Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author, said he was sure members would agree with him that The Institution was greatly indebted to the Author for the description he had given of a very important work, the largest bridge of its kind in Europe—possibly the largest in the world. He had an opportunity some months ago of examining it, just before it was completed, and that view had enabled him to form for himself an opinion in regard to its great importance.

The Author. The AUTHOR, having exhibited a number of lantern-slides and several models, pointed out that the actual test with the leaf at the centre of roll (pp. 49 and 50), in which the arc of contact, carefully measured on the three girders with the same feeler, was found to average about 7 inches, indicated that the working-pressure on the bridge was really about 8 tons per square inch.

Mr. Ross. Mr. ALEXANDER ROSS, Past-President, remarked that in one way he had perhaps more knowledge of the previous history of this bit of railway than had most of those at the meeting. The old bridge was under his supervision for many years, and it was gradually getting into a bad state, and so causing anxiety. It was built about 60 years ago by Sir William Fairbairn. The iron—not steel—girders were of the cellular type so commonly used by the Fairbairn firm. Having had to do with other bridges on the Trent of a similar character, he said, with the greatest confidence, that he had never seen better iron plates in his life: he could not call to mind the test-results, but they were remarkable. He had had to renew or remodel one of these bridges near Gainsborough, and he had been afraid that, when he looked into the ironwork, the cellular work would be found to be very much corroded; but, to his great surprise, there was no rust, and although the ends were more or less open, there was little amiss. He attributed that to the fact that the ironwork had been very well coated—though he did not know what was the actual coating used—and that the air did not pass through in the form of a definite current: it lay rather stagnant in contact with the ironwork, and hence, he supposed, oxidation did not take place to any extent. He had seen the bridges being built in Chicago, and there could be no doubt that the rolling lift bridge had not only made its mark, but had really come into almost universal use. It could be used not only on a very large, but also on a very small scale, namely, for ordinary canal bascule bridges. The bridges at Chicago were much smaller than the one now under notice, but they were of an earlier type and many improvements had been devised and introduced. He knew that the bed of the river Trent at that place was very treacherous, and he congratulated the Author on the fact that he had detected the threatened accident so soon, and dealt with it successfully. Occurring as it had done, it had proved of very little consequence, though it had been alarming. There was a large amount of detail in the Paper which would prove very valuable for reference. Mr. Ross.

Mr. C. S. MEIK wished to make some remarks about the Scherzer system, as against other forms of opening bridges, and in doing so he wished it to be understood that his criticisms applied not to the particular bridge under discussion, but to the system generally. The Scherzer principle did not give an economical form of bridge by any means. There was an enormous useless load, a mass of material which was not utilized in any way except to balance the opening span. In the case of the swing bridge, which until recently had been the commonest form of opening bridge in this country and in America, one span balanced the other; in other words, one opening span could be balanced by another opening span. In the Scherzer bridge the great weight required for balancing was not of much importance where the foundation was good; but in such a case as the present, in which there were troublesome foundations, it became a serious matter, because a foundation had to be provided capable of carrying that load. Taking Scherzer bridges as against swing bridges, and taking the Keadby bridge as an example of the former, he found that in that case the weight of the moving-span girders and counterweight was 2,922 tons, this being the load necessary for an effective opening span of 163 feet, or a weight of 18 tons per lineal foot of effective span. This weight necessitated foundations equivalent to 8·5 square feet for each lineal foot of span, taking the load on the foundations as 2·12 tons per square foot, which, according to his reckoning, was the effect of the weight of 2,922 tons brought on the foundations. Taking now a swing bridge, with two 150-foot spans, one balancing the other, a total length of 380 feet over the moving part was required and a total moving weight of, roughly, 2,250 tons. That was equivalent to 5·92 tons per lineal foot of effective opening, and required, to give the same load per square foot on the foundations, 2·8 square feet of foundation per lineal foot of bridge. Mr. Meik.

Mr. Meik. He put those facts forward to show that, after all, the swing bridge was the most economical form of opening bridge if the circumstances allowed of its adoption. Possibly—and he thought it was almost certainly the case—it had been found in the Keadby bridge that a swing opening span could not, on account of the navigation, be allowed on the river Trent. It would have helped considerably if a small key-plan had been given in the Proceedings, to show the course of the river above and below the site. He could sympathize somewhat with the Author and the railway company in the troubles they had had to begin with, before the site was fixed. Reference was made to the Royal Commission on Canals and Inland Waterways, as having had considerable influence on the requirements made on the railway. Some years ago his firm acted for a syndicate which had promoted a bridge across the Trent, lower down, near the mouth of the river, and he thought it was due to the action of that Royal Commission that the bridge in question did not get beyond its initial stages.

Mr. Thorpe. Mr. W. H. THORPE remarked that on p. 65 there was a description of the gear for working the bridge, in which occurred the words:—"The independent gear-trains terminate in a differential placed on the second driving shaft, designed to equalize the torque in the shafting, and so exert equal effort on each of the racks." He ventured to question whether, in operating a bridge of that kind, it was desirable that the torque on either side should with certainty be equal when the bridge was opening. Owing either to the vagaries of the wind or to the differing coefficients of rolling friction on the two sides, it might happen that there was at times a difference of resistance to be overcome. If this were less on one side than on the other, the driving effort on either side being the same, one outside girder might be expected to advance and make a greater angular movement than the other. He did not suggest that this effect would be considerable, or in any way serious, but, to his mind, it disposed of the advisability of putting in a differential. Of course, the Author might have had in his mind reasons of which Mr. Thorpe was not cognizant. He had known one or two instances in which structures operated by mechanism had shown undesirable peculiarities. Some small lock-gates which he had had occasion to investigate were operated by an arrangement of chains acting near the top and bottom of each leaf. From the nature of the arrangement, the pull above and below was equal. When the gates were to be opened, they would sometimes stick at the mitres, either at the top or at the bottom, resulting in a severe twist on the gates. In another case, that of a little bascule span operated on each side by hydraulic rams, owing to the lengths of small-bore piping leading from the valve to the rams being very unequal, with many bends, the operation of the rams was also unequal. The result, with lack of positive control, was that one bascule arm would lead, and in coming down to the bearing first one extreme end would touch and then the other, one end touching before the other by some inches. When the two arms of the bascule had settled down on to their bearings, there was found to be an appreciable displacement of the centre line of the span. He thought that in both the instances he had referred to there should have been positive operation with definite movements. In the Keadby case, also, it might perhaps have been better if there had been a connecting shaft from pinion to pinion (the differential gear being dispensed with) in order to turn the two outside girders through the same angle in the same time. The dead weight of the Keadby opening span was described by the Author as being carefully counter-weighted, but it was stated that when the bridge was being opened against a wind, the wind forces were not balanced in any way, and had to be taken up by the rack and pinion. With respect to the statement that, with 20 lbs. per square foot normal wind-pressure over the area of the leaf there was a horizontal thrust of 153 tons on each of the racks, by what means was that thrust developed? The pressure came first on the whole surface of the span; but with regard to the wind-pressure about the middle of the bridge, half of that was first taken by the centre girder, and got to the outside girders through the cross framing and possibly as to part, through the cross girders. The wind-pressure taken by the centre girder was about 40 tons, or at each of the frames say 5 tons pressure, which had to get to the side girders chiefly through the frames. On Plate 2 one of those frames was shown. He did not suggest that it was not sufficient to carry the load of 5 tons across the width of the bridge, but it did not strike him as being of a form well suited to carry such a load. This, however, was largely a matter of scantlings and strength. In the "Remarks" column on p. 92 it was stated that in arriving at the number of shears required, where the stresses in the bars meeting on the boom were unlike in sign, one-third of the smaller was added to the larger, and that in the case of like signs both were added. If the Author would give further information as to the precise basis for that, Mr. Thorpe, and possibly others also, would be obliged. Mr. Thorpe.

Mr. R. Elliott-Cooper, Past-President, had had the advantage and pleasure of seeing this bridge at the time when the President inspected it. He also had been struck by its magnitude, its Mr. Elliott-Cooper.

Mr. Elliott-Cooper.

boldness, and the manner in which—so far as it was possible, in a visit like that, to see—it was being carried out. He would like to refer to one or two points which were not matters of detail, but were rather general principles applicable to this or to any other bridge that had been built, or might be built in the future, over the Trent. He believed he was the only engineer who had built a bridge across the Trent since the old Keadby swing bridge was constructed. In 1892 he was engineer for the Lancashire, Derbyshire and East Coast Railway, which extended, or was meant to extend, from sea to sea. The difficulty which they met with at the Trent was much the same, he imagined, as the Author and the Great Central Railway Company had met with when they attempted, as they had done on one or two occasions, to cross the Trent with the object of doing away with the old bridge. According to the deposited plans, the bridge consisted of four girder spans of 120 feet each, with a headway above the water of 25 feet. As the point at which the river was to be crossed was higher up than Gainsborough, it could not compare with the situation of the bridge now being discussed so far as navigation interests were concerned, and he thought that enough headway had been provided for any barge or boat likely to use the river Trent above Gainsborough. But the Trent Navigation Company had very ambitious ideas at that time: they seemed to have in mind a ship-canal, and they strongly opposed what they considered would be a great obstruction to the development of the river between the sea and Nottingham. As this bridge was only part of a scheme involving 160 miles of line and an expenditure of about 8 millions sterling, the promoters did not feel disposed to fight in Parliament a question which might have been fatal to the whole scheme, and which could be modified without very serious expense. They therefore agreed to lift the bridge 40 feet, giving a headway of 60 feet at ordinary water-level. Of course, in a bridge of that kind, this arrangement was open to the great objection that it would involve long gradients of, he believed, 1 in 100 on each side. Considering that the route in question would form the outlet from the Derbyshire coalfields—which, since that time, had developed enormously—it was obvious that as the railway dealing with this traffic fell generally towards the sea, the interposition of a rising gradient of 1 in 100 was a very serious matter. However, the Act was obtained with that obligation. At the end of 12 months, however, nothing having been done, and the Trent Navigation Company not appearing to have any chance whatever of carrying out their ambitious scheme, his clients brought into Parliament another Bill, which provided for the lowering of the

Mr. Elliott-Cooper.

bridge 20 feet, leaving a headway of 40 feet, and they obtained the necessary powers. Another year passed, and still there was no sign of anything being done to make the proposed great waterway. The railway company thought they would try again to obtain powers to build the bridge at something nearer the original height. At that time the Trent Navigation Company was not in a very good financial position, and naturally they hesitated to embark on a costly Parliamentary fight, so that a compromise was arranged, and the company were able by paying £5,000 to build the bridge with a headway of about 30 feet, or nearly what had been originally intended. He was glad to say that, so far as he knew, not the slightest inconvenience, either to the navigation of the Trent or to the people of Nottingham, had resulted from the construction of that bridge. Of course, he had not prepared the plans without having first satisfied himself as to the facts. Between the bridge to which he had referred and the sea there were, he thought, three or four bridges with fixed spans less in headway and clear opening than his. In carrying out that bridge the Keuper marl was met with at much the same depth as at Keadby. There were about sixty land arches, in addition to the four 120-foot spans, because the landowners were unreasonable enough to require openings between the extreme limits of high floods. When the incoming tide met the flood-water in that valley, the flood was remarkable, extending in some cases nearly ½ mile across. At a depth of 15 to 20 feet below the surface, remains of the antlers of what he was told were red deer were found, also remains of oak, showing that, in the course of thousands of years, the valley had gradually been filled to its present level. Of course, the sea must originally have been at a much lower level on the east coast than it was now. What he had referred to was ancient history, but might explain a point that would be in the minds of some when they compared the great bridge shown on the wall with the old swing bridge it had replaced. Naturally, no railway company would dream of replacing a comparatively inexpensive bridge with one of the magnitude of the Keadby bridge unless they were obliged to do so. Under ordinary conditions there were two other methods by which the river might be crossed, supposing there were no unreasonable opposition: one was a high-level bridge, which would have been open to great objections here; the other was a swing bridge, which would probably have cost less than the rolling-lift bridge. But he believed the engineer had not had a free hand: here again the Trent Navigation Company and the Humber Conservancy had interposed, and as it had been impossible to pull

Mr. Elliott-Cooper. down the swing bridge until the other was built, the Great Central Railway Company had been in the hands of those who controlled the river. Everyone who knew the Author would feel sure that he would not advise needless expenditure. Another question which might be in the minds of some was why a road-bridge had been built beside the railway-bridge. It was obviously not to the interest of the railway company to develop the roads of Lincolnshire. That also, he believed, had been done in order to obtain the good will of the county authorities; at any rate they had paid a substantial sum towards the cost of building the road-bridge. He had been nominated by the Board of Trade to certify whether the extra expense involved by the addition of the road-bridge was as much as the sum provisionally agreed to by the road-authorities, and he had been able to report that not only was it sufficient, but that he thought they had made a very good bargain, because they certainly could not have built a road-bridge across the Trent, even if they had ever dreamed of having a rolling-lift bridge, for anything like the money. The construction of this bridge seemed therefore to have satisfied all parties. Perhaps the Author would be so good as to explain a few small points. One concerned the permanent way: did the continuous fish-plates take the place of chairs on the longitudinal timbers? If not, he did not see why with 40-foot rails a continuous fish-plate was needed. Again, he noticed that the moving load for the road-bridge had been calculated as consisting of two trollies weighing 40 tons each, hauled by a traction-engine weighing 30 tons, and it was assumed that two such trains might cross the centre of the bridge at the same time. He did not think there was the slightest chance of such a thing occurring in the wilds of Lincolnshire. But road-authorities had large ideas as to their requirements; probably they were following the ideas of London, and felt they were equally entitled to a bridge of great carrying-power.

Sir John Griffith. Sir JOHN P. GRIFFITH remarked that it had been gratifying to him to learn from the Paper that the Report of the Royal Commission on Canals and Inland Waterways had had some influence on the requirements of the river-authorities in regard to the design of the Keadby bridge. As one of the engineering members of that Commission, he had been greatly impressed with the importance of the river Trent and its potential value to the trade of the country, if it were improved under a comprehensive scheme, including the regulation of the Upper Humber between Hull and Trent Falls. The importance attached to that navigation by the Royal Com-

Sir John Griffith.

mission was shown by the following extract from the Commissioners' report.[1]

> "We are of the opinion that the improvement of the river Trent up to Nottingham on a scale suited to sea-going vessels carrying 750 tons is one of the most pressing reforms to be undertaken. But we are sure that the whole benefit of such a measure cannot be obtained, unless the Humber from Trent Falls to Hull is taken in hand, and made as safe and easy a navigation as the portion of the River Ouse above Trent Falls, recently improved by the Aire and Calder Navigation Company. This subject demands prompt and careful attention."

It was satisfactory to know that the new bridge across the Trent would not prove a hindrance to the future improvement of that river. One of the lessons of the war had been the importance of inland navigation: it was to be hoped that the country would profit by that lesson, and would, at an early date, take advantage of its natural waterways and improve both them and the canals, to suit them to modern requirements and form a useful supplement to the road and railway systems. He congratulated the Author on his decision to adopt the Scherzer type of rolling-lift bascule bridge, which he believed was an absolutely right decision, and on having made his opening span in a single leaf. Sir Benjamin Baker had been, he thought, the first engineer in England to adopt the Scherzer design. It was an indication of his greatness as an engineer that he had been prepared to use in his works what he believed to be the best, irrespective of its source, and had not sought to evade patent rights by adopting some inferior method of dealing with the problem before him. The best engineering was to adopt the best methods and the best designs for the work in hand. The bridge described by the Author was, Sir John Griffith believed, the longest Scherzer span in Europe, but there were several somewhat longer spans in the United States. With the experience in the States available, there would not appear to be much cause for apprehension in regard to the contact pressures between the rolling segments and the roller-paths. The experiments carried out in connection with that by Messrs. Sir William Arrol and Company were, however, of considerable interest. There was one risk the importance of which could only be determined by prolonged experience, namely, the possible stretching or extension of the plates in contact on the rolling segments. The steel was of course of high tensile strength, but it was almost impossible to believe that a slow creep would

[1] Fourth and Final Report (England, Wales and Scotland) of the Royal Commission on Canals and Waterways of the United Kingdom, para. 828.

Sir John Griffith. not take place in consequence of the rolling motion and the high pressure. That might lead ultimately to shearing of the rivets connecting the rolling plate with the curved segmental girders. He was especially interested in the description of the opening span, because, about 1910, he had to consider the reconstruction of the bridge across the Royal Canal, where the canal intersected the most important quay in the Port of Dublin, namely, the North Wall Quay. The old drawbridge, which had been in use since 1860, consisted of two carriage-ways, about 9 feet wide, with narrow footpaths. It was a great obstruction and danger to traffic. The North Wall Quay roadway had been widened to 45 feet, and it was clear that the old bridge would nullify the usefulness of the widened roadway. The Royal Canal was approached from the river Liffey by a tidal lock, and the old drawbridge was just outside the lock-gates. A new bridge, corresponding in width with the roadway of the quay, would pass partly over the lock and partly clear of it. It had, therefore, been obvious that if a single bridge, 45 feet in width, were adopted, it would form an obstruction to a vessel in the lock, and would have to be closed to street traffic while vessels were being locked in or out, and while they were passing through the entrance. It had also been obvious that a swing bridge would be unsuitable for the site, and that a bascule bridge would have to be adopted. Under those circumstances, he determined to adopt the Scherzer design, and to build two bridges instead of one, which would allow one bridge to pass over the lock, and the second bridge to be clear of the lock. The outcome had been the construction of the twin Scherzer bridges on the North Wall. The reasons that had induced him to adopt the Scherzer rolling-lift bridge in preference to any other type were the following:—First, it had the minimum length of movable span, because when opening it rolled back from the channel; secondly, it did not require a counterweight pit, which in the case of the North Wall bridges would have been very costly and an extremely difficult work to undertake; thirdly, the friction in opening and closing was practically nothing, the large rolling surfaces, on smooth and level steel tracks, getting rid of all sliding friction; fourthly, the bridge being thoroughly braced throughout, and the main girders united by their counterpoise box girders, the structure was perfectly stiff and rigid. Between these bridges and the Keadby bridge there were some points of similarity and of difference to which he desired to draw attention. In the first place, the counterpoise was carried as a portal girder across the roadways and connecting the main girders. Secondly, the density of the counterweight

Sir John Griffith.

material at Keadby was 163 lbs. per cubic foot, while the density of the counterpoise at Dublin was 310 lbs. per cubic foot. Thirdly, the bridges both at Keadby and in Dublin were worked electrically. At Keadby special electric plant had had to be provided, with the alternative of a petrol engine and a hand-winch in case of accident to the electric supply. At Dublin the bridge was worked from the electric power-supply of the port, with the alternative of working off the lighting mains, or by hand-gear in case of necessity. In the fourth place, sufficient power had been provided to open the bridges when exposed to a wind-pressure of 20 lbs. per square foot. The usual American practice was to provide power for a wind-pressure of 12 lbs. per square foot, but as the Port Board in Dublin was responsible for opening the bridge for navigation purposes he decided to adopt 20 lbs., and so reduce the chances of demurrage-charges on ships delayed in passing the entrance through default in opening the bridge. He was pleased to see that the Author had adopted the same working-pressure. In the fifth place, at Keadby pitch-pine flooring with jarrah sets or blocks had been adopted for the carriage-ways and footpaths, the object being lightness. In Dublin he had experienced so much difficulty from wood paving on the dock bridges, where traffic was very heavy and congested, that he decided to floor the lifting spans with steel buckled plates, and to form the roadway with stone sets on concrete. The wear was very localized, the wheel-tracks being confined within limits of a couple of feet for each wheel, and the repair of the wooden sets had caused a great deal of inconvenience to traffic, and had become a serious item of expenditure. He therefore broke new ground, contrary to American practice, and many remonstrances were made when he decided to floor the lifting spans with steel buckled plates, and to form the roadway with stone sets on concrete. Small 3-inch cubes were used, very similar in size to the wooden sets of the Keadby bridge. They were machine-made, a 3-inch cube being a very difficult set for an ordinary set-dresser to make, but he had been fortunate enough to find a contractor who undertook to make them by machinery. The result had proved completely satisfactory, and the interference with traffic for the purpose of making repairs had been negligible. The objections raised had been based upon the extra weight to be dealt with and the extra cost, but he considered that the results had fully justified the expenditure. It was certainly a curious sight to see the stone pavement set up on end when a bridge was raised, but he could speak with full satisfaction of the results attained.

Mr. Saner. Mr. J. A. SANER remarked that on the east side, that was, the side on which the lifting span was placed, there had been a tendency in the first instance for the piers to move forward into the river. He had had a very similar experience at Northwich, where he had put two swing bridges on ground which was in the first place not very sound, owing to subsidence due to salt-workings. In excavating the same difficulty was experienced, and it was necessary to set back the foundations of the tail end of the bridge some considerable distance. Had he known that it would be necessary to do that, he would have made the bridge an equal-ended swing bridge; and he wondered whether, in the present instance, had the Author known that he would have to make an extra span, he also would have adopted a swing instead of a rolling-lift bridge. With regard to the girders, it was always very difficult to keep cross girders bearing evenly upon main girders without putting uneven stress on the members of the main girders. In the present instance, so far as he could follow the small diagram in the Paper, the cross girders were suspended from the main girders, and therefore the bearing could be brought equally on both portions of the main girder itself, a method which he thought had great advantages and should be adopted wherever possible. The next point that occurred to him was that—on the drawings at all events—no protection was shown for pier No. 2, which was of considerable size. Probably the vessels now navigating the river were nothing like as heavy as the pier itself, and it occurred to him that timber dolphins or some timber framework should be put up, if not to protect the pier, to prevent vessels from hitting it, because the stream ran with considerable velocity at times, ebb and flood. That was a point which he thought would require attention, if the dolphins were not already there. The load limits on the bridge seemed to be very ample at present, especially on the roadway, though it was very desirable, of course, that bridges should be strong enough to bear any loads that might come upon them. A good deal of trouble had occurred in Cheshire through the bridges not being strong enough, and perhaps in course of time the load allowed for the Keadby bridge would be absolutely necessary: he only wished to point out that on a 15-foot roadway it would scarcely be possible for two traction-engines, drawing loads of the size mentioned, to pass each other. With regard to the ballast, Sir John Griffith had forestalled what he had been going to say on the question of the weight of the concrete. He was somewhat in doubt as to the advisability of having so large a mass of concrete all in one place. Very great difficulty would be experienced if any necessity arose for dealing with it, through rivets getting loose or anything of that sort. In one or two cases on the river Weaver, where an attempt had been made to ballast with concrete, great difficulty had been experienced, because it had been found necessary to break it all out before it was possible to get to a few rivets that required attention. It did not seem practicable to have mechanically-operated gates at both ends of the bridge, but the bridge appeared to be completely safeguarded, ample provision being made for warning the traffic. He had experienced the same difficulty in a case where it was proposed to operate the swinging gates by electric power. Fortunately he pointed out, before that plan was put into operation, that if one of the swinging gates caught an unwary person in the back it would probably throw him into the river or hurt him very severely. It was necessary to have the gates attended to by hand, because it was impossible to be quite sure that everybody was on the alert. It was difficult to criticize the electrical machinery from the description given in the Paper, but it seemed to him that ample power had been provided. That was always the right course, but he would have liked to see an ammeter diagram showing the required power to open and close the bridge, more especially when there was a wind blowing directly across the river in either direction. That would have shown the effect of the wind first on the rising and then on the falling roadway: as the roadway became very nearly horizontal, the counterweight would come into action, and another wind-pressure would come into play, so that there would be a considerable variation in the curve of the diagram, depending on the direction of the wind. In his first electrically-operated bridges, which were put up in 1899, he installed an ammeter in which the paper travelled at the rate of 6 inches per minute, and some interesting diagrams were obtained, which were shown at the Institution shortly afterwards.[1] In conclusion, he desired to emphasize the remarks made by Sir John Griffith as to the great importance, in all cases where navigations or canals were crossed by railway- or road-bridges, of preserving the waterway as fully as possible for the use of the traffic. Everyone now realized that had the proposals of the Royal Commission on Canals and Inland Waterways been carried into effect, there would have been much less congestion on the railways at the present time, and that a large portion of the cost of the reconstruction and alteration of the waterways would have been actually saved and refunded during the past 2 years. Mr. Saner.

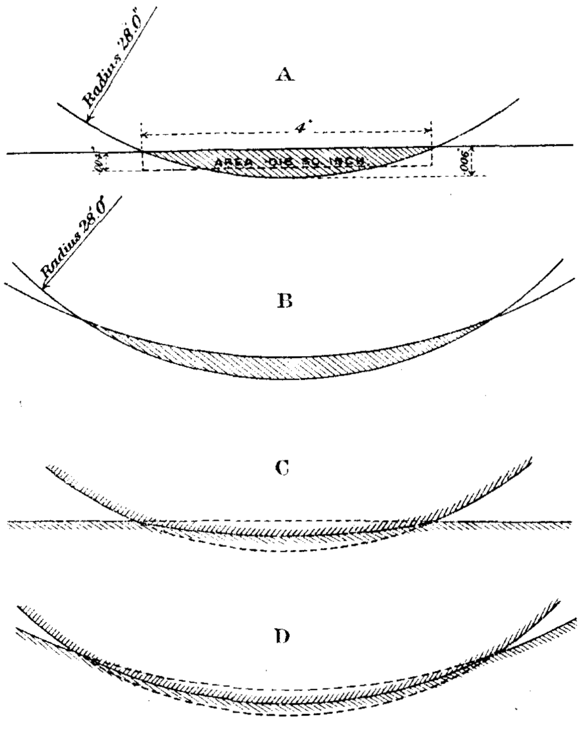
[1] Minutes of Proceedings Inst. C.E., vol. cxl, p. 86.

Mr. Yeatman. Mr. M. E. YEATMAN could not altogether agree with Mr. Meik's conclusions as to the lack of economy on account of the foundations required by Scherzer bridges. Mr. Meik had pointed out that the very heavy counterweight required put a great deal more load on the foundations than did the bridge itself, and that the foundations had to be proportionately larger. No doubt that would equally be the case with a swing bridge if it were not a balanced one; and if it were a single-opening bridge it would have to have a counterweight tail in the same way. Therefore the advantage of doing without a counterweight applied only to a balanced swing bridge over two equal openings; but it was by no means always the case that two small openings were as good as one large one. Even if they were, he doubted whether in very soft material the foundations would be proportional to the weight to be carried, for in ordinary cases the structural conditions required a large central pier in a swing bridge. The central pier of the old bridge at Keadby was a very large one, to carry the railway. The new bridge which carried a road as well as a railway, if built on the balanced swing principle, would undoubtedly have required a very large central pier to turn on. That being the case, even if the total load to be carried were not as great, the foundations required would be quite as large as for a Scherzer bridge. The advantage of the Scherzer bridge, which had brought it so largely into use after its invention on the Chicago river, was a different one, namely, that whereas a swing bridge occupied or obstructed a frontage on the river equal to the whole of its length, a bascule bridge or a Scherzer bridge did not occupy a frontage of more than its own width. On the Chicago river frontage was very valuable, and that fact had caused nearly all the swing bridges there to be replaced by Scherzer bridges. On looking at some notes which he made at the time, he found that up to 10 years ago seventy-three Scherzer bridges had been erected. Ten years ago, however, there seemed to be rather a reaction in Chicago in favour of the pivoted bascule bridge as against the Scherzer bridge, in spite of the great advantage of the Scherzer bridge that it rolled back from the opening instead of turning on a fixed pivot, and therefore required less total length to get the same clearance. He had always understood, though he did not know whether he was correct, that the main reason for the reaction was the heavy royalties charged for the use of the Scherzer design. He desired to ask the Author whether that was still the case, or whether the patents had run out, so that anyone was now free to construct bridges on the Scherzer principle. Passing to the structural part of the bridge, an interesting point in the Paper was the load allowed per lineal inch on the rolling surface. That had interested him very much, because it had seemed for some time to be a moot question whether the load bearing on a roller should be proportional to the diameter of the roller or to the square root of the diameter. The Author cited Messrs. Bryan, Johnson and Turneaure's book, and gave 400 or 500 times the diameter in inches as a safe load in pounds per lineal inch. Those figures appeared in later editions of the book, while in earlier editions 1,200 times the square root of the diameter was given as the safe load. For bridge rollers 4 inches or 5 inches in diameter it did not make much difference which of those formulas was used; the result was about the same: but in dealing with a rolling segment of 28 feet radius there was a great difference. If 1,200 times the square root of the diameter was adopted, then, instead of putting 60 tons per lineal inch, it would only be possible to put 14 tons. He was glad that proportionality to the diameter, and not the square root of the diameter, seemed to have been indicated. The only other question he desired to raise was whether it was necessary to make such an elaborate box for the counterweight, and whether the latter, being of solid concrete, could not have carried its own weight, consisting simply of a block of concrete with the ends of the structure embedded in it. Mr. Yeatman.

Mr. G. F. Barber desired to refer to that portion of the Paper which dealt with the question of the bearing pressure of the segmental girders on the track-plates, though he did so with hesitation, feeling that he might have failed to grasp some essential point in the Paper. In the second table on p. 48 the Author gave the results of certain tests. In the third test, which Mr. Barber selected because it involved no fractions, under a load of 72 tons, the arc of contact was 4 inches long, by, according to the text, 1 inch wide, thus giving a contact area of 4 square inches. Dividing the 72 tons by the 4 square inches, the Author obtained a pressure of 18 tons per square inch. That appeared to Mr. Barber to be the mean or average pressure for one flat surface resting on another flat surface. The actual conditions, however, were, he thought, shown at A, in *Figs. 27*, that was to say, a certain volume of metal equal to the shaded area multiplied by its thickness normal to the plane of the paper disappeared under the compression. If the load remained constant, that volume also would remain constant, no matter what its shape might be: under other conditions the volume would vary directly as the load, and inversely as the modulus of elasticity within the elastic limit of the material. In some Mr. Barber.

Mr. Barber. respects that volume was, he thought, comparable with the displacement of a floating vessel. The shaded area might also be considered as a strain and stress diagram for the material of both the rolling segment and the track on which it rolled, in that its ordinates represented or were proportionate to the varying intensity of strain and stress from point to point throughout the arc of contact. He had found by calculation that a 4-inch chord on a

Figs. 27.



curve of 28 feet radius would give a versine of 0·006 inch, and would enclose an area of 0·016 square inch (to the nearest third place of decimals). As calculated by the Author, those ordinates were all of equal length, and resulted in the rectangular strain and stress diagram shown in dotted lines at *A*, in *Figs. 27*, and if Mr. Barber's argument as to the constancy of volume of the displaced material was correct, that length would be $\frac{0\cdot016 \text{ square inch}}{4 \text{ inches}} = 0\cdot004$ inch, as compared with a central ordinate of 0·006 inch in the segmental compressed area. As the stress was proportionate to the strain, the mean stress would be to the maximum stress in the ratio of 0·004 and 0·006: the maximum stress would be 27 tons per square inch instead of 18 tons per square inch. The actual working-load of 58 tons per lineal inch occurring in the bridge on an arc of contact of $3\frac{1}{2}$ inches, would give a maximum pressure of $24\frac{3}{4}$ tons, instead of the $16\frac{1}{2}$ tons per square inch mentioned on p. 50. The same reasoning, if correct, would apply when a convex segment bore on a concave segment of larger radius, as was the case in the present instance when the deflection of the track girder came into play, and as the ordinates of the compressed area (shaded at *B*, in *Figs. 27*) varied very similarly to, if not exactly as, those of the compressed area at *A*, the same ratio would apply. Taking the worst case, that of girder *C*, referred to on p. 50, 58 tons $\div$ $6\frac{3}{4}$ inches $= 8 \cdot 6$ tons per square inch mean pressure, and $8 \cdot 6 \text{ tons} \times \frac{0 \cdot 006}{0 \cdot 004} = 12 \cdot 9$ tons per square inch maximum pressure. What really took place was illustrated at *C* and *D* in *Figs. 27*. Both the roller and the track were compressed, the pressure on them being equal at any point. If other conditions, such as the thickness of the metal, were equal and they were made of material having the same modulus of elasticity, the areas compressed would be equal, while if their moduli of elasticity varied, the areas would vary in an inverse ratio. Mr. Barber.

Mr. CHARLES HAWKSLEY, Past-President, remarked that several references had been made to the improvement of the Trent navigation. A number of years ago an Act of Parliament was obtained for that very purpose, and certain works were carried out, but unfortunately the Company could not proceed to the fulfilment of their aspirations for want of money, and that was the stumbling-block even at the present time. Considerable improvements, however, had been made for light traffic. Mr. Hawksley.

The AUTHOR, in reply, observed that he had been much gratified by the interest shown in the Paper, because at a time like the present anything not connected with the war must necessarily take a secondary place. He believed that Mr. Meik's calculations referred to the swing bridge at Hawarden, which had been fully described in the Proceedings.[1] That bridge was only 15 or 20 feet shorter than the Keadby bridge, taking the total length of the opening and the fixed spans; but the Keadby bridge had been designed for a running load about 25 per cent. heavier than that The Author.

[1] F. Fox, "The Hawarden Bridge." Minutes of Proceedings Inst. C.E., vol. cviii, p. 304.

The Author. allowed for in the case of the swing bridge, and that in itself naturally added considerably to the weight of the structure. He had taken out those weights approximately, and, considering the weight of the whole span—steel and concrete ballast—and supposing that the swing bridge had been designed for the same loads as the Keadby bridge, and with a road-bridge, the result came out, curiously enough, at about 6 tons per lineal foot in both cases. Mr. Meik had argued that the weight of a swing bridge, with equal arms of 150 feet span each, was about the same as that of a Scherzer bridge of 150 feet lifting span. Considering that there was much less steel in the Scherzer bridge, a false conclusion was perhaps arrived at by taking the gross weight of the two bridges. For instance, in the Keadby bridge there was about 1,600 tons of concrete, which, at £1 per ton, differed considerably in cost from 1,600 tons of steel at, say, £25 to £30 per ton. There was also another point to be considered, in connection with the river-improvement. The old dolphin was a serious obstruction to the river, and to build adjoining it a bridge that would require a dolphin about 380 feet long and 70 feet wide in the river, would be detrimental to the channels on either side. The river Trent changed its channels frequently, and was a very difficult river to deal with. At the place in question they ran obliquely across the river almost from the west side to the east side, and when the old bridge was removed and there was a clear waterway of 150 feet between the two piers on either side, an important river-improvement would certainly be effected. As to why a differential had been used to equalize the torque in the shafting, in a bridge of that type a good many points had to be considered in connection with the gearing: among other things, there might be some distortion due to a difference in temperature. The movement on the track spans, due to deflection and other reasons, had led the Author to conclude that it was desirable to put in a differential. The span had been opening on an average four or five times a day for the last 6 or 8 months, and now that everything had settled down, the gear appeared to be working much more freely than at the beginning, although even then it ran well. In fact, the balance of the bridge was so accurate that, before the machine-driven gear was coupled up, the span was moved by the erecting-winch alone when standing at an angle of 45°, with only one man at each end of the winch. The span was then moved freely with little effort. The 153 tons horizontal thrust on each side of the rack, to which Mr. Thorpe had also referred, was the pressure which would require to be exerted, between the rack-teeth and the pinion engaging with the

The Author.

rack, to hold or start the raised leaf against a 20-lb. normal wind-pressure over the whole surface of the leaf. He thought Mr. Thorpe had forgotten that the ballast-box united the ends of the three main girders and formed a rigid mass, which together with the portal bracing was ample to take up such a thrust as would result from a 20-lb. pressure. When he was in America he saw Mr. Scherzer, the originator of that type of bridge, or the son of the originator, and ascertained that the wind-pressure provided for in the bridges erected in America was only $12\frac{1}{2}$ lbs. per square foot. He came to the conclusion, however, that that was not sufficient; he therefore increased it to 20 lbs., and power was provided accordingly. Mr. Elliott-Cooper and Mr. Saner had commented upon the heavy loads adopted for the roadway of the bridge. It should be borne in mind, however, that the bridge was situated in a large iron-field which was developing rapidly; new furnaces had been put down and would be put down in the future, and large ironworks were in course of erection, and it was not known what loads the bridge might have to carry in the future—possibly armour-plates on road-tractors, as in the Lancashire district at the present time. Provision had been made for such a contingency as that. In addition, as this line would probably form one of the main arteries of traffic between Doncaster and that important iron-field, and on to the docks on the south side of the Humber, it had been considered essential to have a bridge which would carry such loads as heavy guns, or anything else that might require to go over it. Sir John Griffith had raised the point that the Scherzer type of bridge required careful watching, in view of the possibility that the loads imposed on the track plates might cause rivet trouble or perhaps a flowing of metal. Mr. Ball had not been surprised, on seeing some of the bridges in the United States, to find that trouble had been experienced, because the early bridges across the Chicago river were, in his opinion, about as badly designed as they could have been to take up the stress which was to be expected on that part of the bridge. He had inspected probably thirty or forty bridges in different parts of America, and had found that only in the earlier type of bridge over the Chicago river had that trouble been experienced. He had been much struck, however, by the entire absence of maintenance work. The engineers seemed to deal with their bridges much as they dealt with their rolling stock, that was to say, they ran them to death and then scrapped them. There was no comparison between the care which was bestowed upon maintenance in America and that bestowed in this country. Mr. Saner had raised the question

The Author. of protecting the river-pier—which was a pretty substantial one. At present the old bridge remained, and there was timber piling between the two bridges, because of their contiguity. A tug was kept in attendance, and hitherto no experience of collisions with the pier had been gained, nor did he anticipate any. The tide flowed across the river, so that any collisions that occurred took place, as a rule, on the east side. Trouble might be experienced on that account, and if so, it would be necessary to put down some protecting piles, but he was afraid collisions would be more troublesome to the vessels than to the pier. Mr. Barber's observations and diagrams were correct. The result of the tests made at the shops should be taken as mean pressure. The actual working-pressure obtained on the whole of Keadby bridge, however, amounted only to about 12 tons per square inch. Mr. Yeatman's remarks in regard to the cost of foundations were, the Author thought, also correct. In the case under discussion it had been impossible to adopt the swing type of bridge on account of the navigable channel of 150 feet being on the east side of the river; and the construction of a dolphin about 380 feet in length and 70 feet in width was quite impracticable in a river with all the conditions which were now found in the Trent at this place. Further, the cost of such a dolphin, in view of the load which would have to be borne on the central pier, assuming that a balanced swing bridge of two equal arms of 150 feet could have been provided, would have increased the cost of the foundations very largely. Such a timber structure and its maintenance would have been considerably more costly than the design carried out. The Author could not say whether the Scherzer patents had run out or not, but in view of the great experience which the patentees had obtained, and the fact that in the case of the Keadby bridge the three-truss span was at that time almost the first of its kind to be adopted on the Scherzer principle, he had consulted Mr. Scherzer and arranged with him to prepare drawings on the Company's design for the lifting leaf; at the same time an arrangement was made that on any points which might arise during construction the patentee could be consulted by correspondence. Subsequently, owing to the adoption of a heavier rolling load, the whole work was re-designed in the Author's London office, and the drawings were submitted to the patentee for his criticisms. He had pleasure in stating that the fee paid to Mr. Scherzer was an exceedingly moderate one, and that the various points which arose during construction had been dealt with fully and frankly by the Scherzer Rolling-Lift Bridge Company.