Discussion.

The Author. The AUTHOR exhibited a number of lantern-slides illustrating his Paper.

The President. THE PRESIDENT observed that the Paper gave full details of all the work that had been done, and it would be very useful for future reference. He would not say very much about the bridge, as time was short and there were other speakers. It was an example of efficient and cheap construction. He had taken out the costs per square foot of various road bridges in London; two of the cheapest of them had been Kew bridge—a granite bridge—which had cost £10 13*s.* per square foot, and Vauxhall bridge, which had cost £7 15*s.* per square foot. The Kincardine bridge had cost £2 5*s.* per square foot. He had brought up the costs of the Vauxhall and Kew bridges to present-day prices, so as to give a fair comparison, and had omitted costs of land, lawyers' fees, engineering fees, and approaches in all cases.

To his mind the principal reason for the low cost of the Kincardine bridge was the whole-hearted co-operation of all those concerned. In the first place, Messrs. Mott, Hay and Anderson had reported on the project for the bridge, and had shown the advantage of the Kincardine site. Next, Mr. F. C. Cook and the local engineers of the Ministry of Transport had been extraordinarily helpful, and without them the work could not have been carried out. The County and Burgh Councils that had subscribed the money had always been most reasonable, and ready to accept any sensible suggestion. The Contractors had taken the contract when times had been bad, and the cost of their tender had been rather low, but they had adhered to their prices and had carried through the work in a most satisfactory manner. The success of the bridge had been very largely due to the excellence of their work and of that of their various sub-contractors. The work had been done for 6 per cent. below the estimate which the engineers had given before the contract had been let, and 17 per cent. below the figure on the basis of which the Ministry of Transport had decided to proceed with the project. The country therefore owed a good deal to the contractors and to the engineers. He wished to express his own thanks to the Author in particular, who had been responsible for the work, had done it extraordinarily well, and had given The Institution a first-rate Paper upon it.

Sir Leopold Savile.

Sir LEOPOLD SAVILE observed that on the north side of the river there had been suitable rock for foundations from the shore to the centre pier. After that there had been no rock, and the foundations had had to be carried on piles driven down to the ballast. When the work had commenced the only borings that had been taken near the fault were one at about the centre of the central pier, whose position had had to be settled beforehand, and one about 200 feet further south; as the central pier was about 50 feet in diameter there had been some doubt whether it would be entirely on solid rock or possibly on the edge of a cliff. However, when additional borings had been taken it was found that the foundations of the pier would be on good sound rock, so the question, which had caused a good deal of anxiety at one time, had been satisfactorily settled.

For opening the bridge and shutting it again only 2 units of electric power were required; the price was $\frac{3}{4}$*d.* per unit, so that the cost of current for opening and shutting the bridge was $1\frac{1}{2}$d. The average number of openings during the year was 600, so that the total cost of electricity for operating the bridge was under £4 per annum—a remarkably low figure.

Dr. Anderson.

Dr. DAVID ANDERSON remarked that before dealing with one or two points in the Paper he wished to digress for a moment by putting in a plea for shorter Papers. The Institution spent about £12,000 per annum on its publications, of which £10,000 per annum might be taken as representing the cost of issuing the Journal. A Paper of average length—about 40 pages—cost about £500 to publish; the present Paper, however, was practically twice the average length, so that it would cost about £1,000.* He did not want The Institution to cut down its printing bill unduly, but he did suggest that Authors of Papers should concentrate on what was novel. There was a good deal which was novel in the present Paper, but there were certain parts which were more or less standard practice, and Authors should cut down such matter as much as they could, bearing in mind that printing was expensive and that it was very difficult to ask an Author, after he had gone through the hard work of writing a Paper, to cut it down. It would be far better to print two concise Papers than a single bulky one.

In the original report on the Kincardine project (and also in the report that his firm had prepared on the Alloa bridge) it had been laid down that the opening span should consist of two openings of

* The figures given above were only a rough approximation. More accurate figures indicated that a Paper as submitted by an Author cost from £250 to £500 to publish, according to its length; the addition of the oral and written discussion increased that cost to from £350 to £650.—D. A.

Dr. Anderson. 100 feet. That had since been increased to two openings of 150 feet, and he would like the Author to state the reason for that increase in span. The river traffic was quite small—about one ship per day, and a single opening of 150 feet had sufficed during construction; would not that opening have sufficed permanently? On p. 724 the Author stated that a rolling lift bridge had been considered in the early stages of the scheme, but had been found to be more costly than a swing span. When the span had been increased, had a fresh study been made of some other type of opening span instead of a swing span? A study of the Bangkok Memorial bridge[1] designed by Messrs. Dorman, Long and Company would appear to show that a bascule opening might have been economical. The Bangkok bridge had a roadway of practically the same width as that of the Kincardine bridge, but provided a single clear opening of 196 feet. The total moving weight was 1,420 tons, so that for a single opening of 150 feet it might be expected to be between 700 and 1,000 tons, instead of 1,600 tons, as in the Kincardine bridge. Admittedly, he himself had suggested two 100-foot spans for Alloa, but the change from 100 feet to 150 feet clear opening was attended with a very considerable increase in cost.

One of the novel features mentioned in the Paper was the driving of piles under the cylinders. So far as he knew, it was the first instance in Great Britain of the adoption of that type of construction, and he desired to congratulate the engineers on its use. He thought that the choice was justified, particularly by the very low cost of the bridge, to which the President had drawn attention. He would ask the Author to divide the very creditable average figure of £2 5*s*. per square foot into one figure for the fixed span and another figure for the swing-span.

It appeared that the obstruction caused by the piers was 14 per cent. both at high water and low water, which was a higher figure than usual; it was also stated that the river was a swift-flowing one. He would like to ask whether any scour was taking place.

It was stated on p. 737 that the interruption to road traffic when the bridge was opened was 13 minutes. Fortunately that only occurred once a day, but 13 minutes was a long time. It was apparently made up of 2 minutes for opening the span, 2 minutes for shutting it, and 3 minutes for dealing with the various locking gears, leaving about 6 minutes' delay due to river-traffic, which was beyond the control of the engineer. Some time ago he had inquired of various

[1] F. W. Thompson, "The Mechanical Gear of Bangkok Memorial Bridge, Siam." Inst. C.E., Selected Engineering Paper No. 149 (1933).

Dr. Anderson.

authorities what average delay took place at other opening bridges, and the replies were as follows :—

Tower bridge, 4½ minutes.
Newcastle swing-bridge, 7 minutes.
Boothferry swing-bridge, 12½ minutes.
Queensferry Scherzer bridge, 8 to 10 minutes.
Keadby Scherzer bridge (a railway bridge), 4 to 6 minutes.
Tees (Newport) vertical lift bridge, 8 to 10 minutes.

He thought that a fair comment on those figures was that river traffic could be and ought to be hustled ; more consideration might well be paid to the general benefit of the community by ensuring as brief a holding-up as possible of road traffic in connexion with opening bridges.

Sir Charles Bressey.

Sir CHARLES H. BRESSEY mentioned that at an early stage he had been associated with the negotiations which had led up to the construction of the bridge, although he had subsequently transferred that responsibility to Mr. Cook. In the course of those negotiations (which had been by no means easy) he had been very much impressed by the amazing tact, patience and skill in negotiation of Lord Elgin. Lord Elgin had had the difficult task of driving a team consisting of three Scottish County Councils, two Scottish Burghs, the Ministry of Transport, and, in the background, another Government department controlling national finance, and he was entitled to the greatest credit for his work. He suspected that Lord Elgin had wished that he could have carried the negotiations through rather faster, because at one time the Treasury had offered an 85-per-cent. grant. Then had come the period of depression, and the grant had been reduced to 75 per cent. However, Lord Elgin had overcome all the obstacles.

The unusual length of the Paper was probably due to the Author's desire to record all features that might be of interest. In his opinion the Paper was especially interesting on account of the candour with which were disclosed the difficulties that had arisen during the construction of the bridge and the need for the modification of processes which had proved to be unsuccessful. The fact that the scheme had been carried through with a considerable balance on the right side showed the success of the methods finally adopted.

Mr. Dixon.

Mr. J. R. DIXON desired only to make a few remarks from the viewpoint of a contractor. The Paper read very smoothly, but it would be realized that the bridge had not been built without a great many difficulties having had to be overcome. The work had been of very great interest, and the staff had taken an especial pride in it and had seen that everything had been of the very best. His own firm, as contractors, attached great importance to the maintenance

Mr. Dixon. of close co-operation with consulting engineers, and the course of the contract under discussion had shown the advantage to be gained by such an attitude. The President had referred in very generous terms to the manner in which the contractors had carried out the work, and for his part he wished to say how greatly the contractors had appreciated the help and advice which had been so freely given them by the engineers.

Mr. Kramer. Mr. J. B. KRAMER remarked that the photo-electric system for automatically and accurately centering the swinging span of the bridge with the roadway had been well explained on p. 744 of the Paper. He did not wish to add anything to that explanation, but merely to emphasize the usefulness and dependability of the photo-cell in engineering. He had been responsible for the application of the photo-electric equipment to the Kincardine bridge, and would say that in the hands of an experienced engineer photo-electric cell equipment could be applied anywhere with perfect confidence.

The principle of the photo-electric cell was very simple. A ray of light, which was itself electro-magnetic in nature, ejected electrons from the light-sensitive caesium atoms of the cathode in the cell. Those electrons were caught by the anode, so that the light-energy was transformed into electrical energy and a current was established between the cathode and the anode. That current was very small, but it could readily be magnified by means of electrical valves up to any required intensity, so as to work a relay and thus control any kind of apparatus.

(Mr. Kramer then demonstrated the action of a photo-electric control device.)

Since the equipment at Kincardine bridge had been installed a peculiar incident had happened; while being swung the bridge had stopped when about half-way open. It was then discovered that a ray of sunlight had got into a photo-electric cell, having been able to pass the protecting baffles when the bridge was in that particular position. Provision had now been made for disconnecting the photo-cells when the swing-span moved away from the abutment, so that the trouble could not recur.

Mr. Deschamps. Mr. JOSEPH DESCHAMPS remarked that when his firm (which had been responsible for the production of the cast-steel rollers used on the swing-span) had started on the job they had realized that serious difficulties would be encountered in producing a perfectly sound steel casting from the design submitted. The original design had been as shown in section in *Figs. 30*. In making the casting, the runners and risers would have had to be arranged as shown dotted, and it would have been impossible to feed the casting adequately; the parts shown cross-hatched would thus have been porous and unsound. Mr. Deschamps. After considering that design his firm had conferred with the consulting engineers and a slightly different design (*Fig. 31*) had been arrived at, which had satisfactorily solved the problem. His object in mentioning the matter was to point out how helpful it had been to

Figs. 30.

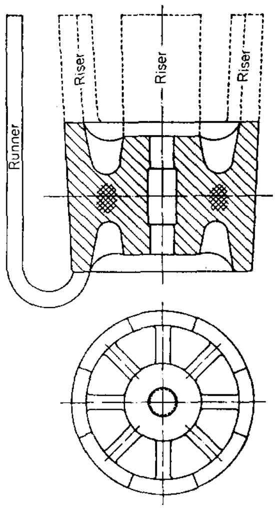
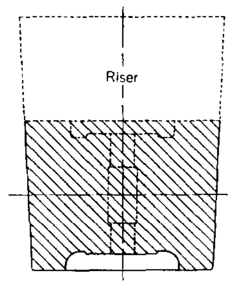


Fig. 31.



the steel-founders to find a considerate firm of consulting engineers who were willing to co-operate with them with a view to producing a satisfactory article. The consulting engineers might have insisted on the original design being carried out, in which case bad castings would have been produced.

⁂ Mr. RAYMOND CARPMAEL observed that on p. 693 it was stated Mr. Carpmael. that there were three continuous spans of 62 feet 6 inches over the L. & N.E. Railway property, and on p. 694 that " due to the existence of the L. & N.E Railway " a difference of about 22 feet between road and rail level was required. It was not apparent from the general lay-out why spans of that character had been provided, and as a material reduction in constructional depth, with compliance with the Railway Company's requirements for headway, could have been given with shorter spans, it would be of interest to know whether

⁂ This and the following contributions were submitted in writing.—SEC. INST. C.E.

Mr. Carpmael. they had been provided at the request of the Railway Company, or to conform with the general elevation of the bridge.

Mr. Cook. Mr. F. C. Cook observed that, apart from its engineering interest, a feature of the Kincardine bridge project worthy of record was that it marked a stage in the advance which had been made in recent years in reducing the number of the many gaps which existed in the chain of road communications in Great Britain owing to the serrated character of the coast-line. The Mersey tunnel, opened in 1934, provided a means of crossing the estuary of the Mersey very close to its mouth. The new bridge at Kincardine afforded a gain of several miles in bringing cross-river communication by road nearer to the mouth of the estuary of the Forth. Work had been started upon the new tunnel under the Thames at Dartford, some 15 miles east of Blackwall tunnel, whilst when the financial position permitted he trusted it would be possible for the Government of the day to give consideration to the erection of yet another bridge lower down the Forth, as well as bridges across the estuaries of the Humber and the Severn.

It was not easy to ensure the pleasing appearance of a structure such as the Kincardine bridge, which was over ½ mile in length, with a difference in level between the two shore-ends of no less than 15 feet, and incorporating a curve of comparatively sharp radius. He was sure that one factor which had contributed to success in that direction was the very generous vertical curve which had been given throughout. From whatever angle the bridge was viewed, the effect of that provision was evident, and its value was worth bearing in mind. Again, there was no attempt at extraneous ornamentation. The design was clearly purposeful and the structure as a whole fitted its setting admirably.

With regard to the use of superelevation, there was sometimes a tendency to regard a bridge as an independent unit and not, as it should be, an essential part of a line of communication, governed by the same requirements as to level and alignment. The curved portion of the bridge, which had a radius of about 520 feet, rendered superelevation desirable, and that had been achieved, not by the addition of filling which would have added materially to the dead load, but by fabrication of the bridge-members in such a manner as to provide a superelevation of 16 inches and a widening of the carriageway of 2 feet 3 inches in the centre of the curve. The task of so fabricating that portion of the superstructure as to give those results could not have been easy, but it had secured a marked advantage to road-users without in any way detracting from the appearance of the bridge.

The cost of £2 5*s*. per square foot was singularly low, but there was always some danger in comparing figures of unit cost without due consideration of the factors involved. There were records of costs of bridge-construction of up to £9 per square foot, but the costs of bridges of similar type might differ substantially, not by reason of merit or demerit of design, but because of under-water or other difficulties which might have been met with and which might not be sufficiently appreciated. Mr. Cook.

Mr. H. G. Lloyd asked what was the grading of the dark sand from the quarry near Denny (preferably in terms of B.S.S. sieves), and of what shapes were the grains? It was unusual to obtain sands which in 3 : 1 portland-cement mortar gave a tensile strength as high as that of 3 : 1 portland-cement mortar in which standard sand was used, and it would be useful if an alternative sand to Leighton Buzzard sand could be obtained. Mr. Lloyd.

Mr. J. A. Saner wished to support the decision to adopt a swinging span for navigation rather than a bascule or lifting form of bridge. Apart from any question of cost or appearance, a swing-bridge could be made to open away from approaching vessels, an important point in a tideway or flooded river, whereas either of the other forms had to be opened to its maximum height before the vessel dared approach. In many cases that prolonged the delay to road traffic. Mr. Saner.

With regard to the buckle-plate flooring, it would be interesting to know what, if any, special care had been taken to ensure an even road-surface. There was always a tendency for the top dressing to become corrugated owing to the material in the trough, being of greater depth than that on the top of the trough, tending to compress under the road traffic and so cause corrugations.

The load of 3,500 lbs. per linear inch on the rollers appeared heavy. That might not be of much moment so long as the bridge was operated only some 500 times in a year, but it had been found necessary in one case at least to put in later an hydraulic ram under the centre to relieve the weight, although the loading had only been about 2,000 lbs. per linear inch. The job had been very expensive, and owing to the contacts on the centre pillar at Kincardine it would be impossible in that case.

In his opinion solenoid brakes were not suitable for dealing with heavy loads, being much too sudden in action, and he had refused to have them on movable bridges designed by him.

The effort to turn the Kincardine bridge appeared low, but the coefficient of friction of the rollers was somewhat high. That might be due to the heavy load per linear inch of roller. The power

Mr. Saner. required per ton per degree of angular movement compared favourably with that required by other bridges.[1]

The Author. The AUTHOR, in reply, desired to express his thanks for the kind remarks which had been made about his Paper, especially those expressed by the President and by Sir Charles Bressey.

When writing the Paper he had in view that one of the principal justifications for its submission was that the design, assembly and control of a very large swing-span had not been recorded in The Institution's publications for many years, and he hoped that the fully detailed description of the foundation-difficulties experienced, the methods adopted for the precise assembly of the structure, and the most modern equipment for its control and operation would be of value to others, and especially to younger members who might have a similar problem to deal with in future.

With regard to Dr. Anderson's remarks, all of which he greatly appreciated, he had found that many Authors of recent Papers had written at equal length, whilst in several instances their Papers had actually exceeded his by amounts of up to 50 per cent. If he had sinned, therefore, it had been in good company.

The width of navigation-opening had been increased from 100 feet to 150 feet in accordance with the decision of the Parliamentary Joint Committee. No doubt the Committee had been largely influenced by the gloomy picture painted by representatives of shipping interests as to the difficulties of negotiating the opening, which had indicated conditions of a dense fog and a south-west gale at the same time!

The preliminary investigations made into the relative costs of a Scherzer rolling lift bridge and a swing-span with 100-foot openings showed that the former would have cost about £10,000 more. The Act definitely required two openings to be provided, so that when the span was increased to 150 feet there was no opportunity possible to reconsider the design. The additional 150-foot opening provided by the swing-span was of great value to the navigation authorities. Mr. Saner had indicateda further advantage of a swing-span, in that it was able to turn away from an approaching vessel. That was one of the reasons why the span in question had been designed to open either clockwise or counter-clockwise.

The sub-division of the bridge costs per square foot, as requested by Dr. Anderson, was as followed :—piled viaduct 17*s.* 6*d.*; 50-foot reinforced-concrete spans 20*s.*; 10-foot spans (average) £1 17*s.*;

[1] J. A. Saner, "Swing-Bridges over the Weaver Navigation, with some Information about other movable Bridges." Inst. C.E. Selected Engineering Paper No. 79 (1929).

swing-span, including machinery, controls, and timber protection-jetty, £6; 62-foot 6-inch spans on curve £1 15*s.*; average £2 5*s.* **The Author.**

A certain amount of scour had occurred at the 100-foot piers on the south side of the river immediately after their construction. The scour had practically ceased thereafter, but it had been considered prudent to stabilize conditions by depositing broken stone around certain of the piers.

The periods of delays to road-traffic at various opening bridges given by Mr. Anderson were of great value. The unknown factor in all those cases was the time taken by river-traffic to pass through after the bridge was open, which was largely affected by tidal and weather conditions as well as by the mentality of the person in charge of the vessel.

With regard to Mr. Carpmael's comment on the span adopted at the L.N.E. Railway, the location of piers Nos. 1 and 2 was determined by definite site-requirements. The railway company had been most helpful throughout. It was true that if shorter spans could have been adopted at that place, which had unfortunately been impracticable, a material reduction in roadway-level would have been possible, though at some sacrifice in the general appearance of the structure.

In reply to Mr. Lloyd, the grading of the Denny sand was as followed:—retained on $\frac{3}{16}$-inch sieve, 3 per cent.; passing $\frac{3}{16}$-inch sieve but retained on 7 sieve, 5 per cent.; 7–14, 14 per cent.; 14–25, 18 per cent.; 25–52, 42 per cent.; 52–100, 14 per cent.; passing 100, 4 per cent. The shape of the sand grains followed the general rule, the elongation-ratio of the major and minor diameters being about 1·5.

No effect of corrugation in the road-surface had been experienced due to the adoption of buckle plating. The concrete had been very fully reinforced, and that would tend to reduce the action suggested by Mr. Saner.

A very usual formula for the allowable pressure on rollers was $200d$–$250d$, which gave 4,000 to 5,000 lbs. per linear inch safe load, whereas 3,500 lbs. per linear inch had been adopted for the rollers on the Kincardine bridge. With regard to the brakes, the avoidance of their sudden application was one of the greatest problems to be dealt with. The provision of brakes on a swing-span was a necessary evil, and the Paper gave particulars of the elaborate precautions which had been taken to prevent their application except when the span was at rest.

Mr. Cook's explanation that the generous vertical curve adopted for the bridge had probably the most marked effect on the attractive

The Author. appearance of the elevation was entirely concurred in by the Author. Whilst he agreed with Mr. Cook that costs per square foot should be viewed with caution, and were mainly of value for approximate comparisons only, he considered that the detailed statement of cost of the various parts of the structure which he had given in his reply would provide a very useful comparison when examining costs of other bridges in Great Britain.

⁂ The Correspondence on the foregoing Paper will be published in the Institution Journal for October, 1937.—SEC. INST. C.E.