

Mr. Conder. whenever they met, instead of only at twelve or fourteen places. An elliptic section, 240 feet by 30 feet, would probably long suffice for the Mediterranean traffic of the world.

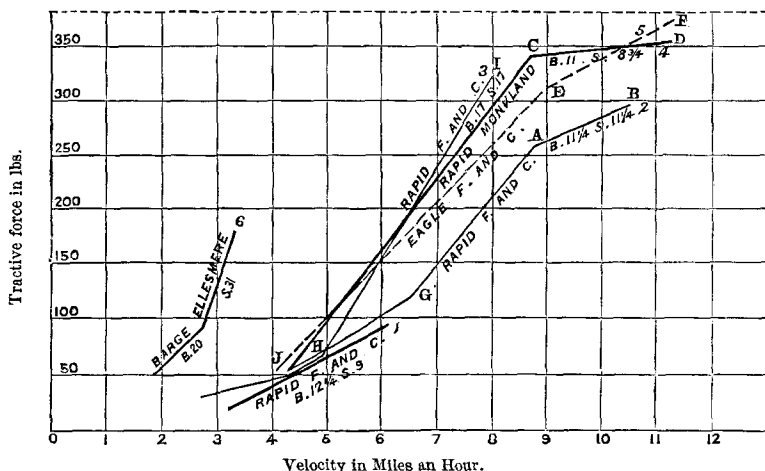
Correspondence.

Mr. Atkinson. Mr. W. ATKINSON stated that in order to ascertain whether in the passage of a boat along a canal water flowed backwards under the boat, or whether it did not, he had prepared a trough 18 feet long, 10 inches wide, and 8 inches deep, and had made a boat to represent a canal boat 70 feet long with 7 feet beam, to a scale taking 10 inches to represent 30 feet, the width of the Ellesmere Canal. Two pulleys fixed on the same axis were used, the smaller one with a weight and the larger one with a string to tow the boat. By this means he had conducted trials of speed and resistance. Small pieces of cork, weighted so as to be slightly heavier than water, were placed on the bottom. The boat drew $1\frac{1}{4}$ inch, and there was a depth of $1\frac{1}{2}$ inch of water under it. At a speed of 1·2 mile an hour the corks did not move forward, but slightly backwards as the boat passed, about the twenty-fourth part of the length of the boat. At a speed of 1·6 mile, the whole body of water moved forward and the corks also as the boat approached, and then as the boat passed the corks moved backwards under the boat for some distance, but returned, and rested behind the point from which they started, as in the previous experiment. He believed that with a trough 40 feet long and 3 feet wide, and by the introduction of various combinations of boards so as to represent various sections of canals, and then trials with different boats, the solution of the problem might be arrived at. Even with the slight experiments referred to the heaping up of the water at the end to which the boat was going, and the fall at the other end was most marked, as also was the very great increase in the wave with a small increase in speed. Further, the ratio of the power and velocity corresponded closely with Palmer's experiments on the Ellesmere Canal, as detailed in the first volume of the "Transactions," and shown as No. 6 on the accompanying diagram (Fig. 17). But although the Author complained that experiments had not been made to ascertain the proper relative proportions of canals and boats, it was possible that he might have obtained valuable information by an analysis of various recorded experiments. Taking Sir John Macneill's experiments,¹ it would be found that

¹ Transactions Inst. C.E., vol. i., p. 237.

the "Rapid" on the Forth and Clyde Canal—90 feet wide and 9 feet 6 inches deep in the centre—required a pull of 200 lbs. to produce a speed of 8 miles an hour, whereas on the Monkland Canal, 60 feet wide and 5 feet 3 inches deep, a pull of 300 lbs. was necessary, the weights carried being the same in both cases. As the same boat was used it would be seen by calculating the cost of the two canals and comparing the annual traffic which was the more economical. As illustrations of how difficult any solution by complicated formula would be, the above experiments showed that when the "Rapid" drew $10\frac{1}{2}$ inches, a pull of 90 lbs. gave a speed of 6 miles, but with a draught of 17 inches a pull of 160 lbs. was necessary. Again, in the ratio of the velocity and tractive force, the power to which the velocity had to be raised varied as the section of the canal varied; also as the draught varied on the same canal, and most curiously diminished greatly when a speed of about 9 miles had been attained. These results were clearly illustrated by Fig. 17, which he had prepared from the experi-

FIG. 17.



'Rapid,' passenger-boat, 65 feet long, 6 feet beam; "Eagle," passenger-boat, 90 feet long, 7 feet 6 inches beam; Barge, 68 feet 6 inches long, 6 feet beam.

F and C—Forth and Clyde Canal. B, bow; S, stern. Figures following denote the draught in inches.

ments already referred to. Taking the same boat on the same canal, but varying the draught, it was seen that No. 1, with a draught of $10\frac{1}{2}$ inches, gave $V^2 : F :: v^2 : f$; but in No. 2, with $11\frac{1}{2}$ inches, it was as $V^{2.4}$ from G to A, and in No. 3, with 17 inches, as $V^{3.2}$. Then by comparing the same boat on two dif-

Mr. Atkinson. ferent canals, on No. 2 and No. 4 the ratio was as $V^{2.4}$ from G to A, and H to C, yet the tractive power required on the smaller canal was about 50 per cent. more than on the larger one. Fig. 17 showed that the power to which V had to be raised fell from A to B to 0.74, and at other rates, from C to D and E to F, there being concurrent evidence in all these of a law, probably dependent on the peculiar wave generated. No. 6 was taken from Mr. Palmer's experiments, and gave about V^3 for a deeply laden barge on a narrow canal.

Mr. Bruges. Mr. C. E. BRUGES remarked that the best form of cross-section for a canal greatly depended on the nature of the soil through which it was cut, and on the kind of traffic for which it was intended. The section which theory pointed to as the best had frequently to be abandoned for various practical considerations. When a vessel passed through a canal she was continually displacing an amount of water equal to the maximum cross-area of the immersed portion of the hull multiplied by its velocity, and this amount of water must be discharged in the same time through the remaining cross-sectional area of the canal unoccupied by the boat, in a reverse direction; otherwise the water displaced would accumulate in front of the boat. A head would be necessary, of course, to give this water its retrograde velocity, but the amount of head required would depend mainly on the hydraulic mean depth of that portion of the cross-section of the canal unoccupied by the vessel. This head had to be produced by the energy of the boat. By increasing the hydraulic mean depth of this remaining area to a maximum, the friction or head required was reduced to a minimum.

The reason of the increase of speed when a boat passed over a deep portion of a channel was, that the remaining cross-area of the channel and hydraulic mean depth were both increased. Since the hydraulic mean depth of the canal itself was $\frac{A}{P}$, where A and P were the cross-sectional area and wetted perimeter of the canal respectively, $\frac{A - a}{P + p}$ would be the hydraulic mean depth of that cross-area unoccupied by the vessel, where a and p were the area and wetted perimeter of the immersed portion of the hull. For a given cross-sectional area of canal and boat, this would be a maximum when P was a minimum; that was, when the hydraulic mean depth of the canal $\frac{A}{P}$ was a maximum. Therefore the hydraulic mean depth of this remaining cross-sectional area was greatest when

that of the whole canal was greatest. Accordingly, canals in- Mr. Bruges.
tended for navigation must be constructed under the same theory
as ordinary water-channels, where for a given area a maximum
hydraulic mean depth was required.

Suppose an intended section of a canal to be trapezoidal, it was
easy to prove by a differential equation that the hydraulic mean
depth was a maximum for a given area, when it was equal to half
the actual depth. If the area was known = A , and also the slope
of the sides, the co-tangent of the inclination = m (1 to 1 = 1, 2 to 1
= 2, &c.), x the bottom width, and h the depth, might be found
from the following equations :—

$$x = 2h (\sqrt{m^2 + 1} - m)$$

$$h = \sqrt{\frac{A}{2\sqrt{m^2 + 1} - m}}.$$

If x and h were calculated in this way, the hydraulic mean depth
would always be a maximum for the given area, *i.e.*, equal to half
the depth. These equations would serve to determine the dimen-
sions of the canal when the area and inclination of the sides were
known ; but more detailed information might be found in various
hydraulic works bearing on this point. The form of section, with
a maximum hydraulic mean radius, might be constructed graphi-
cally by describing a semi-circle, and drawing the sides of the
canal to touch the circle, the waterline passing through the centre.
All such sections would have a hydraulic mean radius equal to
half the radius of the circle, and this might be extended for any
number of sides, merging into the semi-circle as the number
increased without limit.

It might be remarked that of trapezoidal sections the semi-
hexagon was the best, as it had the least area when the hydraulic
mean depth was half the depth of the canal. Where the canal
was of considerable width to enable ships to pass each other, it
would not be practicable to excavate the canal to the depth
necessary to give a maximum hydraulic mean radius to the sec-
tional area, on account of the great depth it would involve. Nor
was it essential, as the great additional area at the side of the
ships necessary for the traffic to pass, compensated to some extent
for the want of depth immediately beneath the ship. The dimen-
sions of the canal would then generally be ruled by the maximum
draught of the vessels it was intended for, and the width at this
depth necessary for them to pass. The sides of the canal would
slope according to the nature of the soil.

Mr. Burke. Mr. G. J. BURKE observed, with respect to the Suez Canal, that the Author expressed much surprise at what he termed the "remarkable phenomenon of the retardation effected in the passage of vessels" of recent years. This admitted of a very simple explanation; namely, that as the traffic had steadily increased whereas the canal section remained constant, each vessel passing through must as a matter of course be detained for an increased length of time, owing to the greater probability of detention at each passing station for vessels, and owing to the increased chance of blocks in the canal. In fact, the converse of the Author's statement would be the correct assumption; and it would be a "remarkable phenomenon" if with increasing traffic the average time of passage remained unchanged. Mr. Samuda appeared to think that the fact that vessels which in open water were able to maintain a speed of 14 miles an hour, could only pass through the canal at about 5 miles an hour was a preventable evil, and that with an increased width of canal a higher rate of speed could be maintained. It seemed certain that owing to the amount of extra damage that would be sustained in consequence of the increased wash, that the canal authorities would never consent to a higher rate of speed. It must not be forgotten that this canal was excavated in quicksand, and that therefore the speed must be kept as low as possible in order to prevent erosion of the sides and silting up of the bed. It seemed a not improbable surmise that the present maximum speed allowed was that which experts considered would be the minimum necessary to enable a vessel to steer properly. Of course this would not apply to all the canal vessels, but the greater number of those passing through were unwieldy cargo ships that needed this amount of "way" to enable them to steer in mid-channel. The best method of shortening the time of the trip would be to arrange for the passage of vessels by night as well as by day. This ought not to be a difficult matter with the assistance of the electric light. It would be an expensive undertaking to light the whole waterway from end to end with lamps at fixed intervals, but this would not be required; each vessel might light her own track by means of a powerful electric lamp or lamps fixed in the fore part, worked by the surplus power of the main engine, or by a donkey-engine. The dynamos might be hired from the canal-authorities, who might keep an adequate supply of them. The elliptical section proposed by the Author for the Suez Canal seemed to be unpractical, taking into account that, as before stated, the channel was excavated in quicksand, and that therefore side-walls would be required, and those of the most

expensive type of construction. On the canal face of each, from Mr. Burke. the nature of the section, there would be no adequate lateral support except the water-pressure. So that the foundations should of necessity be carried down to a considerable depth below the bed of the canal, and the whole structure down to at least the bed-level should be designed as a retaining wall. The enormous expense of such a work would be a fatal bar to the adoption of the proposed section. In the course of his remarks made after the reading of the Paper, the Author stated that the well-known formula for the discharge in channels—

$$V = c \sqrt{r s}$$

would be more precisely expressed if put in another form, thus :—

$$V = C \sqrt[a]{R^m S^n};$$

but giving no indication as to the manner in which the values of a , m , and n were to be determined, or not giving a single reason in support of his assertions. Now in "Downing's Hydraulics"¹ a very clear and succinct investigation had been given, and the mathematical proof established of the form of expression for the velocity—

$$V = c \sqrt{r s},$$

and it would need something more than the mere assertion of the Author to upset this proof.

The Author also expressed the opinion that hydraulic formulas in general were mere "rule of thumb" and worth very little. It seemed difficult to understand how any engineer who had much to do with the practical application of these formulas could express such an opinion; they rested on a double basis, mathematical and experimental. Such defects as they possessed, and they were far from perfect, were owing to a want of completeness in the experimental part of the question, although of late years much had been done by men who, like Darcy and Bazin, Humphreys and Abbot, and Major Allan Cunningham, had, in the true spirit of scientific inquiry, pursued their experiments and had placed the laws of hydraulics on a more secure footing; and it was only from the labour of competent and careful observers like these that further improvement in hydraulic formulas could be looked for; doubtful

¹ 3rd edition, 1875, pp. 195-211.

Mr. Burke. theories and unproved assertions such as had been put forward in this Paper would be of little help.

Mr. Culverwell. Mr. G. P. CULVERWELL wished to point out that in general a double-way canal possessed some important advantages over a pair of single-way canals.

As regarded cost of construction. Assuming the canals to be in 30 feet depth of cutting with slopes $1\frac{1}{2}$ to 1, then the pair of single-way canals entailed an excess of excavation of 264,000 cubic yards per mile, an excess of 52 statute acres of land per mile, also double the cost of slope-protection. In maintenance and working the "double-way" canal was economical owing to concentration of management and superintendence, and only a single set of dredging and other plant was required; also much less dredging had to be done, it being recognised that the chief wear and tear was in the slopes, the superficies of which in the "double-way" were only half that in the pair of single-way canals, and where there were locks, or where water was scarce, the double-way was economical both as regarded water for lockage and evaporation. Then, in affording facilities for traffic the "double-way" possessed some distinct advantages. As the proportions of up-and-down traffic were not constant but varied throughout the year, the extra width of canal could accommodate the varying conditions. This was an advantage which public roads in common with canals had over railways.

Again, not only increased depth but increased width was of importance in reference to the speed and easy movement of the vessel, and this again reacted favourably in producing less wear and tear per unit of slope area. In cases of vessels foundering, the advantages of the "double-way" were obvious, and likewise where dredging and other plant usurped the water-way. No doubt these matters were elementary, but at the same time they were of fundamental importance.

Before concluding he wished to refer to the point whether vessels moving in canals created a backward keel-current. A little consideration would show they did. When a vessel moved the water was compressed towards the bow, and, so to speak, relaxed towards the stern. Take two extreme cases, that of a vessel in the open sea, and that of a vessel on a very contracted canal.

In the open sea, suppose the vessel moved forward, a vacuum would be formed immediately in the rear of the stern but for the water which flowed in from all sides, and likewise the water would be heaped up towards the bow, but that it was free to flow back and assist in filling in the deficiency towards the stern. It was to

be noted that the water at the stern at and below the line of the keel flowed in at a maximum velocity, the hydraulic depth being here a maximum, and thus even in the open sea a backward keel-current was generated. Mr. Culverwell.

Now, in a very contracted channel, where the spaces between the sides of the vessel and the slopes of the canal vanished, it was obvious that for every length the vessel moved forward, a body of water equal to its displacement passed in the same time in the form of a backward keel-current, and the greater the velocity of the vessel and the less the distance between the bottom of the vessel and the floor of the canal, the greater would be the velocity of the back-current. According to the velocity of the vessel so would the water rise at the bow, until the hydraulic depth was such that the cube of water equal to the displacement was discharged in the same time that the vessel took to traverse its own length.

All this went to show why it was so much harder to propel a vessel in a contracted channel than in the open sea-way, because in the former so much work was absorbed in the movement and heaping up of water. How far it might be economical to economize this back-keel current for keeping channels free from silt or weeds was an interesting question. The whole matter of backward current was an important one. From it arose the great difficulty in steering vessels in contracted channels. It was a question whether ocean-going vessels which had to traverse long canals ought not to be provided with some arrangement for steering from the bow or elsewhere, in place of from the stern where there was no undisturbed water to act against. A simpler plan might be, upon entering the canal, temporarily to add to the width of helm, so that it might strike further back into the less broken water. In the case of a vessel moving in a contracted channel, the increased head of water at the bow would elevate that portion, whilst at the same time the stern would be depressed through the relaxed pressure there. It appeared therefore that the tangent of the angle of the inclined plane was the measure of the special resistance due to the form of the channel, the form of the vessel, and the velocity.

Mr. J. R. Mosse remarked, having passed five times through the Suez Canal, he could corroborate the fact of "the damage caused to the banks by the wave produced by steamers," the rough retaining-wall, more like pitching, having been in many places destroyed by the wave-action. He had three times passed through the canal in from thirty to thirty-three hours; but on one occasion was detained nearly three days. It was found very difficult to

Mr. Mosse. steer vessels of from 3,000 to 4,000 tons, and dredgers were continually at work deepening the canal. When traversing another canal about 40 feet wide, contained within retaining walls, in a small boat holding three persons, hauled by four men at a speed of four or five miles an hour, he found the boat produced a wave of a precisely similar nature to that which obtained in the Suez Canal. Mr. Mosse then referred to previous Papers which had appeared in the Minutes of Proceedings, and to discussions at the meetings, which bore upon the subject of the speed of vessels in canals;¹ the injury done to the banks of canals at various speeds;² and to formulas relating to the movement of water in channels.³ With respect to the latter, practical men, unfamiliar with the calculus, might have the satisfaction of knowing that there was very high authority for the adoption of simple formulas, as sufficiently accurate for ordinary purposes. For instance, in the "Report to the Metropolitan Board of Works, upon the Main Drainage of the Metropolis," by Messrs. Bidder, Hawksley, and Bazalgette, dated April 6th, 1858, the formula $v = \frac{\sqrt{1 \cdot 6 a f}}{p}$ was adopted, in which v = velocity in feet per second, a = area of stream in square feet, f = fall in feet per mile, and p = wetted perimeter in feet.

A complete and simple summary of the corrections necessary to meet the various circumstances arising in general practice, was to be found in 'Engineering,'⁴ where, taking as a base the well-known formula $v = 100\sqrt{rs}$, numerous coefficients were given to meet different cases arising from larger or smaller volumes of water.

Mr. Ridings. Mr. H. S. RIDINGS remarked, that when the Author discovered that H.M.S. "Warrior" did not pass through the Suez Canal, and that the ship of the same name was only one of 700 tons, it would have been better to have omitted that part of the Paper containing calculations based on an error.

He happened to be in a position to give a few particulars of the passages of H.M.S. "Shannon" through the Suez Canal in the year 1878. This ship was suddenly detached from the Mediterranean squadron in April, 1878, and ordered out "to protect British interests" in Chinese waters, then threatened by the Russian North Pacific fleet. Speed was therefore of importance.

¹ Minutes of Proceedings Inst. C.E., vol. 1., p. 262.

² *Ibid.*, vol. xxvi., pp. 17 and 447.

³ *Ibid.*, vol. lxxi., p. 1 *et seq.*

⁴ 1873, vol. xvi., p. 13.

Notwithstanding that Sir F. de Lesseps himself went on board Mr. Ridings. the "Shannon," and personally superintended all the arrangements, as no vessel of her size had traversed the canal before (and he thought that no vessel of greater beam had passed through since), yet she took from noon of April the 19th till 10 A.M. on April the 22nd, to pass from Port Said to Suez. There was but a comparatively small wave at the bow, but the water rushing in to fill the displacement, caused a great sweep on the sides of the canal behind the vessel. When one of the Indian troopships, the "Serapis," was signalled, the "Shannon" was ordered to close up into one of the "gares" for the night, and wait until she had passed. The "Serapis" drew 25 feet; but her beam was barely 50 feet. Just as she had passed, the following wave lifted the "Shannon," straining to the utmost the numerous hawsers, and the after hawser tore the fair lead out, and cast it into the canal. This was a very heavy casting secured by strong bolts. On the return voyage, the "Shannon" left Suez at 6 A.M. on November the 11th, 1878, and reached Port Said on the following day at 3 P.M., a very rapid passage for a vessel of her size, and considering that she was tied up in a "gare" during the night. The dimensions of H.M.S. "Shannon" were:—Length, 275 feet; beam, 54 feet; draught, 24 feet; tonnage, 5,390; HP., 3,500.

A class of steamer with a stern-wheel (common on American waters), built by Messrs. Yarrow, of Poplar, would maintain a speed of 10 miles an hour through the water, on the Dique Canal, Cartagena, South America. The canal steamers were 120 feet long, 25 feet beam, 3 feet 6 inches draught, and they weighed 90 tons, and carried about the same load. The upper deck was conveniently arranged with state-rooms and a saloon. The wave after these stern-wheel steamers was not formidable, though he had known it to swamp deeply-laden cargo-canoes. The banks of the canal in the upper part were composed of very dense clay, which stood erosion well, and in the lower parts, the land was swampy, and mangrove forests occurred. The canal was an ancient means of communication between the River Magdalena and the city of Cartagena, having been begun by the Spaniards in 1570. It had been allowed to fall into bad repair; but efforts were being made to improve it. The canal was seventy-three miles in length, including the various lagunes on the route, and fourteen miles more across the bay of Barbacoa and harbours of Cartagena, made a total of eighty-seven miles from the river to Cartagena. From what he had seen and heard abroad, it was

Mr. Ridings. evident in regard to the possibilities of inland steam navigation, that many nations were far ahead of the British.

Capt. Steele. Captain JOHN STEELE observed that in China and Japan a canal of almost any shape would suit the "Junk" 50 feet long, 20 feet beam, and 8 feet depth of hold, with flat bottom lifted at the ends, and with a rudder in width one-third the beam of the craft. The case was, however, altered when a passage had to be provided in the canal for ships 350 feet long, 40 feet beam and drawing say 24 feet of water, with straight keel, a rise of floor, and a small rudder. It might be admitted without question that the freer a ship could move in the water the greater would be her speed, and the more exact her steering; consequently the deeper and wider the canal, the more rapid the transit through it. Thus one broad canal would be better for heavy traffic than two narrow canals equal in depth to the former. The Suez Canal, as at present existing, appeared to have been cut with more regard to the avoidance of obstacles than for the facilities of ships passing through it, and to suit the ground there were many forms of "cutting." In those parts of the canal where the sides were nearly perpendicular the vessel steered better than where the sides sloped, and where the sides not only sloped but ended abruptly some feet below the surface of the water, as in the "Small Lake," steering was most difficult if the vessel's draught brought her keel near the ground. Free "floating" being a primary consideration in steering a vessel, it might be assumed that when under the conditions found in this "Small Lake" the water displaced by the vessel on rising to the surface found free expansion; and with so little water or lifting-power under her the vessel shrank or settled nearer the ground. With so small a quantity of water to rush from under the vessel upwards along her "run," it had little effect upon the rudder when crossing it about 2 feet below the surface. This point in modern vessels of fine run, was that where contact between the helm and the passing water was keenest. In a more modified extent the same slackness in steering occurred where the sides had much slope. In the same depth of canal but with perpendicular sides, the bank of the canal rising above water, the water displaced by the vessel, in this narrow space added to the depth and gave ease to steerage. Thus at an early date at equal depths of water a vessel would pass freely through the narrow but precipitous cutting of Serapeum, that could with difficulty navigate the sloping portion of the canal between Port Said and Kantara, and would ground in the Small Lake. A large vessel passing along

this narrow canal, carried so much of the displaced water with her, that little was left to flow past the rudder for leverage in steering; add to this the bore ready to cant her from whichever side gained a preponderance, and it might readily be inferred that easy speed would alone prevent frequent grounding in the Suez Canal. Most vessels frequenting the canal had an additional rudder attached during their transit through the canal. His own experience, with a ship drawing over 20 feet depth of water, was that a speed beyond 4 knots an hour resulted in mishap. The canal had he understood been deepened about 3 feet since that date, namely 1872. More readily to show the action of the water forced onward by the ship, he might state that when passing a siding it was necessary to reduce speed to the lowest "steerage way," say 2 or $2\frac{1}{2}$ knots per hour. These sidings, which were 400 feet long and 20 feet indent, were used to draw up one of two crossing vessels in order that the other might pass on. In approaching an empty siding in a large vessel, even with speed reduced, the strictest guard was required over the helm, that she did not rush after her own displaced water flowing into the siding, and again when approaching the other end with the water rushing out. If such were the defects of a narrow canal, with the general increase in the size of ship there was a necessity for a much wider canal than the present Suez Canal; but whether this should be done by enlarging the existing canal, or by cutting another must depend upon the cost. Considering the banks at the side of the present canal, the refuse of the original cutting, all of which would have to be removed in widening the canal, it would seem that a new cutting which would not embarrass traffic while the widening was in operation, would yield more satisfactory results.

Mr. EDWIN THOMAS remarked that the subject of the Paper was Mr. Thomas. unquestionably of great interest and importance, both to the scientific and commercial portions of the community, and one that had for many years occupied the attention of those most directly interested therein, more especially since the introduction of railways and their concomitant competition for the heavy traffic of this country, which until then was almost exclusively carried by canals and navigable rivers. Canal companies had not been so idle as might be generally supposed, but being stimulated by the powerful competition and rapid advances of their rivals the railway companies, had made many endeavours so to improve their waterways, and the vessels trading thereon, as to bring about something like an equality in the merits of the two prin-

Mr. Thomas. cipal means of inland communication ; but notwithstanding all that has been done, the canal companies had been compelled to admit, in so far as long-distance traffic was concerned, that of the two the railway was the better carrying-machine. He apprehended that the main object of the Author, in introducing this subject to the notice of the Institution, was to elicit such practical and theoretical opinions as might ultimately bring about great improvements in the highways and machinery of inland navigation ; but if it were contemplated to remodel the existing waterways of this country, by initiating improvements in the hope of inducing canal companies to expend large sums of money in practically reconstructing their undertakings, then he feared that the difficulties in the way of achieving success in that direction were wellnigh insurmountable, unless it could be shown that considerable pecuniary benefit would be derived by the carrying out of such improvements. It having hitherto been proved that canals could not hope to compete with railways in point of speed, local and heavy traffic had been fostered, and such as did not require to be conveyed at high rates of speed, so as to enable a fair dividend to be earned on the capital invested in the undertakings. Consequently, and in order to minimise the expenses in working the craft, vessels had been constructed with the view to the greatest carrying capacity possible in the channels and waterways through which they were intended to pass, the limit being controlled by the minimum dimensions of the locks and the contraction of the waterway at bridges and tunnels. He was of opinion that if this question were to be treated in a scientific manner, and without reference at all to the commercial bearings of the case, the two most important principles for consideration would be, first, the section of waterway, and second, but of no less importance, the form of vessel. With regard to the first point, the views which he would advance on the subject had resulted from a practical experience in the construction and management of canals and docks, extending over a lengthened period, during which he had been engaged in the construction of the latest canals made in this country, and which had been of the common type of section. His experience proved that such type of section was not that from which the best results could be obtained, as it not only involved the occupation of a greater quantity of land than was necessary for the construction of a channel of better form, but it was not best adapted for facilitating the passage of the craft. The waterway of a canal should, he thought, be rectangular in section, having a depth at least one-half more than the maximum draught of the vessels

frequenting it, with a width equal to twice their wetted perimeter. Mr. Thomas. For example, for a vessel of 7-feet beam (the maximum gauge of vessels which could navigate the whole of the present system of canals, owing to the narrow gauge of the locks on the greater mileage), and say with 3 feet 6 inches draught of water, the depth of channel section would, by the above formula, be 5 feet 3 inches; while, with regard to the width, twice the wetted perimeter of the vessel, namely, 14 feet, gave a waterway section of 28 feet by 5 feet 3 inches. By a judicious application of this form of section, the canal companies, whose waterways now occupied considerable width of land, would be enabled both to improve the carrying capabilities of their navigations and to obtain the use of surplus land, which could be utilized at such a cost as would probably yield an ample dividend on the capital that would be expended on such conversion. This form of section, too, apart from the consideration of the better utilization of the land, would facilitate the speed of vessels. The case referred to by the Author, in reference to speed increasing with greater depth of waterway, accorded with his view as to the depth of water beneath a vessel; the effect of it was to give a better supporting power and freer escape of the water to the vessel's stern, thus obviating the tendency of vessels to "smell" the ground, and also to lessen the retardation arising from back-draught. The form of vessels was more directly a matter for the consideration of traders and owners of craft, inasmuch as canal companies were in most cases analogous to the trustees of turnpike roads, being proprietors only of the means of communication, and not of the vessels which navigated the canals. The Regent's Canal Company some years ago offered a substantial premium for the best steam tug-boat for working vessels on their navigation, great importance being attached to the question of speed. Observations made by him in reference to the successful vessel, and the results obtained therefrom, had appeared in the Minutes of Proceedings.¹ With regard to the loss of time, which varied considerably in the passage of vessels through the locks on the several navigations, the time occupied in lifting a vessel from one level to the other in the Regent's Canal had been reduced by him from three minutes and three-quarters, in some of the locks of 7-feet lift, to one minute fifty-seven seconds; and the time of emptying the locks from two minutes ten seconds to one minute forty-three seconds. These were locks capable of passing barges of upwards of 100 tons

¹ Minutes of Proceedings Inst. C.E., vol. xxvi., p. 14.

Mr. Thomas. burthen. But lockage was not the chief cause of detention. The more serious impediment was the want of greater depth of water upon the sills, for allowing the vessels to move more freely in entering and leaving the chambers, by providing a greater space beneath the vessel for the escape of the displaced water. But to these causes must be added the time occupied in slackening the speed in approaching, and putting the vessel in motion again when leaving the lock. If canal companies could be induced to combine and offer premiums for determining, by scientific and practical research, the best section of waterway and form of vessel for the purposes of inland navigation, it would, in his opinion, lead to good and practical results, and until some such authentic and exhaustive inquiries were instituted, any formulas that might be deduced must be more or less hypothetical.

Mr. Conder. Mr. CONDER in reply to correspondence, had not much to add to his previous remarks. Mr. Atkinson had carried on experiments very similar to those proposed by Mr. Conder, though on a smaller scale. He had also plotted the results of Sir John Macneill's experiments more in detail than the Author had done; but the remarkable diminution of resistances at high velocity still required explanation, and the need of further experiments was evident. Mr. Bruges had put in other words the suggestions of the Paper as to the resistance due to section, and had repeated some of the remarks replied to as falling from Mr. Vernon-Harcourt. The calculations as to the hydraulic radius were reducible to the well known truth, that the circumference of a circle was the shortest possible boundary of area, and that the proportion of periphery to area was exactly in accordance with the approach of any figure to a circle. Mr. Burke was singular in the expression of the opinion that it was unworthy of remark—although a stronger word might be used—that the expenditure of £200,000 a mile on a canal involving not “a single work of art from one end of the canal to the other, with the exception of the sea jetties,”¹ had been so conducted as to result in nothing better than to allow five vessels per day each way to dribble through with difficulty at the mean rate of 1 mile in thirty-two minutes. His opinion that “the canal was excavated in a quicksand” was also peculiar. Attention had been given by the directors of the canal to the subject of lighting the course; but with proper section and duly protected banks, the capacity for traffic would be almost unlimited. So far from having recommended the formula criticised

¹ Minutes of Proceedings Inst. C.E., vol. xxvi., p. 451.

by Mr. Burke, Mr. Conder had given the entirely different formula Mr. Conder, of Hagen (p. 182), and had only again to refer to the mathematical objections to the ordinary formula which were before stated. The formulas for stream-energy might also be here cited as based on the same principles as Mr. Conder's diagram, Fig. 5. Whether the formula of Lord Rayleigh, $E = p + \frac{1}{2} \rho v^2$, or that of Kirchoff, $E = p + \frac{\pi}{4 + \pi} \rho v^2$, were adopted, the sum of the potential and kinetic energies was equal to that taken by Mr. Conder as the element to which the coefficient of friction applied on diagram Fig. 5.

Mr. Culverwell's remarks bore evidence of careful consideration of the subject, and were in complete harmony with the Paper. Mr. Mosse had added his testimony to that of Mr. Aitken and others as to the difficulty of passing the Suez Canal; and had also incidentally shown the imperfection of the common formulas by referring to the numerous coefficients which were necessary to meet different cases. Mr. Ridings had given a very interesting account of the transit of the "Shannon" through the canal, which would have been still more valuable if he had stated the midship cross-section, and the rate of movement. Captain Steele's nautical experience went altogether to support Mr. Conder's ideas; and Mr. Edwin Thomas's communication might be frankly accepted by the Author as a reply on his behalf to much that he had omitted to notice. The proportions of Mr. Thomas's model canal were almost exactly those of Mr. Conder's section; and it was only necessary to cut off the corners of the rectangle, which would diminish channel-resistance, to arrive at identity of design. Mr. Thomas's commencing and concluding paragraphs showed a just appreciation of the motives of Mr. Conder's Paper, and formed a suitable close to the discussion.

12 and 19 February, 1884.

Sir J. W. BAZALGETTE, C.B., President,
in the Chair.

The discussion upon the Paper "Speed on Canals," by Mr. Conder, occupied both meetings.