Mr. Burge. no reason to believe that blows had occurred in this case. Speaking from memory, a main span of the bridge as launched weighed about 950 tons, and, adding the roadway girders of the overhang, which were fixed after launching, and the permanent way throughout, the weight as completed would be about 1,020 tons. It was difficult to conceive how both Mr. Ewing Matheson and Mr. Maynard got the notion that such a bridge as this, or indeed any important bridge, had been founded on mud, in the face of the plain statement, repeated twice in the Paper, that the caissons were sunk well into the sand; and this was especially mentioned with regard to pier No. 5 to which Mr. Maynard alluded. The Hawkesbury River opened into a wide estuary immediately below the bridge, so that floods had little or no effect there, not so much in fact as the tide, and there was practically no scour of the mud in its bed from either cause. Mr. Ewing Matheson had stated his impression that the American constructors had information that was not available in England, in regard to the exact nature of the soil. As far as the Author was aware they had no advantage over others in this respect.

Correspondence.

Mr. Bouscaren. Mr. G. Bouscaren observed that the Papers of Messrs. Burge and Walton, describing the methods of construction used for the deep foundations of the Hawkesbury and Dufferin bridges, were of special interest as dealing with an engineering problem, of which there were, as yet, only a few applications, and which required, perhaps to a greater extent than any other, the forethought in designing, and the fertility of expedients and perseverance in execution which characterize all great works of engineering, and often wrenched success from the very brink of disaster and failure. When considered in connection with the similar works done for the Poughkeepsie and Hooghly bridges, they were particularly instructive, as illustrating how the same results could be accomplished by different means, and also from the similarity of the accidents to the caisson in all these undertakings. Ample security in the strength of the anchorage and fastenings designed to hold and guide the caisson whilst sinking, until it was firmly engaged into the bed of the river, seemed to be the first desideratum. The difficulty experienced in guiding the caisson, and keeping it in a vertical position whilst sinking through the mud and sand, was suggestive of more effective means being employed to overcome

Mr. Bouscaren. the unequal friction by unequal loading or pressure at the four corners of a rectangle over the pier, in addition to the filling of the side pockets, or to decrease and equalize the friction by the use of water-jets through the outer skin, which did not appear to have been tried in either case. The use of water-jets also at the base of the dredging-chambers, would probably facilitate the dredging and the regularity of descent of the caisson, and might be of great assistance in removing boulders and other obstructions from under the cutting edge of the caisson. Such contingencies, which fortunately did not seem to have occurred in either of the four great undertakings where the method of dredging in open caissons were resorted to, were liable to happen, and would be very unpleasant to meet, where the obstructions would present themselves beyond the limit of working depths in compressed air. Tree trunks were found in the Mississippi river far beyond this limit; and he might mention, in this connection, his experiences with a huge cyprus trunk under an open cylinder, which was sunk for the foundation of the bridge across Pearl river in Louisiana, for the crossing of the New Orleans and North Eastern Railway. Although scarcely 30 feet under water, this tree caused a great deal of annoyance and delay. It lay in a horizontal position, with the ramification of its roots under about two-thirds of the circumference of the cutting edge of the cylinder. It was finally removed by cutting the roots and pulling them out singly, the water-jet being of great assistance in loosening the roots from the sand. He fully agreed with Mr. Burge in respect to the sizes in plan to be given to the caisson as compared with those of the piers, and thought that notwithstanding all the precautions which might be taken to prevent the shifting and canting of the caisson, the possibility of these accidents remained, and should be allowed for, by ample provision in the sizes of the caisson. The extra cost, incurred by the increase in sizes, might possibly be compensated by filling the greater part of the dredging chambers with sand instead of concrete, provided that the side pockets were filled with a good quality of concrete, and the bottom and the top of the dredging chambers were also sealed with concrete. The methods applied for the erection of the superstructure at Hawkesbury and for the Dufferin bridges were probably the best suited to each case, seeing that independent spans were to be used; but where cantilever spans are permissible, the method of building out with travellers, as applied at Poughkeepsie, was certainly the safest, if not the cheapest. The pontoon plan was open to objections for the risks arising from the currents and winds, and from the fact that, under certain circumstances, the breaking of a hawser, or a wrong movement at the critical moment, might cause the loss of an entire span. Mr. Bouscaren.

Mr. E. G. Carey stated that the steel in the superstructure of the Hawkesbury Bridge was similar in all respects to that employed in the Forth Bridge to resist tensile strains, and had an ultimate strength of 30 to 33 tons per square inch, with an elongation of at least 20 per cent. in a length of 8 inches. Strips with a minimum width of $1\frac{1}{2}$ inch, and either cold or tempered by being heated to a bright red, cooled in air to a dull cherry red, and plunged into clean water at 82° Fahrenheit, being required to bend without fracture to a curve whose inner radius equalled $1\frac{1}{2}$ time the thickness of the bar or plate. In practice, the elongation considerably exceeded 20 per cent., ranging as high as 30 per cent., whilst the material would frequently bend double without fracture. One tensile test was made from every fifty bars or slabs; whilst a cold or temper bend test was made from each bar or slab. The following analysis, selected at random, represented the average chemical composition of the material:— Mr. Carey.

	Per cent.
Carbon	0·200
Silicon	0·031
Sulphur	0·038
Phosphorus	0·047
Manganese	0·692
Copper	trace
Difference	Iron

The plates were rolled in double widths and up to 40 feet long, varying from $\frac{3}{8}$ inch to $1\frac{1}{4}$ inch in thickness. The rivet-steel had a tensile strength of 26 to 30 tons per square inch with an elongation in 8 inches of 20 per cent., ranging in actual practice as high as 36 per cent. Bend tests similar to those for plates and bars, already quoted, were required. The above material was rolled by Messrs. David Colville and Sons, Dalzell Steel Works, Motherwell, from material manufactured by the Siemens-Martin open-hearth process.

Mr. Thomas Curtis Clarke believed that it might interest the Institution to know the position of "Constructing Engineers," in the United States, meaning by that title those engineers who both designed and executed their own works. During the rapid development of iron-bridge construction in the United States certain engineers, whose attention had been particularly directed to that branch of construction, soon found that a sufficient clientage could not be obtained if they confined themselves merely to making Mr. Clarke.

Mr. Clarke. designs for others to execute. In order to gain the support of railroad managers, they found it necessary to guarantee the correctness of their figures, by offering to construct the work for those figures. This led to the necessity of their controlling both a large manufacturing and an erecting plant. Steel and iron could always be bought in the open market, but this control of the manufacture and the erection of bridges enabled them to name with certainty both the cost of a bridge and the time in which it could be built—an equally important consideration with railroad men in America. This developed their constructive skill and ability on the same lines, and they learned to make designs of any required strength at the least cost; and it was one of the reasons why the combined design and tender of the Union Bridge Company for the Hawkesbury Bridge was found acceptable. To show how close estimates could be made in advance, here were the estimated quantities of the Hawkesbury Bridge made in 1885, and the final measured quantities of 1889:—

	1885.	1889.
Tons of steel in grades	6,200	6,320
" " caisson	1,600	1,668
Cubic yards of concrete	27,600	26,593
Masonry	4,900	5,630
The excess of masonry was due to a modification of the plan.		
Time	30 months.	34 months.

Mr. Burge criticized the form of the caissons. No doubt they could be improved. Engineers learned from every piece of work executed how to do better next time. But after all, it must be allowed that the plan was not an unsuccessful one. The piers were sunk to depths never before reached, not enough out of position to do any harm, and in the estimated time, as the four months' excess was admitted to be due to unavoidable causes, and not to any fault of design or execution. The rapid sinking of these caissons was due to the fact that they were so designed as to carry a large mass of concrete between the inner and outer skins, forming part of the permanent construction, and by its weight overcoming the side friction, and preventing the necessity of the slow and expensive process of piling rails or other weight on the caissons to sink them. This excess of downward pressure had one disadvantage. Where the material passed through was softer on one side of the caisson than on the other, it naturally worked over to that side, and this was what actually took place at pier No. 5, possibly increased by the batter on the sides of the caisson, as pointed out by Mr. Burge. This, however, was the only pier which gave trouble, and the rapid execution of the work was due to the great weight of the caissons, exceeding the resistance of the side friction in the proportion of nearly 2 to 1. The deductions to be drawn by engineers from the sinking of the deep caissons at Hawkesbury were :— Mr. Clarke.

1. Open dredging, rather than compressed air, should be used wherever the material was soft enough to dredge.

2. Caissons should be designed so that the downward pressure should far exceed what was believed to be the probable side friction, varying from 300 lbs. per square foot of rubbed surface in mud, to 500 to 600 lbs. in sand, and 700 to 800 lbs. in clay.

3. The sides of the caissons should be made vertical, and the bore should increase by offsetts rather than by batter.

The designers of this bridge felt some pride in their design, and as from the Paper of Mr. Burge no one could possibly tell who the Hawkesbury Bridge was designed by, Mr. Clarke might be permitted to state that the plans of the caissons were designed by Mr. Charles Macdonald, M. Am. Soc. C.E., and Mr. Thomas Curtis Clarke, M. Inst. C.E., conjointly, a year before the Hawkesbury competition, for a proposed deep foundation in the United States. Complete plans and models were made of this, and it was adopted for the Hawkesbury Bridge, and built without charge. It might also be of interest to know that this plan coincided almost exactly with a sketch made by Sir Benjamin Baker two or three years before, which, of course, was not seen until after the award. The erection of the superstructure on a large pontoon, was also designed by Messrs. Macdonald and Clarke. Small spans had been erected on a number of pontoons; but nothing like this, requiring the loaded pontoon to be carried so far, had been done before. Its success was due in a large measure to the foresight and ability of Messrs. Ryland and Moore who carried it out. The prompt action taken by them at span C, as described by Mr. Burge, saved a heavy loss. It seemed "curious" to Mr. Burge that though the tender was made by an American engineer, the whole of the steel and iron, except the eye-bars, were provided by the United Kingdom, where also it was manufactured. There was nothing curious or strange about this. Bridge shops in the United Kingdom were perfectly able to work to drawings, and the drawings were made by the Union Bridge Company's office. Where the bridge was manufactured, depended on the price of iron and steel at the time. Sir William Arrol, who constructed these girders at his shops in Glasgow, and constructed them very well, would have made the eye-bars also, if it had been

Mr. Clarke. worth his while to put in the expensive plant required for one order. In making the designs Mr. Macdonald and he carried out an idea, which at that time would not have met the approval of American engineers, namely, to rivet all connections except those uniting the main diagonals to the chords, where pins, as large as $7\frac{1}{2}$ inches in diameter were used. It might be of interest to refer to the tests of the eye-bars, made with the 600 tons testing machine[1] at Athens, Pa., U.S. The steel bars were made by the Steel Company of Scotland, upon the following specifications of the Consulting Engineers, Sir John Fowler and Company. "Strips cut lengthwise or crosswise to have an ultimate tensile-strength of not less than 30 tons, and not exceeding 33 tons per square inch with an elongation of at least 20 per cent. in 8 inches. Tests of full-sized bars will be made as follows:—Out of every lot of one hundred and three bars, three shall be selected by the inspector. If two out of three break in the body of the bar with a stress of not less than 28 tons per square inch, nor a less elongation than 10 per cent. in the length of bar, then the lot of one hundred will be accepted if otherwise satisfactory. If but one out of three so breaks, the testing shall be continued at the expense of the manufacturers until the required proportion of two-thirds be reached. But if five bars break in the head without developing the above specified qualities, then the whole lot of one hundred shall be rejected. All pins shall be accurately turned to a gauge. Pin-holes shall be drilled to fit the pins with a play of not over $\frac{1}{50}$ inch. The length of eye-bars shall be adjusted to such accuracy that when ten bars are piled upon each other the pins shall pass through the holes at both ends. All eye-bars shall be annealed after manufacture."

Mr. Collingwood. Mr. F. Collingwood directed attention to the desirability in all caisson work of introducing a considerable amount of what he would name safety-bearing surfaces. For example, in the Brooklyn caisson of the East River Bridge, when the cutting edges were sunk 6 inches into the earth, they would furnish about 550 square feet of bearing. The five bearing frames, 2 feet thick, furnished about 1,000 square feet more at the same time. In the New York caisson, when the cutting edge was buried 6 inches, instead of 1,550 square feet, about 2,500 square feet came into bearing; 3 inches further penetration brought about 650 square feet more, and 2 feet penetration brought in all nearly 5,000 square feet. The Brooklyn caisson was sunk only

[1] Transactions of the American Society of Civil Engineers, vol. xvi. 887, p. 1.

44½ feet, and was at one time 12 inches out of level; while the New York caisson only touched mud at a depth of 37 feet, and was sunk through worse material to 78 feet depth, with but 9 inches variation from true level. Experience there showed the importance of this rapid increase in bearing surface, as it prevented downward movements from being so great as to cause wide deviations from verticality in case of variations in hardness of the material passed through. It was also a great safeguard against damage to the caisson, or serious derangement, in case of a blow-out. The reason given for the easterly movement of caisson No. 5 of the Hawkesbury Bridge might be correct; but the Brooklyn caisson, with a batter of 1½ inch per foot, moved away from, not towards, the harder material, a distance of 2 feet in a descent of 26 feet. This he attributed, however, to the pressure from a greater height of bank on the hard side. If it was true that the softer material filled in more quickly and closely against the caisson, might not the excess of pressure thus caused by it, rather than its resistance, have produced the movement noted. This would seem to be indicated by the decided success in correcting the positions of the caissons of the Dufferin Bridge, by external pressure. This latter experience would suggest also the use of the righting moment of weighted cantilevers on the high side of caissons, when out of the vertical. It was evidently not wise, in sinking very deep foundations, to limit too closely the size of the caissons. If the material to be passed through was at all yielding, the wedge-shaped cutting edge would readily penetrate from 1 foot to 2 feet into it before the inertia of the moving mass was overcome. Under such conditions, any inequality in hardness caused at once a difference in the amount of penetration at the sides or ends. This, though perhaps but a few inches, becomes feet in the amount of deviation caused at the top of a tall caisson, being more and more as the caisson was narrowed. A uniform progression in settlement was always to be preferred to extensive movements, and rapidly-increasing bearing surface tended to prevent the latter. The lateral, as well as longitudinal, distribution of wells recommended by Mr. Burge, was undoubtedly to be desired. Mr. Collingwood.

Mr. THEODORE COOPER noticed that the Author of the Paper on the Hawkesbury Bridge said: "It is a curious circumstance connected with this bridge that, though the successful tender was made by an American firm, the whole of the steel and iron, except only that of the eye-bar heads, was provided by the United Kingdom, where also it was manufactured." The steel for the Mr. Cooper.

Mr. Cooper. eye-bars was made in Scotland; the bars, however, were shipped to the United States for the purpose of forming the eyes according to the accepted practice of American bridge manufacturers, namely, upsetting and forging them from the solid bars. This work could not have been done satisfactorily in the United Kingdom, as no firm was, he believed, prepared to make eye-bars of the sizes required, which would comply with the ordinary requirements of American bridge practice, namely, that the bars should break preferably in the body of the original bar rather than at any point of the head or neck; and that the fulfilment of this requirement should be determined by testing to destruction a certain number of the full-sized bars. The girders and other riveted parts of this bridge were made in the United Kingdom; but it was understood that the cost of manufacturing such parts was fully up to the cost of similar work at the home works of the American firm. The only advantage, therefore, which the American firm obtained, over manufacturing the whole work in America, was the better market rates for structural material then existing in Great Britain, and possibly better facilities and rates for shipments of material to New South Wales. During the past year the market rates for structural material would have been more favourable to the United States than to Great Britain. It was curious and also very interesting to note that, with the advantage of the same markets, the tenders of firms in the United Kingdom for this work ranged from £50,000 to as high as 100 per cent. in excess of the tender of the successful American firm. The only advantage remaining to the American firm must have been its wider knowledge and experience in works of this magnitude, and its ability to minimize the risks involved in the execution of works of this character. The bridge engineer and bridge manufacturer were recognized specialists in America. They had built within the present generation upon the 160,000 miles of railroads in the United States over 3,000 miles of bridges. In addition, they had built a very large mileage of bridges upon the highways, much more difficult to estimate, but exceeding several times the mileage of railroad bridges. As this amount of experience comprised foundations and structures of all kinds and magnitudes, and as the greater portion of such work had been done under close competition, the American bridge-builder was prepared to estimate very closely the cost of any such piece of work as the Hawkesbury Bridge. The description of the Dufferin Bridge and its erection supplied an explanation why American bridge-builders could underbid, to the extent of 50 per cent., Mr. Cooper.

their competitors in the United Kingdom, on works of magnitude involving great risks. A method of erecting a span $355\frac{1}{2}$ feet long, involving incessant work throughout the twenty-four hours of each day, for one hundred and thirty-two days, over a river having the characteristics of the Ganges, would certainly justify an increased percentage of 20 to 100 over the methods employed by American engineers. The erection of bridges over the Ohio, Missouri, Mississippi, and other great rivers of America was subject to similar risks as were to be expected over the Ganges and other rivers of India. The erection of the two channel spans of the bridge over the River Ohio, near its mouth at Cairo, Illinois, was a fair example of the possibilities of the American system of construction and erection. These spans were each 518 feet 6 inches from centre to centre of the end pins, 61 feet deep from centre to centre, 25 feet wide from centre to centre of the trusses, the panel length 30 feet $5\frac{3}{4}$ inches, and the total weight of one span, 2,055,200 lbs. The first span was erected in six days. Then the false works were taken down, the supporting piles drawn and re-driven for the second span, the false works again put up, and the second span erected. The whole time, covering the erection of the two spans and moving the false works, was one month and three days, including five days' lost time, waiting for the completion of the masonry. The false works and traveller were in position, ready to commence the erection of the second span, by 2.30 P.M. on the 30th of October, 1888. At 2.50 P.M. on the 3rd of November, the trusses of this span and the top tracing were all connected. No work was done at night. The material was run on trucks about 1,025 feet, from the storage yard to the nearest end of the span being erected. About twenty-four men were employed in delivering the material, and fifty in erecting the parts and connecting them together. The false works stood about 104 feet above low water. The bents being 72 feet high above the capping of the piles, the depth of water at its low stage was about 20 feet. The piles were from 50 to 75 feet long. When a thoughtful consideration of the relative cost and hazard of these two examples was taken, it did not appear so curious or unintelligible why an American firm of the ability and experience of the Union Bridge Company should be the successful competitor, on a work it was so well prepared to estimate and execute. Nor need it be matter for future surprise should American engineers and bridge-builders be able to meet successfully their competitors of the United Kingdom whenever the opportunity was given for a fair and free competition.

F 2

Professor Gaudard.

Professor J. GAUDARD could not refrain from expressing his admiration of the foundation works of the Hawkesbury and the Dufferin bridges, which marked a great advance upon all examples cited hitherto, as of exceptional magnitude in the depth of water or of soil. Summarizing several of these cases, and noting the great mortality among the workmen, attendant upon the employment of compressed air in foundations below 100 feet in depth, he referred to the boring-head and hydraulic extraction adopted at the Gorai Bridge, and to the plan adopted by Mr. Jandin at the bridge at Palma del Rio over the Guadalquivir, by which work might be carried on at a depth of 130 to 160 feet in permeable soil, and to the occasional execution of works in the open air with provision for the use of compressed air if necessary. He thought, however, that provision for manual labour was required only to a certain depth where descent was still in progress, and where it was necessary to examine the soil below the pier; and that this limit was certainly not in excess of 100 feet. Below that point the conditions of stability did not appear to make such examination requisite. The resistance of the soil below the pier, the loss of weight by immersion, and the lateral friction, the three elements in the case, were all capable of exact expression and graphic demonstration. Thus it could be determined in a general way what would be the requisite depth of the foundations for the resistance of the soil, and the lateral friction to support the pier in a state of repose, and without adding to the normal pressure upon the site of the foundation, in accordance with the formula given by Rankine. In dealing with the pressure of the soil, as affecting all parts of the foundation, it was, of course, assumed that the ground must be treated as sufficiently fluid for the pressure to be so exercised; but in dry soil the deficiency of lateral pressure would be more than compensated by the resistance to direct compression and to disaggregation. He agreed therefore with Mr. Walton, that, in the case of the Dufferin Bridge, the friction and hydrostatic displacement would probably not exceed one-half the total resistance, leaving the base to support the other half of load. The principal risk, in sinking high and relatively slight piles or piers, was the lateral displacement or deviation from the perpendicular, in an uneven soil. This might be caused by the current, but in such case it would affect the operation in its earliest stage when the pier was simply being guided into place, and its position could be rectified. There was also the yielding of soft beds to the scour of the current, and obstacles and sources of dislocation in varying strata, or the inclined surface of a hard bed.

Mr. Walton had referred to the success of the means of replacement employed in the Dufferin Bridge, and other methods might be equally successful in other cases. The difficulties occasioned by slipping of the soil at the base of the pier, in beds of heterogeneous formation, were very clearly shown in Mr. Burge's Paper; and impressed Professor Gaudard with the importance of avoiding the bottom outward splay; as confirmed also by the Saint Leger Viaduct on the Grande Ceinture Railway, of Paris, which afforded an instance of the risks of a pier sinking too rapidly through a soft and yielding soil. A pier with vertical sides had considerably the best chance of retaining the perpendicular in its descent, provided it were well guided for the first 30 feet or so. It was to be regretted that in the greater depths of water, guiding piles should be abandoned; for where the depth precluded the use of timber, iron piles could be employed, and properly secured. It might perhaps be objected that such piles would have shared the fate of the cribwork in the Hawkesbury Bridge, but they would be planted more deeply and firmly. He thought it would be eventually feasible, by the adoption of a temporary outer cylindrical casing on the Gaertner system,[1] to diminish the lateral friction during the sinking of the pier, while restoring its full effect on the stability of the structure when the operation was completed. The method of sinking the foundations for the Blackfriars Bridge, presented itself to him as open to some criticism, but was doubtless necessitated by the circumstances of the case. The question of securing the ironwork to the masonry appeared to have been successfully dealt with by Mr. Cruttwell; but it was a most difficult one, and disastrous consequences might accrue in case of insufficient provision for alterations of temperature, as happened to several bridges, where abutments had been split throughout their height. He could not understand, in the case of bridges such as those over the Hawkesbury and the Ganges, why independent girders were employed, since the system of cantilever bridges had been so successfully carried out. The exactitude of the measurement of the width of the Ganges confirmed the excellence of the method adopted by the verification of the calculation. Professor Gaudard.

Mr. T. Gillott remarked that the amount given as the tender for the Hawkesbury Bridge, namely £327,000, appeared to be a very moderate sum; but he should be glad to know the actual cost, and also the weights and quantities of the respective parts, as in these Mr. Gillott.

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[1] Wochenschrift des österreichischen Ingenieur- und Architecten Vereins, 1885, p. 19.

Mr. Gillott. items the Paper on that bridge was deficient. The account of the erection of the Hawkesbury Bridge was most interesting; great skill had been exercised, and the defective arrangements of the caissons with respect to the outward splay, and the position and number of the dredging tubes (p. 7) which were candidly pointed out, would serve as valuable hints to designers of future works of a similar character. From the comparative ease with which Nos. 1, 2 and 3 caissons were founded, the small range of the tide (7 feet), and the velocity of the stream (3 to 4 knots per hour), he should be glad if the Author would state whether, in his opinion, there was any reason for the adoption of such large spans as 415 feet, and whether the stream could not have been bridged at a less cost by shorter spans. The settlement of the girders for the Hawkesbury Bridge, as apparent from the built camber of 12 inches being reduced to $3\frac{1}{2}$ inches when the spans were left on the piers, seemed to him more than should have been expected, and appeared much more in proportion than that of the Dufferin Bridge, which, being built with a camber of 9 inches, had still $4\frac{1}{2}$ inches left when under the total dead-load. Owing to the great depth of the pin-connected girders of the Hawkesbury Bridge, he should have expected the respective settlements of that and of the Dufferin Bridge would have been about the same, and should be glad if the Author of the first Paper would state the deflections of the Hawkesbury Bridge under a rolling load, to compare with the deflection of 1·45 inch, given for the Dufferin Bridge, as Mr. Gillott believed that the net strains were the same in both bridges. The use of power riveters during erection would no doubt tend to place riveted structures at greater advantage compared with pin-connected girders; and the greater stiffness of the former could now be secured without involving undue expense for hand-riveting on the site.

Mr. Parkinson. Mr. H. H. Parkinson stated that, in sinking brick wells in India he had found that the porous nature of the brickwork caused the well, when emptied of water, to suck so large a quantity of moisture from the surrounding soil, as to very much increase the friction while sinking; and that, in the beds of some rivers, a ring or cylinder of partially dried soil immediately surrounding the well clung to it with such tenacity as to follow it down in its descent, breaking away from the surrounding wetter soil in preference to parting from the sides of the well. In the event of the corner of a large caisson encountering a rocky projection, during its descent, he should sink a well or second caisson inside the first, at the opposite end to where the impediment occurred in the first; and, when a sufficient depth had been attained, join the two together by a step, or bring the upper caisson to bear on the lower by means of cross beams. When seeking for water in India at any considerable depth, he had sunk wells in two parts, the first well of large diameter, intended to go down to the water-bearing strata, by which time it would be pretty well knocked about, and might even have lost its shape, having numerous horizontal partings in the brick rings, and possibly having become out of plumb. He then found it convenient to start a fresh well at the bottom of the first, correcting any crookedness, and obtaining at the same time, a platform at an intermediate level for the men to work from. Mr. Parkinson.

Mr. C. O. Burge, in reply to the correspondence, said he was pleased to find that the only fault found with his Paper was that it was too short. In describing a structure of such magnitude as the Hawkesbury Bridge, a Paper might be read on each of the parts into which the work would naturally be divided, namely: 1. The triangulations for determining the position of the piers—an operation of considerable difficulty; 2. The foundations; 3. The masonry; 4. The superstructure; 5. The method of launching the latter. Nos. 2 and 5, being of a specially novel character, had been principally dwelt on, the others presenting no very remarkable features differing from similar works already described. The want of information alluded to by Mr. Gillott and others had reference chiefly to the superstructure, which had been thus purposely left undescribed except in general terms. He was not aware of the actual cost of the work to the contractors. To the Government the contract sum of £327,000 had been increased by extras, ordered by the Government engineers before the bridge was begun, to £340,000, and there was a slight increase to this on the completion of the work. With regard to the fixture of the spans at 416 feet: as the design formed part of the tender, it was a matter on which the contractors had to decide; but he believed that, owing to the difficulties which were to be expected in such unusually deep foundations, longer spans rather than shorter might have been anticipated in the successful design. With regard to the comparison between the difference of camber when built on the staging, and on taking their own weight, of the Hawkesbury and the Benares girders, Mr. Burge would remark that though the ratio of depth to span was greater in the former, the total span of the Hawkesbury girder was more than one-sixth greater than in the Indian work; moreover, the former was a pin-connected truss, each eye in the top and bottom boom being made $\frac{1}{64}$ inch larger than the pin passed through it; and to drive the pin easily a substantial erection camber had to be provided. Mr. Burge.

Mr. Bu: According to the description, the Dufferin Bridge was a riveted structure. The deflection of the Hawkesbury truss under a rolling load of three Consolidation engines, followed by a heavy train on each line of rails, was $2\frac{1}{2}$ inches, or $\frac{1}{1,964}$ of the span. The 9 tons per square foot, given as the maximum pressure on the foundations, referred only to the heaviest pier, and from this would have to be deducted the buoyancy and the skin friction.

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11 March, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Papers by Mr. C. O. Burge, Mr. F. T. G. Walton, and Mr. G. E. W. Cruttwell, on "Railway Bridges," occupied the whole evening.