Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his The President very interesting communication, observed that the novel method of crossing wide waterways described in the Paper was possibly capable of further development. Its salient feature was the avoidance of the expensive approaches which were necessary for most bridges crossing large rivers. He would like to ask the Author and the railway-engineers who were present how far the system might be adapted for carrying railway-trains. It would of course be impracticable to carry a whole train across on such a carriage as that used at Widnes, but it was quite possible to conceive an enlargement of the design which would render possible the transport of railway-trains in running order across a wide river.

The AUTHOR mentioned that since the Paper was written, and The Author. since the opening of the bridge, one or two alterations had been made, a description of which might be of interest. In the first place, some difficulty had arisen in connection with the heating of the main bearings of the trolley-motors. Various kinds of anti-friction metal were tried, and some improvement was made, without, however, quite remedying the defect, and forced lubrication had to be adopted. The trolley was articulated into five sections, and each section was originally designed to be connected with the contiguous section by a single pin. It was found that, on account of the deflection of the girder from the passing load and local deflection, the section of the trolley which carried the motors was getting more than its share of the load, the joints of the trolley-sections not being sufficiently yielding vertically. The single pins were therefore dispensed with, and double pins with coupling-plates were substituted for them, with the result that the load on the bearings was now more evenly distributed, the bearings ran perfectly cool, and forced lubrication was not necessary. In designing the trolley-wheels, one point had been overlooked. It would be seen from *Figs. 31* that the centre of the tread of the wheel was not in line with the centre of the bearing; the position of the tread of the wheels was fixed by the amount of clearance when passing the

The Author. rocker, and any increased length of bearing could be obtained only on the one side. The bearing had been made as long as possible in order to keep down the unit-pressure, and thus had arisen the unequally loaded bearing. As there was more tractive resistance offered than had been anticipated, upon calculating the actual pressures on the bearing it was found that the maximum pressure was at

Figs. 31.

the collar end of the bearing, and that the pressure gradually decreased—as shown by the ordinates marked A in *Figs. 31*—until it reached zero at a point about 1 inch from the axle-box end: beyond this point—as shown by the ordinates marked B, the pressure became an increasing negative pressure; that was to say, for this short length the bearing was acting as a brake. *Fig. 32* showed the pressure-curves on different lengths of bearing measured from the collar end, where a load of 10,000 lbs. was assumed to be applied in the direction of the arrow in all cases, this position being the exact relative position of the load on the tires in the actual structure. The ordinates gave the unit pressure on the bearing at the collar end and the axle-box end of the bearing; for example, if the bearing were 4 inches long, the collar-end pressure was 1,000 lbs. per square inch, and at the axle-box end it was 430 lbs. per square inch. It would thus be seen that, for the two pressures to be the same, the length of the bearing must be $3\frac{1}{2}$ inches, when

the pressure over the whole bearing would be uniform. By reducing the bearings to this length, although the maximum pressure was reduced and the negative pressure eliminated, the average pressure was increased. In order to overcome this difficulty, more wheels had been fitted to the trolley, and instead of having them running on a single fixed bearing, bogie-wheels with spring attachments had been adopted. The Author then exhibited a number

of lantern-slides illustrating the progress of the construction of The Author. the bridge; also a working model of the bridge, a full-sized section

Fig. 32.

of the cable, a sample of one of the strands, tested samples of wire, and the pins referred to in the Paper.

Mr. W. B. WORTHINGTON mentioned that about 20 years ago he had charge, as the Divisional Engineer on the London and North Western Railway, of the inferior mode of crossing then in use, namely, the ferry, the approach to which had to be maintained by the railway-company. It was obvious that the excellent means of crossing provided by the Author's bridge had greatly increased the traffic, which showed how the provision of facilities fostered traffic. It would be interesting if the Author could give particulars of any observations he had made on the deflections as the load passed across, as that point had some bearing on the President's suggestion that the design might develop into one for transporting railway-trains,

Mr. Worth-
ington.

Mr. Moore. Mr. R. St. GEORGE MOORE was particularly interested in the work, as he had been considering for some time the question of constructing a similar bridge for crossing the estuary of the Ribble. In 1899 he visited Portugalete with Mr. J. T. Wood, of Liverpool, the Author's partner in the work under discussion, to inspect the bridge Mr. F. Arnodin had built there, and which had been in use for about 6 years, though at that time, with the exception of the small bridge across the Devil's Dyke at Brighton, the system was unknown in England. The many details given in the Paper were of the utmost value to anybody who was considering the subject. He himself had prepared designs for a conveyor-bridge of 500 feet span, in which the conditions differed somewhat from those of a bridge of 1,000 feet span. After much thought, he had come to the conclusion that an ordinary suspension-bridge was not the best form where the rolling load was out of all proportion to the permanent load; and the whole question of deflection had seemed to him to be so complicated that he had chosen a braced-chain bridge. A rigid girder-bridge in some form, he found, had been adopted by French and by American designers, and an example was afforded by the conveyor-bridge over the harbour at Marseilles. So that, while three or four designers had adopted a very rigid form of girder, the suspension-bridge had been adopted only by Mr. Arnodin and by the Author. Another reason for not adopting the suspension-bridge was that unless the stiffening-girder was strong enough to carry the load when it was suspended from the joint in the centre and from the end, the apportionment of the stresses between the stiffening-girder and the cable was absolutely indeterminate. If the girder was stiff enough to carry the load when supported at those two points the stresses could be determined as shown by the Author on p. 102, but then there was a concentration of deflection at the centre; the result being that a suspension conveyor-bridge must have either indeterminate stresses or concentrated deflection when the load was passing the centre. He gathered from what the Author had said that deflection had given rise to considerable trouble in the passage of the car; at times the load was unequally distributed on the wheels, with the result that it had been necessary to increase the flexibility of the trolley. If the flexibility was increased, the question arose—What happened to the suspension-cables of the car? Any divergence of the travelling car from the straight line must mean a difference in the tension of those cables; and he would like to know how that distortion was provided for in the car, and whether the suspending cables were of such strength that some of them could carry the load without the support of others rendered slack by distortion.

Mr. JAMES C. INGLIS questioned whether the fact that only a single Mr. Inglis. line of communication had been provided at a cost of £133,000 did not suggest that the limit of development of the method had been reached. It might perhaps be possible to increase the capacity of such bridges by an adaptation of the mono-rail idea, so as to have two cars passing simultaneously in opposite directions, though of course there would be difficulties due to the swaying of the cars in a wind. He did not see why such a structure could not be made to carry a train; for there was no reason why the ingenious trolley on the bridge should not be extended and, instead of five sections, have fifteen, in order to carry a long train. But before such a sum as £133,000 was spent in bridging an estuary in this way, consideration would have to be given to the point whether a more frequent service would not be required ultimately; and if so whether a permanent structure should not be obtained, with its approaches, for even a much larger sum of money. The Great Western Railway might one day have to face the problem of crossing the Severn. Obviously, if an arrangement of the kind described in the Paper could be adopted there, it would save a great deal of capital expenditure in the first instance; but he doubted the wisdom of adopting an arrangement which would involve limitations like those of the Widnes and Runcorn bridge. A similar bridge was approaching completion at Newport, Mon. He did not know what the intentions of the Corporation were, but an advance might be made in the direction of carrying trains by taking the tram-cars across, and perhaps Sir William Thomas Lewis could say whether that was contemplated. The Paper was particularly interesting, inasmuch as the information given was very complete and the difficulties as well as the successes had been explained. He had been especially interested in the point with regard to the pin coupling, because it had occurred to him that with a single pin there would be difficulty.

Sir WILLIAM THOMAS LEWIS, Bart., stated that he knew nothing Sir William
T. Lewis. about the Newport Bridge, or he would have been glad to give the meeting any information he could.

Mr. A. T. WALMSLEY thought that if the system was to be Mr. Walmisley adopted in any way to carry a railway-train, or any portion of a passenger-train, the mode of suspension would have to be altered. He desired to know what amount of deformation of the cables the Author had found with the travelling load. Certain satisfactory results had been obtained from a model, but in such experiments there was an absence of lateral pressure produced by wind. In order to adapt the method to carrying trains it would be necessary to introduce a system that would prove as effective as Ordish's

Mr. Walmisley. system of rigid suspension, which had been adopted for the bridge over the Moldau at Prague, for a bridge at Singapore, and for the Albert bridge over the Thames at Chelsea, where the cables were prevented from deformation due to variation in the position of a passing load by a system of vertical bracing. The late Mr. W. H. Barlow had calculated that that system of rigid suspension was economically applicable to spans of 1,100 feet—100 feet longer than the Widnes bridge—so that with a braced girder no doubt greater rigidity would be obtained than appeared to be obtainable in the system adopted.

Dr. Stanton. Dr. T. E. STANTON could not agree with the Author in his description of the records of wind-pressure and velocity from Bidston Observatory as being totally unreliable because in any two of them, although the velocity recorded was practically the same, the pressure in one was 40 per cent. higher than in the other. Before accepting the Author's conclusion it should be borne in mind that the records were records of two instruments which were necessarily placed some distance apart. The velocity was measured by Robinson cups and the pressure by an Osler anemometer. He did not know what the actual distance was, but it would probably be about 5 feet, and might have been 15 feet. If it were true that in a gale the velocity of the wind at two such points was even approximately the same, the criticism would be just; but it was not certain that at any instant the velocities at two points 5 feet apart were equal. Mr. Dines had experimented 12 years ago by putting up two sensitive anemometers, 11 feet apart, and taking a series of observations, with remarkable results. It was found in many cases that one of the instruments would register 25 per cent. above, and in some cases 25 per cent. below the other. Recently Dr. Stanton had been carrying out similar experiments at the National Physical Laboratory. He used similar instruments, but put them 18 inches apart, and took simultaneous readings; and while in the majority of cases the readings agreed, still very considerable differences did occur. Therefore he thought it was practically certain that in an ordinary wind this considerable difference of 25 per cent. did frequently exist. Applying that reasoning to the Bidston records, the discrepancy was fairly easily explained. The two velocities were practically equal, but the two pressures differed by 40 per cent. Assuming that, instead of the two velocities at the pressure gauge being equal, one was 20 per cent. in excess of the other, then the pressure would be approximately 40 per cent. more on the one, which was the error indicated in the Table. He thought it likely that the rejected observations practically

represented the truth, when the circumstances under which they Dr. Stanton. had been taken were considered. In his own work at the National Physical Laboratory the difficulty was accentuated, because a plate 100 square feet in area was being used, and it was impossible to measure the velocity anywhere near the plate: the instrument had to be placed 15 feet from the centre of the plate in order to estimate the velocity, and the experimenters were in the habit of getting results differing from each other by the amount he had mentioned. They felt confident, however, that by taking enough observations, say, two, three, or four hundred, an approximately true relation between the velocity and pressure would be arrived at.

Sir BENJAMIN BAKER, K.C.B., Past-President, had no doubt that sufficient experience had now been gained in different parts of the world to show that there was a future for transporter-bridges, where the circumstances were suitable. With regard to Dr. Stanton's remarks, naturally any engineer who took up the problem of making the lightest possible superstructure for carrying a car would consider wind-pressure, and by adopting the Board of Trade allowance of 56 lbs. per square foot and using a factor of safety of 4, he would find that the wind was of more importance than the load. But in practice it was otherwise. In the Menai suspension-bridge, which had been standing for so many years, the floor originally consisted simply of timber planks without any wind-bracing. On being called in some years ago to advise he had put in a steel floor; but he had been unable to find any evidence that the absence of wind-bracing interfered with the traffic, even in considerable gales. There was a vertical undulation—a kind of wave along the bridge—but no lateral oscillation; the result of the undulation was that a number of the suspension-rods had been broken at different times, but, as they were only 1-inch square bars, that did not imply any great force. The effect of wind was therefore not what a student would expect if he proceeded on the ordinary data given by text-books. With regard to the system generally, the most primitive mode of crossing a river was of course by a ferry-boat. Where the range of level of water was considerable, on account of either tidal influence or floods in the river, the slope of the foreshore caused great inconvenience in regard to approaches, carts having to go down the foreshore and foot-passengers having to wade through the river-mud along the causeway; to meet that difficulty ferry-boats were constructed with a deck which could be raised so as to keep it always at the level of the approach. More than 50 years ago a Past-President of the Institution, Robert Stephenson, constructed such a ferry-boat for carrying railway-carriages and other things across the Nile at Cairo, and it was in use for many years. Before

Sir Benjamin
Baker.

Sir Benjamin Baker. the insurrection of Arabi and the bombardment of Alexandria some of the officers of the Intelligence Department at the War Office came to him to know if the ferry-boat was still in existence. As it had been broken up about 15 years previously, their information was not quite up to date. Such a ferry was now working across the Clyde at Glasgow. Even ferry-boats with raised decks, however, were still subject to the nuisance of the current, which made it difficult to fetch the opposite landing-stage in a fog. Consequently, a transporter-bridge was an improvement, because it gave the same facility in respect of approaches, and the difficulty caused by the current—and to a considerable extent also that due to fog—was overcome. But that method would suffice only where the traffic was not excessive, because, as Mr. Inglis had pointed out, the accommodation was not nearly so good as that of an ordinary bridge. Quite recently he had had to consider a number of alternative schemes for the traffic between Barrow-in-Furness and Walney Island, and he had submitted transporter-bridges and ferry-boats with raised decks; but none of these would meet the case, for the same reason that railways in London had great difficulty in dealing with the suburban traffic—everybody wanted to travel at the same time. After going into the matter in great detail with the local authorities the conclusion had been come to that a transporter-bridge would be useless where thousands of workmen wanted to cross to their dinner at the same hour, with only limited time at their disposal for getting to and fro. The result was that a fixed bridge with opening spans had been found to be well worth its cost, and there was hardly any limit to a bridge with opening spans if the money was available. At Detroit they were once contemplating a bridge with an opening span of 600 feet, but he fancied now they would substitute a tunnel, which was another way of getting continuous communication across a river. But there were many cases in existence, and there would be more in future, where bridges of the kind described by the Author would be the proper solution of the problem, and he was glad to see that the conditions had been met in every respect by the Author, who deserved great credit for the way in which the work had been carried out, and for the manner in which the details had been placed before the Institution.

Mr. Blount. Mr. BERTRAM BLOUNT pointed out that the particular interest of the specimen illustrated by *Fig. 22a*, lay in the fact that it clearly displayed the nature of the metal. The bolt was as homogeneous as mild steel usually was. He had been taken to task at least once in the Institution for denying the homogeneity of mild steel; but he thought that any impartial person who examined

a photograph of that bolt would admit that when he stated, a year Mr. Blount. or two ago, that mild steel was a bundle of muscles and nerves, he was not far wrong. He would like very much to know what was the remarkable substance found when cutting the foundations for the piers—the curious yellow substance said to have the consistency of white lead. He congratulated the Author on his excellent plan of abolishing the absurd practice of leaving the metal-work exposed in the anchorage-pits. Metal embedded in good concrete might be dismissed from further consideration; it would remain unchanged until the whole structure perished. It was known to many engineers, but was not so generally realized as was desirable, that metal structures—at all events steel structures, which mostly concerned engineers—were permanent in concrete; the iron would not rust or decay. It delighted everybody who knew the difficulties of the matter to know that the National Physical Laboratory had not relaxed its efforts to determine so important a set of data as the facts of wind-pressure. If the Laboratory confined itself to the determination of such data it would be performing services of greater public utility than some services which it seemed to be intent on rendering in other directions.

Mr. A. S. E. ACKERMANN understood from hearing the Paper read that the load had been put on the anchorage before the concrete round it had been put in. He recognized the advantage it would be to do this if it were possible, but he did not see how it could be possible. He noticed that several curved members had been used in the structure, an example being the top and bottom booms of the second cross girder from the top, between the towers. That might have been done for the sake of appearance, but it seemed very faulty design, and he would like to know why it had been adopted. Mr. Ackermann.

Mr. R. J. G. READ asked the reason for coating the anchorage-bars with tar-varnish before concreting them. According to his experience, extending over several years, steel embedded in concrete, if put in without any paint or covering whatever—and even in a rusty condition—was preserved perfectly intact and bright. It seemed to him that any coating like tar-varnish or paint would only prevent the concrete from adhering to the steel and would be detrimental instead of advantageous. The same remark applied to the cables. The Author described the cables as being coated with a bituminous compound and covered with canvas, but it seemed to Mr. Read that if concrete or cement was good for embedding the anchorage it would be good also for covering the cables. When in New York he had inspected the old Brooklyn bridge, and had Mr. Read.

Mr. Read. been struck by the covering of the cables, which appeared to be a kind of cement grout or fine concrete. He did not know whether underneath that there was a bituminous compound, but certainly the outside had the appearance of a rigid concrete bar. The erection derrick seemed to have been very suitable for its purpose, the height being moderate. In the case of high towers, such as the Eiffel and Blackpool towers, the crane and erecting apparatus usually travelled up the tower itself as the construction progressed, which was about the only practicable method.

Mr. Whyatt. Mr. H. G. WHYATT had tried tar-varnish both buried and above the ground as a sort of skirting, and he had found it very unsatisfactory; it did not protect metal-work at all in that position. Had the Author used it previously, or was this his first experience of it?

Mr. Bernays. Mr. J. BERNAYS could not quite see how the stiffening-girder was prevented from shifting longitudinally. If he understood aright it was carried at both ends by movable struts, but he had not come across anything in the Paper to show how the girder was prevented from moving longitudinally, because the suspension-rods could offer very little resistance to horizontal movement of the girder.

The Author. The AUTHOR, in reply, remarked that there would be no difficulty whatever in giving effect to the President's suggestion to adapt the system to the carrying of railway-trains; it was simply a question of designing the car and trolley to accommodate the train, and these could be made to carry any load. The question of the amount of the actual deflection of the girder with the passing load, referred to by Mr. Worthington, was a most interesting one, and the results of the Author's observations were given in Tables I and II. With regard to Mr. Moore's remarks, before the construction of the bridge at Portugalete by Mr. Arnodin 6 years ago, the first design for a transporter-bridge, as stated in the Paper, was made 35 years ago for crossing the River Tees at Middlesbrough; the bridge, however, had not been erected. The transporter-bridges abroad referred to by Mr. Moore which had rigid girders were all of much smaller span than the Widnes bridge, and the Author himself would not recommend a suspension-bridge under such conditions. The braced-chain mentioned by Mr. Moore would not, however, as he supposed, eliminate the question of deflection; and his statement that the stresses in the cable and the stiffening-girder were absolutely indeterminate unless the girder was strong enough to be supported at the end and at the centre pier, was hardly correct; for the deflection of the girder so supported could be determined, and the correction made for the uniform pull of the suspenders, which could be ascertained

TABLE I.

The Author.

Amount and Position of Load, including Trolley, Car and Traffic.	Vertical Displacement of Girder at			Remarks.
	Centre of Widnes Girders.	Central Hinge.	Centre of Runcorn Girders.	
75 tons at centre of Widnes girder	Feet. -1·17	Feet. -0·55	Feet. +0·05	Negative sign denotes downward displacement. Positive sign denotes upward ditto.
75 " " central hinge	-0·46	-1·73	-0·46	
75 " " centre of Runcorn girder	+0·05	-0·55	-1·17	
90 " " centre of Widnes girder	-1·25	-0·57	+0·06	
90 " " central hinge	-0·50	-1·90	-0·50	
90 " " centre of Runcorn girder	+0·06	-0·57	-1·25	
110 " " centre of Widnes girder	-1·50	-0·80	+0·04	
110 " " central hinge	-0·72	-2·42	-0·72	
110 " " centre of Runcorn girder	+0·04	-0·80	-1·50	

TABLE II.

Amount and Position of Load, including Trolley, Car and Traffic.	Actual Deflection of Girder at its Centre.		Remarks.
	Widnes Girder.	Runcorn Girder.	
75 tons at centre of Widnes girder	Feet. -0·89	Feet. +0·32	Negative sign denotes downward deflection. Positive " " upward
75 " " central hinge	+0·38	+0·38	
75 " " centre of Runcorn girder	+0·32	-0·89	
90 " " centre of Widnes girder	-0·96	+0·39	
90 " " central hinge	+0·45	+0·45	
90 " " centre of Runcorn girder	+0·39	-0·96	
110 " " centre of Widnes girder	-1·10	+0·45	
110 " " central hinge	+0·50	+0·50	
110 " " centre of Runcorn girder	+0·45	-1·10	

The Author. from a diagram similar to one shown in Figs. 12, Plate 2. There was no difficulty in dealing with the deflection at the centre of the span, the rails being raised at this point to counteract it; and in order to allow for the unequal pull on the car-suspenders due to the curvature of the girders during the passing load, helical springs were attached to the bottom of each suspender, and the car itself was not absolutely rigid longitudinally. Judging from Mr. Walmisley's statement that it would be necessary to introduce Ordish's system of suspension for heavy loads, such as a train, he appeared to have a misconception of the action of a stiffening-girder, of which the finest and most recent example was in the new East River bridge at New York, which carried two elevated railway-tracks, four trolley-car tracks, roadways and footways. For such a bridge the Ordish system was impracticable, but the stiffened suspension-bridge gave all necessary rigidity. Notwithstanding Dr. Stanton's very interesting explanation of the possibility of wind-gauges recording different results when placed near to one another, and admitting such a possibility, it was only by assumption that the recorded differences referred to were caused by the action he described; and in the absence of any proof of the accuracy of these instruments when under very high pressures, the Author still felt justified in doubting their reliability. Apparently Mr. Ackermann had not quite understood the statement in the Paper about putting the concrete in the anchorage after the load was applied; this of course referred to the concrete put in to cover the links, not to the concrete supporting the load. As to his objection to the curved members in the bracing between the towers, and the reason why it had been adopted, although theoretically the line of stress between two points was of course straight, with an elastic material it was not necessary for this line to fall within the plane of the material; and so long as the member was properly designed to withstand a given stress, the shape of it was quite immaterial; in the present case, a curve had been adopted, principally for æsthetic effect, the towers and other portions of the structure being curved for the same reason. In reply to Mr. Read's question about tar-varnishing the links before the concrete was laid, this had been done to protect the links from the weather during many months of exposure before the concrete was laid; it is not necessary for the concrete to adhere to the links in order to protect them; but as a matter of fact, the tar-varnish did not prevent it from doing so. Mr. Read's suggestion as to covering the cables with concrete was impracticable; the working of the cables would very soon disintegrate the concrete, and it was for this reason that the more plastic bituminous

compound had been adopted. Mr. Whyatt's experience with tar- The Author.
varnish appeared to have been unfortunate; and it suggested that the material was either faulty or improperly applied, for the Author has used it extensively for many years on outside work, such as iron piers, bridges, etc., with great success. Before selecting the material to be used to coat the structure, he had a dozen wrought-iron plates, 12 inches square, covered with two coats of different compounds, and suspended them about 50 feet above some chemical-works in the district for 3 months; this was a severe test, as the atmosphere was heavily laden with chemical fumes. From the results obtained, he decided upon the paint or compound to be used for the various parts of the structure. The longitudinal movement of the stiffening-girder was checked, as stated in the Paper, by the adoption of raking guys $3\frac{1}{4}$ inches in diameter, fixed between the centre pin and the cables.

The PRESIDENT remarked that deposits corresponding in appearance The President.
with the one alluded to in the Paper were found in many places in the neighbourhood of lakes and estuaries, especially in the north of Ireland. The material had the appearance of clay, but was entirely composed of diatomaceous material; it was used largely in the preparation of explosive compounds such as nitro-glycerine, also for non-conducting covering for boilers.

Correspondence.

Mr. F. ARNODIN, of Châteauneuf-sur-Loire, observed that the Mr. Arnodin.
Widnes and Runcorn transporter-bridge was a remarkable work in more than one sense. The fact that this bridge was the longest suspended span in the United Kingdom rendered it the more regrettable that in its construction the improvements realized in transporter-bridges erected in other countries had not been introduced. In the following critical examination of it questions of details and cost of construction would be neglected, and only defects which might have an influence on the security and life of the work would be considered. Judging by Fig. 1, Plate 1, the back-stays were inclined at an angle of 58° to the vertical, while the tangent to the parabolic cable was inclined at an angle of 71° . The resultant force due to the tensions in these two directions acted along the bisector of these combined angles, that was