Discussion.

Mr. Anderson.

Mr. DAVID ANDERSON remarked that he had more reason than anyone else present to congratulate the Authors. Three out of the four were or had been on his staff, and he therefore knew a great deal about the work which they had put into the structures and the Papers describing them. As would be seen, both structures were in some ways novel; for that reason particularly the engineer responsible had to rely very largely upon the faithful work which his assistants rendered to him. He was very glad to have the present opportunity of thanking the Authors for their efforts. They had taken as much interest in the work as he himself had done. When difficulties had arisen they had got over them. and he could truly say that the success which had been achieved was largely due to the good work which the men in the office and in the field had put into the job. He desired also to congratulate the Contractors. The workmanship throughout had been excellent, and the scheme of erection was particularly remarkable. The specification which had been issued to the various tenderers outlined a suggested scheme of erection by means of wire ropes, treating the vertical span as if it were the stiffening girder of a suspension-bridge. It had certain disadvantages, and the scheme which Messrs. Dorman, Long had adopted was distinctly better; if he might mention names, he would like to congratulate Mr. Pain in particular on its neatness.

With regard to the design of the bridge, he hoped that Mr. Leith, the engineer for the Tees Conservancy, would be able to explain why that body had insisted upon a span of 250 feet. He thought it was unnecessary. In the original report a clear span of 200 feet had been suggested—which was the same as that of the Tower Bridge—and he still held that it would be quite sufficient. The extra 50 feet had added £50,000 to the cost.

The reasons for adopting a vertical-lifting bridge instead of some other type of opening span had turned very largely upon the particular loading adopted, and also upon the span being 250 feet. He had felt some hesitation in adopting a lifting span of 5,400 tons total weight. The heaviest lifting span then built in the United States weighed less than 2,000 tons, and that at Rotterdam weighed 1,200 tons. It had therefore been a bold step to build the first span of its type in Britain with a weight of 5,400 tons. There were a number of objections to a double bascule bridge such as might have been adopted. It seemed to him that with a large span and corre-

Mr. Anderson. spondingly great weight there would have been considerable difficulty in keeping the line-pressure of the segmental member on the tracks down to a safe figure. Another objection to a rolling lift bridge was that unavoidably the counterweight acted at a bad leverage, and therefore the total rolling weight went up. Further, where the two noses met, with the special load of 100 tons plus 50 per cent. impact travelling off the end of one leaf and on to the end of the other leaf, a heavy impact-load would be set up, even though theoretically there should be no shock. Another disadvantage was that when the leaves were raised they were subject to very considerable wind-pressures which imposed heavy loads on the steelwork and foundations. His last objection to a double-leaf bascule bridge was the "pumping" action that went on at the foundations. As the bascules were raised the rolling loads travelled back on the tracks, causing a relief of pressure on the riverward cylinders and an increase of pressure on the landward cylinders. When the bascules were lowered that action was reversed, and in his opinion such reversals might be detrimental to the foundations. All these considerations had led him to prefer some other type.

A vertical-lifting bridge had two disadvantages. One was that the greatest dead loads in the lifting span were out at mid-span, and so was the machinery-cabin and machinery (which in the case under discussion weighed 300 tons). A considerable weight of steel had therefore to be provided to carry those loads, which were at the worst place from the point of view of stresses. In the Paper attention was drawn to the reasons for placing the machinery-house out at mid-span. Careful consideration had been given to that point. At the bridge at Rotterdam the machinery-cabin was placed in one of the towers, and he thought that one of the lift-bridges in Chicago had it placed on shore, but he believed that those were the only two instances, out of several hundred bridges of that type, in which the machinery-cabin was not at mid-span. Even in the case of a very light structure of some 700 feet span, which, he thought, carried only American buggies, the machinery-cabin was at mid-span. The reason was that, if the machinery-cabin were put on shore, the operating ropes would be short on the one side and long on the other side; they would therefore stretch unequally, and it would be difficult to keep the lifting span level. The other disadvantage of the lifting-span type of bridge was the multiplicity of ropes. There were 160 counterweight-ropes, and they had to be kept in order, as Mr. Hamilton knew to his cost! He would utter a word of warning. Such ropes should not be made up in petroleum-jelly, as it would throw off any lubricant which was subsequently applied. The vertical-lift type of bridge certainly had those two disadvantages, but no type was free from objections, and, considering all the factors, he had no reason to regret the decision to adopt a vertical-lift span of such very heavy weight in the case under discussion. Mr. Anderson.

A loading had been adopted of 150 lbs. per square foot acting in conjunction with a lorry of 100 tons on four wheels with 50 per cent. impact, so as to conform with that of the Tyne bridge at Newcastle and the Wearmouth bridge at Sunderland. The resulting axle-load of 75 tons was very severe. In discussing the question of loading, he did not intend to withdraw anything he had said in connection with Lambeth bridge,[1] but he had since had an opportunity of discussing the matter with officials of the Ministry of Transport and they had pointed out to him that he had been under a misapprehension on one point. In his remarks on Lambeth bridge he had taken it for granted that for every 10 feet width of roadway, no matter how wide the road, the Ministry had wanted their standard train of loading, and had been rude enough to say that that was absurd. It appeared, however, that with a road wider than 30 feet, the Ministry did not lay down that every 10 feet should be occupied by one of their trains; they were quite prepared to consider each case on its merits and to decide the number of trains that should be taken as passing simultaneously over the bridge, and he was glad to hear that that was the case. He would suggest, further, that perhaps in some cases the Ministry would even consider only two such trains passing simultaneously any one cross girder; that was more important than reducing the weight of the individual train. He understood from the Ministry of Transport that they would really prefer engineers to work to their curve of equivalent loads; it was a convenient curve to use, and he would be quite prepared to employ it in future.

The very special loading of 100 tons plus 50 per cent. impact could, he thought, be taken as relating only to special districts. The last point on which he desired to touch was the effect that that loading had upon the structure in question. He and those associated with him had endeavoured to design a timber deck which would carry a 75-ton axle-load. They had not been able to do so, and had therefore had to adopt a very heavy deck of steel buckle-plates, concrete, and wood blocks. If a more usual axle-load could have been adopted, a timber deck could have been employed and about £50,000 saved, but that had not been possible. He did not object to the loading under the circumstances of the district. It was true that it had involved a heavy expenditure, but there was at least the satisfaction of knowing that the bridge would stand any load which (should he

[1] Minutes of Proceedings Inst. C.E., vol. 239 (1934-35, Part I), p. 209.

Mr. Anderson. say it) any wicked haulier cared to take over the roads. He did think that the position was rather absurd. On the railways axle-loads were limited, but on the roadways, so far as he knew, a contractor could take a 100-ton boiler from one end of England to the other without penalty. It was surely uneconomic to design the roads of the country to take such excessive loads, and there should be some means of ensuring that no unreasonable loads were put upon the road-crusts.

Mr. Gribble. Mr. CONRAD GRIBBLE said that the Billingham Branch bridge described by Messrs. Haldane and Roberts had some novel features. The Authors had omitted to explain some points of interest, and he hoped that they would be good enough to fill in one or two gaps. The novel features of the bridge were the use of Rotinoff cylinders in the foundations, and of an all-welded steel superstructure, but another unusual feature of the design was that a bridge 210 feet long, costing £28,000, had been required to carry a 60-foot highway over a goods line. The cost seemed to him to be about three times as much as would be expected, but the reason for such an extraordinary expenditure was not fully explained, the only reason given being that the nature of the soil required special foundations and that there was a possibility of the railway embankment being disturbed while the bridge was being built. The Billingham branch line had been built about twenty years ago as a goods siding to develop the north bank of the Tees, and it seemed to him that any possible disturbance of that goods line, either laterally or vertically, due to the use of ordinary piling, should not have cost £20,000 to put right. It occurred to him that possibly there was a special reason for the construction of the 48-foot side spans. The main opening was large enough to take four lines of railway, which would be ample for any future widening which the railway might want to carry out on that line; but there was a hint in the Paper that a future roadway might pass through one of the side openings. There was, however, no direct suggestion that the openings had been made to accommodate such a roadway, and he hoped that the Authors would be able to clear up the matter. According to p. 538, " In order to reduce the height of the embankment and, consequently, the weight of tipped material, it was decided to introduce continuity in the girders, and also to have the upper flanges of the girders built to a curve." That was a very good idea, but he took it that the embankment as reduced by those means would not be very much smaller than that required for an ordinary bridge.

The use of Rotinoff cylinders was most interesting. He had had the pleasure of knowing the late Mr. Alexander Rotinoff, M. Inst. C.E., whose ingenuity amounted to genius; his method of sinking foundations was novel and might be of widespread utility. In the present Paper, however, there seemed to be nothing to indicate in any way what had been the cost of that work; nor was there any very clear reason why such cylinders had been required. Ordinary piles had been used successfully for the piers, and, although it was suggested that cylinders would be more rigid and better adapted to support the abutments, concrete struts had still been found to be necessary; the question thus arose of whether, had that been known before the cylinders had been adopted, the engineers would have still considered that anything more than ordinary piling would have been required. He believed that a very elaborate compressed-air plant had been required for sinking those cylinders, and would like to have some information as to its extent and cost, as otherwise no opinion could be formed as to the practicability of using the Rotinoff method in other cases. Perhaps the Rotinoff Company, anxious that their method of sinking cylinders should be generally known and appreciated, had been prepared to sink those cylinders for the same price as that of ordinary piled foundations. In that case it might be that the engineers had not precise information as to what they actually cost, but if such information were available he was sure it would be of great interest. Mr. Gribble.

With regard to the welded construction of the bridge, it was stated that the Contractors had undertaken that the structure should cost no more than an ordinary riveted bridge. He did not know whether that meant that they had been prepared to do it for the same money, or that it had actually cost them no more than riveted work. He did not think that engineers in Britain had yet been able to produce designs for welded bridge-work that could compete with ordinary riveted work. There were various reasons; for example, the electrodes were costly, and since, when the work was on a large scale, it had to be turned over and over in the shop in order to avoid overhead welding, the labour costs were very high; but he thought that the appearance of an arc-welded bridge might be very superior to that of a riveted structure, and that, when methods of manufacture were better understood and more economy could be obtained, welding would be used much more generally than it was to-day. It would be very interesting in the present case to know how the costs of the work compared with those of a riveted structure, and what reduction in weight was effected by the omission of angles, covers and so on.

Mr. A. J. Lyddon said it had been his pleasure as well as his duty, on behalf of the Ministry of Transport, to be in constant contact with some of the Authors during the erection of the bridges under discussion, so that he already knew the answers to many of the questions which would arise in the minds of those reading the Papers for the Mr. Lyddon.

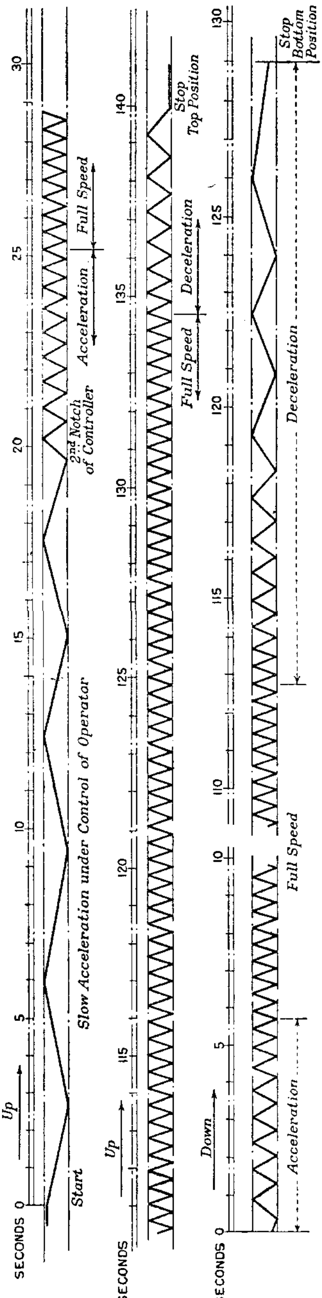
Mr. Lyddon. first time. The last speaker, however, had given him cause to raise a further query. Mr. Gribble had referred to the welded bridge as being an expensive erection, which seemed a somewhat mysterious remark. Mr. Lyddon thought that the reverse was the case, as from his experience he would regard a cost of the order of £2 5*s*. per square foot as being distinctly economical. His Department had found the usual cost of bridges of comparable size to be about £3 10*s*. per square foot. However, the Authors in their reply would doubtless deal adequately with that question.

He had watched the sinking of the Rotinoff cylinders with great interest, and the methods adopted of endeavouring to keep the cylinders of the Newport bridge straight while sinking were also noteworthy. On a much smaller bridge over the Ouse in Yorkshire, with which he had had some connection, the cylinders had gone 18 inches out of the perpendicular in sinking to half the depth of those of the Newport bridge, and great difficulty had been experienced in getting them back to the vertical. It was interesting to read of the Authors' methods of anticipating and allowing for troubles of that nature, particularly in connection with the movement towards the river.

Mr. Thompson. Mr. F. W. THOMPSON remarked that he thought the scheme of rope-operation which had been adopted was certainly the most satisfactory of the many which had been proposed. In rope-operated mechanism it was essential that the accelerations and decelerations should be very carefully considered. In the case of the Tees bridge there was a mass of 5,400 tons moving at 75 feet per minute. If the deceleration were too great the load would be transferred from the down-haul to the up-haul ropes or *vice versa*, producing a very heavy shock both on the ropes and on the machinery, and also causing whipping of the ropes. *Figs. 1* showed the acceleration and deceleration of the Tees bridge span. The time-scale was drawn horizontally, the travel of the lifting span being plotted as a zig-zag line. The two upper diagrams showed the upward movement of the bridge; a comparatively small acceleration went on for 19½ seconds on the first notch of the controller, after which it was increased fairly rapidly until the full speed of 75 feet per minute was attained. The middle diagram represented the deceleration at the end of lifting, which was automatically controlled. The lowering speed in the 5 seconds preceding the final 3 seconds was reduced to about 9·8 feet per minute. After that the speed was further reduced, and the span was brought gently to rest by the air buffers. The speeds adopted had been found to be quite satisfactory, and when on the bridge no motion could be felt. The downward motion was shown by the lower diagram of *Figs. 1*.

Mr. Thompson.

Figs. 1.



RECORD SHOWING ACCELERATION AND DECELERATION OF TEES BRIDGE SPAN.

Mr. Webster. Mr. T. H. WEBSTER remarked that the lifting portion of the Newport bridge had cost £330,000, and Mr. Anderson had said that that cost would have been reduced by £50,000 if a 200-foot span had been adopted instead of one of 250 feet. It seemed, therefore, that a normal 200-foot lifting span would cost something like £250,000, and it would be interesting to know how that compared with the costs of the older solutions of the problem (namely, the double bascule of 200 feet open span, or the swing bridge with two side spans of 100 feet), without regard to the particular merits or defects of the respective types, which had been discussed by Mr. Anderson.

He would like to ask a question regarding the remarkable freedom of movement of the Newport bridge span. It was stated that four men were able to move the bridge at 1 foot per minute. That was most astounding, as the span weighed 5,400 tons and was 20 tons out of balance. He calculated that four men turning a handle could do approximately 40,000 foot-pounds of work in 1 minute, but to lift 20 tons 1 foot in 1 minute 44,800 foot-pounds were required. That did not seem to leave much work in hand for overcoming frictional resistance! Would the Authors give the actual current which the electric motors consumed when the bridge was moving at constant velocity, so that the power necessary to keep the balanced mass in motion could be calculated?

Mr. Haldane. Mr. HALDANE, in reply, tendered his sincere thanks to the meeting for the manner in which the Papers had been received.

Mr. Gribble had referred to the fact that Billingham branch bridge had spans totalling 216 feet across one goods-line. The Railway Company, however, would not have agreed to much less, and the reduction in the weight of the embankment was of importance. The profile of the bridge had a gradient of 1 in 30 on the outer spans for a distance of 72 feet. It thus took about 3 feet off the height of the embankment, which was about 60 feet wide at the top and had side slopes of 1 in 1½, so that there was an appreciable saving not only in quantity and cost but in weight. He thought that the resident engineer had been glad when the banks had thus been reduced a little, because, owing to the nature of the ground, it had not always been possible to predict their behaviour.

The precise costs of the Rotinoff cylinders were not available, but he could say that they had been more costly than reinforced-concrete piles. They had been an experiment, and experiments had sometimes to be paid for. The reward was experience. Probably the cost would be recouped, though not by the people who had put the money down for the particular job. It had also to be borne in mind that it had been decided to use those cylinders before the adjacent 74-foot reinforced-concrete piles had been driven, and those carrying out the work had not been absolutely confident that the piles would be successful. Mr. Haldane.

He was able to give some figures with regard to the cost per square foot of the works of various types comprised in the Tees lifting bridge and its approaches (*Figs. 1*, p. 568). Starting at the Middlesbrough end, first of all there was a length of side-wall construction, namely, a ramp enclosed between two retaining walls, which had cost 9*s.* per square foot. Next, span 11 had cost £2 4*s.* per square foot. Between spans 11 and 10 there was a box abutment, which had cost 10*s.* per square foot. Span 10—a through span of 154 feet—had cost £2 4*s.* per square foot; spans 8 and 9, with web girders, £2 1*s.* per square foot; the tower span and towers and lifting span, taken as one item, £12 5*s.* per square foot; spans 2, 3 and 4, adjacent to the river on the north side, £2 per square foot; the Durham approach-embankment, 7*s.* per square foot; and the Billingham branch bridge, £2 10*s.* per square foot. Those costs were approximate and were in terms of useful square feet—on the basis of a roadway 38 feet wide and two footpaths each 9 feet wide.

Mr. Roberts. Mr. ROBERTS, in reply, referring to Mr. Gribble's criticism of the cost of the Billingham branch bridge, said that perhaps he did not appreciate how very bad the foundation was at that site. The state of the ground could be gathered by the fact that it had been possible to pump and blow it out in the form of mud by the Rotinoff process, and with the heavy embankment-tip quite close up to the railway (which, by the way, was on the centre line of a former course of the river Tees) it might be imagined that the displacement of that mud would have serious consequences. Any such displacement would not only have caused a hump in the railway-line, but would have very seriously displaced the foundations of the bridge itself. Also, in considering the cost of the bridge, it should be remembered that the loading was exceptionally heavy and that the bridge was of a considerable width for its fairly short span.

With regard to the cost of the welded steelwork as compared with that of riveted steelwork, it was difficult to compare the cost of something which had been made with that of something which had not. The form of construction adopted, with curved flange-plates and rigid frames, was one which would be very expensive to construct by riveting. The heavy flange-angles as well as the flange-plate would have to be bent to the curve, whereas with the welding process there was only one flange-plate to be bent. Furthermore, the effect of the skew on the bridge would make the roadway-deck connections very expensive if they were riveted. The comparison was that between a welded structure, which was rather costly, and a riveted structure which would probably have been just as costly.

Mr. Roberts. In considering the matter of cost, and speaking from the point of view of the steelwork-fabricating firm, he would suggest that the possibility of saving by the use of welding lay rather with the engineers who designed the structure than with the shops responsible for its fabrication. He meant that by the proper design of a welded structure a very large saving in weight of material was possible. In the present case, according to the estimates, the welded bridge weighed only about 70 per cent. as much as the equivalent riveted design. Thus, although from the point of view of the shops it might appear that the cost per ton of the welded work was rather more than that of the riveted, the cost of the completed structure would, he thought, be less for welding than for riveting. He was sorry he could not give a definite answer on that point, but it should be understood that when a welded job was being fabricated, as in the instance now under discussion, in the midst of riveted work, it was quite impossible to separate the overhead costs and to proportion them as between one class of work and the other. It would not be possible to draw a true comparison in cost until welded construction became more general and works were laid out entirely for it.

Mr. Hamilton. Mr. HAMILTON, in reply, said that Mr. Anderson had extended very handsome congratulations to all of the Authors, but no one had spoken of Mr. Anderson's courageous initiative. He felt that that should be done, and done in a much better manner than he himself was capable of doing. It was Mr. Anderson's vision that had brought the Tees bridge into being, and he had been responsible for both the vertical-lifting bridge and the welded bridge, which were novel features. The adoption of those two types of bridge and of the Rotinoff cylinders by Mr. Anderson deserved the heartiest congratulations of the engineering profession.

During the first 13 months of operation, the bridge had been raised and lowered 1,660 times, or about 4 times per day, and during that time there had not been a single complaint from any of the river-users.

Mr. Thompson's graphs (*Figs. 1*, p. 605) were very interesting as they showed what very smooth acceleration and deceleration Mr. Thompson and his associates at Messrs. Broadbent's had produced. They illustrated the value of the Ward-Leonard system of control, by which the torque delivered by an electric motor remained constant and was independent of the speed of the motor.

At Boothferry swing-bridge the Ward-Leonard system had been installed, but the control of the electric motors there had been done by means of a potentiometer with about twelve studs. That control worked with extreme smoothness; but at the Tees bridge the Ward-Leonard system was incorporated in a tramway type of controller which had only two studs, giving a creeping speed and full speed. Some initial trouble had been encountered in adjusting the creeping speed to give the smooth result shown on the graphs, but once that had been done no further difficulty had been encountered. The bridge started up from rest almost imperceptibly and moved into full speed quite smoothly; in fact it was sometimes difficult to realize that the bridge was moving at all. Mr. Hamilton.

Mr. GRAVES, in reply, said that if Mr. Webster would again read p. 590 he would find that it was not stated that four men could move the lifting span at 1 foot per minute. What was stated was that four men could move the span, and that was correct. He thought also that Mr. Webster had perhaps overlooked the gear reduction when the hand gear was in use. Mr. Graves.

Correspondence.

Mr. P. S. A. BERRIDGE observed that, having investigated the strengths of various welds used on bridges on the North Western Railway (India), he found the Paper by Messrs. Haldane and Roberts of considerable interest. Referring to the form of the test-specimens (shown in *Figs. 7*, p. 551), used to investigate the strength of end fillets, it would appear that the load was not applied axially and that the plates must have been subjected to bending along the edges of the welds under shear. The form of those test-pieces probably accounted for the irregular nature of the results obtained (Table II, p. 552.) Mr. Berridge.

The test-pieces which had been used on the North Western Railway were as shown in *Figs. 2* and *3*, p. 610. They were of a double-covered butt-joint form, and would appear to be more reliable than the single lap-joint type for comparisons of the strengths of welds. The experiments were made with two kinds of electrodes, one covered with blue asbestos (Quasi-Arc mild steel) and the other covered with white asbestos (Murex Welding Processes special A), the results being distinguished in *Figs. 2* and *3* by the letters Q.A.M.S. and M.W.P.Spl.A. respectively. Tests were made to determine the strength of longitudinal (side) and transverse (end) fillets of sizes ranging between 10/4-inch and 10/12-inch fillets. The test-specimens were welded in the horizontal position by one of the regular Punjabi