Cres, Glasgow.
1868, Dec. 23:	Henry H.	West,	13A Exchange Buildings, Liverpool.
1876, Oct. 24:	Francis W.	Willcox,	64 Fawcett St., Sunderland.
1875, Dec. 21:	John	Williams,	Marine Engineer, °/o Messrs M'Kinnon, M'Kenzie, & Co., Calcutta.
1878, Oct. 29:	Thomas	Williamson,	1 Hallside, Newton.
Original:	John	Wilkie,	33 Renfield St., Glasgow.
1874, Feb. 24:	Alexander	Wilson,	Engineer Surv., Harbour Office, Melbourne.
	Alex. H.	*Wilson,	Aberdeen Iron Works, Aberdeen.
1868, Dec. 23:	James	Wilson, C.E.,	Water Works, Greenock.
1863, Mar. 18:	James E.	Wilson,	1 Ranfurly Place, Paisley Road, Glasgow.
1876, Oct. 24:	Jno. Paul	Wilson,	Tweed Shipbuilding Yard, Berwick-on-Tweed.
1870, Feb. 22:	John	Wilson,	Florence Bank, Hillside Terrace, Springburn.
1858, Jan. 20:	Thomas	*Wingate,	Viewfield, Partick.
1879, Oct. 28:	John	Young,	Phœnix Iron Works, Glasgow.
1867, Nov. 27:	John	Young,	Galbraith Street, Stobcross, Glasgow.
1871, Apr 18:	James	Young,	137 W. Regent St., Glasgow.
1870 Nov. 22:	William	Young,	Vulcan Foundry, Ayr.

ASSOCIATES.

	Thomas	*Aitken,	8 Dock Place, Leith.
	Andrew	*Armour,	68 AnderstonQuay,Glasgow.
	T. S.	*Begbie,	36 Walbrook, London, E.C.
	Capt. Alex.	*Blackwood,	Leith.
1876, Jan. 25:	John	Brown,	11 Somerset Place,Glasgow.
1877, Nov. 20:	Capt. Wm.	Brown,	15 St. Vincent Pl.,Glasgow.
1865, Jan. 18:	John	Bryce,	82 Oswald Street, Glasgow.
1875, Feb. 23:	Daniel	Cocking,	202 Hope Street, Glasgow.
1870, Dec. 20:	Joseph J.	Coleman, F.C.S.,	45 W. Nile St., Glasgow.
1859, Nov. 23:	Arch. Orr	Ewing, M.P.,	2 W. Regent St., Glasgow.
1863, Mar. 18:	Robert	Gardner,	52 North Frederick Street, Glasgow.
1865, Dec. 20:	James	Haddow,	43 Oswald Street, Glasgow.
1860, Jan. 18:	George T.	Hendry,	79 Gt. Clyde St., Glasgow.
1864, Dec. 21:	Anderson	Kirkwood, LL.D.,	12 High Windsor Terrace, Glasgow.
1878, Oct. 29:	John	Langlands,	88 Gt. Clyde St., Glasgow.
1865, Dec. 20:	John Jex	Long,	12 Whitevale, Glasgow.
1874, Mar. 24:	Peter	Marshall,	6 Park GroveTer.,Glasgow.
1873, Feb. 18:	John	Mayer, F.C.S.	2 Clarinda Terrace, Pollokshields.
1874, Mar. 24:	James B.	Mercer,	Broughton Copper Works, Manchester.
	George	*Miller,	1 Wellesley Place, Glasgow.

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

1865, Dec. 20:	John	Morgan,	Springfield House, Bishopbriggs.
	James S.	*Napier,	33 Oswald Street, Glasgow.
	John	*Phillips,	17 Anderston Quay, Glasgow.
1869, Nov. 23:	Capt. John	Rankine,	31 Airlie Terrace, Pollokshields.
1867, Dec. 11:	William H.	Richardson,	19 Kyle Street, Glasgow.
1876, Jan. 25:	George	Smith,	101 St. Vincent St., Glasgow.
	John	*Smith,	Aberdeen Steam Navigation Co., Aberdeen.
	Malcolm M'N.	*Walker,	45 Clyde Place, Glasgow.
	H. J.	*Watson,	62 Jamaica Street, Glasgow.
	T.	*Westhorp,	West India Road, London.
1860, Nov. 28:	James	Young,	Kelly, Wemyss Bay.
	William	*Young,	Galbraith Street, Stobcross, Glasgow.

GRADUATES.

1875, Dec. 21:	Sanchez de	Agreda,	30 Lancefield Quay, Glasgow.
1876, Jan. 25:	James	Aird,	96 Buchanan St., Glasgow.
1880, Feb. 24:	George	Almond,	Belmont, Bolton-le-Moors, Lancashire.
1874, Feb. 24:	James	Anderson,	38 Berkeley St., Glasgow.
1870, Apr. 19:	John	Anderson,	c/o J. H. W. Shaw, 115 Buchanan St., Glasgow.
1876, Dec. 19:	Robert	Anderson,	175 Hope Street, Glasgow.
1875, Dec. 21:	G.	Arnison, jun.,	81 Berry Street, Bootle, Liverpool.

1869, Nov. 23:	J. de Caynoth	Ballardie,	°/o Messrs Ballardie Bros., 2 W. Howard St., Glasgow.
1877, Nov. 20:	James T.	Baxter,	83 W. Regent St., Glasgow.
1871, Feb. 21:	W. S.	Beck,	26 Granville St., Glasgow.
1880, Mar. 23:	Alexander	Bowie,	5 India Street, Glasgow.
1873, Dec. 23:	Wm. G.	Bowser,	Great Wellington St., Paisley Road, Glasgow.
1873, Dec. 23:	William	Boyd, jun.,	2 Park Quadrant, Glasgow.
1878, Dec. 17:	Rowland	Brittain,	18 Petershill Rd., Glasgow.
1873, Dec. 23:	James	Broadfoot, jun.,	4 La Belle Place, Glasgow.
1876, Jan. 25:	A. M'N.	Brown,	Castlehill House, Renfrew.
1874, Jan. 27:	William	Brown,	Castlehill House, Renfrew.
1879, Feb. 25:	Alex. T.	Brown,	116 South Portland Street, Glasgow.
1872, Oct. 22:	Hartvig,	Burmeister,	°/o Messrs Rahr & Raundrap, 14 Brown Street, Manchester.
1876, Dec. 19:	Lindsay	Burnet,	University College, Gower Street, London.
1873, Dec. 23:	Archibald	Butters,	27 Renfield Street, Glasgow.
1873, Dec. 23:	David	Campbell,	Milton Iron & Steel Works, Motherwell.
1873, Dec. 23:	Walter M.	Chambers,	Messrs Laird Bros., Engineers and Shipbuilders, Birkenhead.
1876, Dec. 19:	Charles	Connell, jr.,	Rozelle, Partick.
1877, Dec. 18:	James	Conner,	9 Scott Street, Glasgow.
1876, Jan. 25:	William M.	Cooke,	13 Alberta Terrace, Byars Road, Hillhead.
1874, Feb. 24:	Andrew	Corbett,	Kelvinhaugh Street Engine Works, Glasgow.
1874, Feb. 24:	Lewis P.	Coubro,	220 DumbartonRd., Gl'gow.
1874, Feb. 24:	James	Davie,	352 St. VincentSt., Glasgow.

1879, Oct. 28: Jonathan L.	Dean,	203 St. Vincent St., Glasgow.
1873, Dec. 23: Walter	Deed,	80 St. George's Rd., Glasgow.
1873, Dec. 23: Peter	Dewar,	25 North Street, Glasgow.
1879, Nov. 25: Alex. B.	Dobbie,	292 St. Vincent St., Glasgow.
1877, Nov. 20: Thomas	Dunlop,	Burgh Surveyor's Office, Kirkcaldy.
1876, Dec. 19: Harry	Edwards,	145 St. Vincent St., Glasgow.
1878, Jan. 22: James R.	Faill,	128 N. Montrose Street, Glasgow.
1875, Apr. 27: Charles	Fergus,	25 Dorset Street, Glasgow.
1873, Dec. 23: E. Walton	Findlay,	33 Bath Street, Glasgow.
1874, Feb. 24: John	Fleming,	52 Dumbarton Rd., Glasgow.
1869, Oct. 26: F. P.	Fletcher,	Engineer Office, Mid. Railway, Derby.
1878, Dec. 17: Hendrick Van	Gelder	17 Croft Terrace, Jarrow-on-Tyne.
1873, Dec. 23: Andrew	Gibb,	c/o Milwall Dock Engineering Works, Milwall Docks, London.
1874, Feb. 24: James	Gillespie,	21 Cleveland St., Glasgow.
1873, Dec. 23: Osbourne H.	Greenslade,	105 South Portland Street, Glasgow.
1874, Feb. 24: James	Grier, jun.,	29 Waterloo St., Glasgow.
1874, Feb. 24: Archibald	Hamilton,	16 Robertson St., Glasgow.
1873, Dec. 23: David C.	Hamilton,	Clyde Shipping Co., 2 Oswald Street, Glasgow.
1874, Feb. 24: C. R.	Harvey,	4 South Wellington Place, Glasgow.
1873, Dec. 23: Guybon	Hutson,	4 Woodburn Place, Glasgow.
1877, Mar. 20: Alex. C.	Jamieson,	15 Craigton Terrace, Paisley Road, Glasgow.
1873, Dec. 23: David	Johnston,	12 York Street, Glasgow.

1880, Jan. 27: Robert	Kerr,	109 Bath Street, Glasgow.
1878, Jan. 22: Easton	Knox,	47 Crownpoint Road, Mile End, Glasgow.
1876, Oct. 24: Jno. M.	M'Currich, M.A.,	203 St. Vincent Street. Glasgow.
1879, Jan. 21: James	M'Farlane,	40 Claremont St., Glasgow.
1874, Feb. 24: George	M'Farlane,	65 Gt. Clyde St., Glasgow.
1880, Feb. 24: Neil	M'Kechnie,	31 Bank Street, Hillhead.
1876, Dec. 19: John	M'Kirdy,	West Bay, Millport.
1875, Dec. 21: Hugh	M'Laughlan,	5 Dowanhill Pl., Partick.
1875, Dec. 21: Allister	M'Niven,	Clutha Iron Works, Vermont Street, Glasgow.
1880, Jan. 27: G. Scott	M'Ritchie,	Gilshochill, Maryhill.
1879, Oct. 28: Donald	M'Taggart,	38 Dover Street, Glasgow.
1874, Feb. 24: Andrew	Maclean, jun.,	Whiteinch House, Partick.
1874, Feb. 24: William	Maclean,	Whiteinch House, Partick.
1874, Feb. 24: Alexander	Malloch,	Linwood, Renfrewshire.
1878, Jan. 21: Robert	Marshall,	17 Minerva St., Glasgow.
1874, Feb. 24: Thomas W.	Meikle,	Viewfield House, Pollokshields.
1876, Oct. 24: James	Meldrum,	Messrs R. Ward & Co., 139 St. Vincent St., Glasgow.
1880, Feb. 24: Robert	Miller,	1 Wellesley Place, Sandyford, Glasgow.
1873, Dec. 23: George	Miller, jun.,	268 Bath Cres., Glasgow.
1873, Dec. 23: John F.	Miller,	1 Wellesley Place, Sandyford, Glasgow.
1879, Jan. 21: Alexander	Mitchell,	55 Kelvinhaugh St., Glasgow.
1880, Feb. 24: James F.	Mitchell,	23 St. Vincent Crescent, Glasgow.
1877, Dec. 18: John	Moore,	26 Raglan St., Glasgow.
1880, Jan. 27: James	Morton,	116 Woodlands Road, Glasgow.

1878, Dec. 17: Robert	Morton,	Balclutha, Greenock.
1878, May 14: Angus	Murray,	47KelvinhaughSt.,Glasgow.
1875, Dec. 21: James S.	Murray,	3 Callander Place, Cathcart Road, Glasgow.
1877, Dec. 18: John J.	Muir,	2 Gt. Wellington St., Glasgow.
1873, Dec. 23: George A.	Newall,	St. Philip Iron Works, Bristol.
1876, Jan. 25: Thos. G. F.	Palmer	Clutha Iron Works, Vermont Street, Glasgow.
1880, Jan. 27: Hermann	Pape,	Grosse Allée 6th, Hamburg, Germany.
1880, Mar. 23: J.	Patterson, jn.,	1 Alberta Terrace, Byars Road, Glasgow.
1879, Nov. 25: Alex. R.	Paton,	Redthorn, Partick.
1873, Dec. 23: Edward C.	Peck,	Messrs Yarrow & Coy., Poplar, London, E.
1876, Oct. 24: John James	Pollock,	Auchineden, by Strathblane.
1880, Jan. 27: James S.	Porter,	449 St. Vincent St., Glasgow.
1875, Apr. 27: Robert	Rankine,	51 Gardner Street, Glasgow.
1873, Dec. 23: Charles H.	Reynolds,	9 Broomhill Terrace, (West), Partick.
1878, Dec. 17: James R.	Ross,	c/o Messrs Mirrlees, Tait, & Watson, Scotland Street, Glasgow.
1875, Dec. 21: James	Rowan,	22 Woodside Pl., Glasgow.
1879, Nov. 25: Charles G.	Russell,	Walkenshaw Foundry, Johnstone.
1879, Nov. 25: Robert	Russell,	Craigie Bank, Crosshill.
1875, Oct. 26: Magnus	Sandison,	455 Paisley Road, Glasgow.
1879, Mar. 25: John	Scobie,	Culdees Minard Rd., Partickhill.
1880, Apr. 27: Archibald	Sharp,	31 Morrison St., Glasgow.

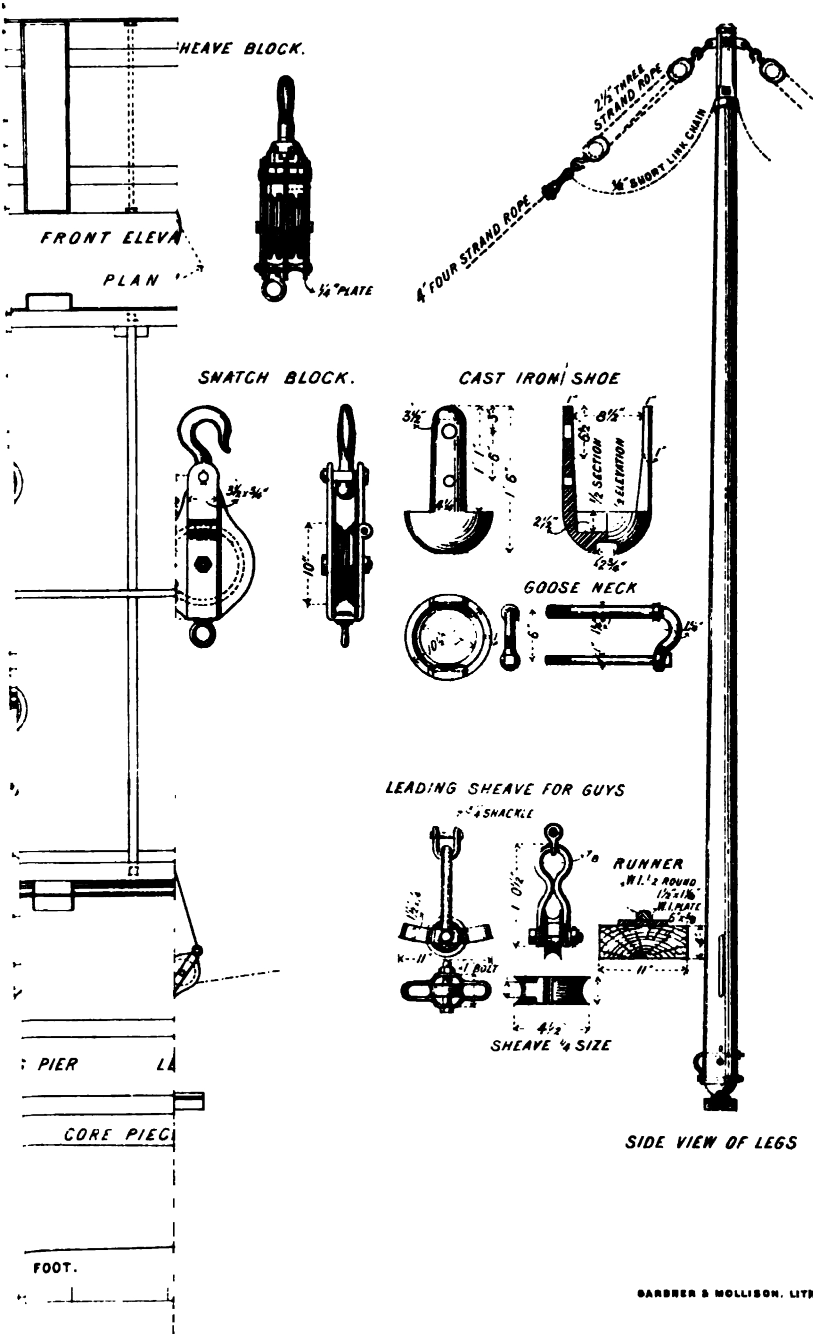
1880, Jan. 27: H.	Sherlock,	91 Kent Road, Glasgow.
1880, Mar. 23: Robert M.	Short,	5 Maxwell Street, Partick.
1877, Mar. 20: Nisbet	Sinclair, jun.,	2 Clelland Place, Paisley Road, Glasgow.
1877, Nov. 20: Robert	Smith,	Parkgrove Iron Works, Kinning Park, Glasgow.
1873, Dec. 23: John	Stewart,	270 New City Rd., Glasgow.
1879, Feb. 25: James	Stewart,	21 Gibson St., Hillhead.
1877, Oct. 30: T. J. R.	Stewart,	23 Miller Street, Glasgow.
1873, Dec. 23: W. B.	Stewart,	2 Provan Place, Glasgow.
1875, Dec. 21: Andrew	Stirling,	98 Dumbarton Road, Glasgow.
1877, Jan. 23: George	Stirratt,	26 Lynedoch St., Glasgow.
1878, Jan. 22: Benj. B.	Sykes,	c/o Messrs Dubs & Co., Locomotive Works, Glasgow.
1874, Feb. 24: George C.	Thomson,	77 Hill Street, Garnethill, Glasgow.
1878, Dec. 17: James	Watson,	138 W. Regent St., Glasgow.
1880, Apr. 27: Robert D.	Watt,	9 Osborne Terrace, Govan.
1875, Dec. 21: Richard G.	Webb,	Clutha Iron Works, Gl'gow.
1878, Dec. 17: Robert L.	Weighton,	133 Dumbarton Rd., Gl'gow.
1876, Dec. 19: Thomas D.	Weir,	Arbroath and Montrose Railway, Arbroath.
1874, Feb. 24: William	Whyte,	37 Dorset Street, Glasgow
1877, Jan. 23: Robt. John	Wight,	5 Clarinda Ter., Pollokshields.
1879, Oct. 28: William	Willox, M.A.,	203 St. Vincent St., Glasgow
1873, Dec. 23: Robert	Wyllie,	7 Ibrox Place, Govan.
1873, Dec. 23: Robert	Young,	138 Buchanan St., Glasgow.

INDEX.

E.

G CONCRETE BLOCKS

PLATE. X



GARDNER & MOLLISON, LITH