Discussion.

The PRESIDENT, in moving the vote of thanks, remarked that the Paper described work which was a notable contribution to the betterment of the roads of Great Britain. It was also interesting as being the only Paper so far presented to The Institution describing work executed out of the Road Fund, and it showed how some of the money in that Fund was being expended. The President.

SIR HENRY MAYBURY remarked that he could claim to know something of the road described and of the excellent way in which the engineering work had been carried out. His railway friends would be gratified to learn that the whole cost of the work was a charge upon the Road Fund and that the railways, as ratepayers, had had no part in providing money for the undertaking. The Paper described how the road over the Grampians was first constructed about the year 1727 by General Wade. Various sections of those old-time roads were still in evidence, and at one point along the Grampians road there was a stone erected by General Wade's engineers when those early works were put in hand. The Author had taken care, in carrying out his work, to restore and replace that old landmark more firmly than it had been established before. The Paper also described how a century later Telford, the first President of The Institution, was called upon to carry out work on that road, and how, like many of his successors, he found before he had gone far that the money voted by Parliament for the purpose had been exhausted, and he could not go on. The road was a very important one. It was perhaps a unique feature that the Government should have borne the whole cost, but for 80 miles between Inverness and Pitlochry the road ran over mountain land having no rateable value. The greater part of the area traversed had few residents upon it, and it was small wonder that the road had got into a very bad state. It was, however, the connecting link for through communication between Perth and Inverness. He had seen a great deal of the work while it was in progress. The contractors had done extremely well. Forty new bridges had been constructed and about 750 culverts, and some of the bridges were quite large. The Findhorn viaduct, quite a big job, had been carried out extremely well by Messrs. McAlpine in a very short time, and they, too, had been responsible for the work on the Spey bridge. In

Sir Henry
Maybury.

Sir Henry Maybury. all the work the Author had shown great zeal and engineering capacity, and he had carried out the work in a masterly way, to the satisfaction of the Department and of the Perth and Inverness County Councils. It was unusual for the Government to pay the whole cost of any work, because in most cases the work was undertaken by the statutory highway authorities. They were responsible for the maintenance of highways, and usually the Government gave assistance. He had always felt that, local government being on its present basis, the statutory body responsible for the work should have some financial interest in its proper execution. In the present case a penny rate represented only about £203, while the expenditure required for the road in question had been nearly £700,000. So that the only way had been for the whole cost to be borne by the Government, the work being carried out under the auspices of the Ministry of Transport.

Sir Murdoch MacDonal.

Sir MURDOCH MACDONALD thought that the Highlands owed Sir Henry Maybury a deep debt of gratitude, because he did not believe the Government would ever have found the money unless Sir Henry had pressed the scheme strongly upon them. The road was originally made by General Wade, at a very much earlier date; it was to his mind comparable with the old Roman roads of England and had probably been made with a similar object in view; but with regard to checking lawlessness, he did not think lawlessness had been greater in the Highlands than in any other part of the kingdom at that time. No doubt a large part of the Highlands had then espoused a cause which put them into a state of rebellion against the Government of the day, and therefore the Government had been justified in making a road in order to keep the inhabitants in check, but not, as the Author suggested, to keep them in check among themselves. The road was of great historical interest to The Institution, for not only was it one of the main thoroughfares of the country, but it so happened that Telford was sent north to make other roads in addition to those already made by General Wade. Under the Wade regime, about 800 miles of military road was constructed. He had not been able to find the cost per mile of road or even any general costs, but under Telford's regime 875 miles of road was made at a cost of £600 per mile, whereas the road described in the Paper had cost £8,390 per mile, which showed the increase in cost during a century. Another point of interest to The Institution, however, was that when Telford had his office in the "Salopian Coffee House" (afterwards known as the "Ship Restaurant") in Whitehall, and lived in Abingdon Street, he had with him two lads of about 17 years of age as apprentices or young

improvers. One of them, named Gibb, was the grandfather of a Sir Murdoch MacDonald. Member of the present Council of the Institution, Sir Alexander Gibb. The other was Joseph Mitchell, who at the age of twenty-one was sent north to take charge of all the roads from Perth northwards throughout the Highlands, and was in charge of those roads for 36 or 37 years. Mitchell wrote a very interesting memoir¹ for private circulation, from which he (Sir Murdoch) had gathered much information, apart from his own personal knowledge, which was extensive, because he had lived on the road in his early years and naturally knew it well. While Mitchell was an apprentice he happened to be writing in his room one day when Telford came in and asked what he was writing. Mitchell replied that he was extending his notes of the discussion held the previous evening at a meeting of the Institution of Civil Engineers. Telford, who was then President of the Institution, asked to see the notes, and was so satisfied that he asked Mitchell to write out a fair copy to be read at the next meeting, and Mitchell was appointed to report the conversations in future. From those notes had arisen the "Minutes of Proceedings." In regard to the road itself, he agreed with Sir Henry Maybury that the work had been extremely well done, and he congratulated Sir Henry and the Author. The only point of criticism he would bring forward was that the two principal bridges, the Findhorn and Spey bridges, while not open to any criticism in regard to their strength, were open to some objection on the score of appearance. He hoped that Sir Henry Maybury or the Author—or any other engineer responsible for bridges on other roads now being made through the Highlands—would not adopt in future quite such bizarre designs and would not use concrete to the same extent in structures of such considerable size. Concrete had, of course, great uses, but it had also its limitations; and in a wild Highland glen, against a background of weathered stone and brown heath, the white cold glare of concrete was not very suitable. He was not alone in that criticism, for he knew that many artists, and, in particular, Scotland's famous artist, Sir D. Y. Cameron, R.A., had commented strongly on that matter.

Sir ALEXANDER GIBB entirely agreed with the criticism that had Sir Alexander Gibb. been passed on the bridges, but wished to point out that he was informed by Sir Henry Maybury that they had not been designed by the engineers of the Ministry of Transport. The bridges had been designed by architects, and the Ministry engineers had had no responsibility for them beyond seeing that they were strong enough.

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¹ "Reminiscences of my Life in the Highlands." London, 1883-84.

Mr. Frank. Mr. T. P. FRANK remarked that he would confine his reference to the historical side of the subject to an allusion to one sentence, the last in that portion of the Paper, in order to show that Sir Henry Maybury had had, if he might be permitted to say so, ulterior designs in making such generous grants. Some few years ago he had the duty of calling on Sir Henry to obtain an increased grant towards a road tunnel scheme for what Sir Henry termed a wealthy city. Sir Henry drew out sheet after sheet of Ordnance maps and pointed to the country through which the road described passed, and told him that the money was wanted for that district and that there could not be any additional money available for a wealthy district; he could not increase the grant. Sir Henry was therefore obviously husbanding the resources of the Road Fund on that occasion, though on the present occasion he had quite rightly given a very generous contribution. In Fig. 2, Plate 3, pitching was shown as the type of foundation for the road, and from the Figure it might be inferred that the pitching was laid almost vertically. He assumed that it was not placed vertically, so as to be rocked each time the roller passed over it, but rather at an angle. He would like to know on what sub-foundation the road base rested, because knowledge of that would probably indicate why pitching had been adopted in preference to concrete. No doubt concrete made of the same material would have called for a considerable amount of labour. Again, it might, of course, be due to climatic conditions that the composition of the road-surfacing material was, as given on p. 115, 10 per cent. of bitumen and 90 per cent. of tar. He did not know if there were any special reasons for using that composition, but, having had to surface a considerable mileage in the last 10 years with that type of tar or bitumen macadam, he had always found it required much more bitumen than that. On another section of road in Perthshire (the A 9 road) he had noticed that the composition used was 20 per cent. of bitumen and 80 per cent. of tar. Coming to the paragraph headed "Curves and Gradients," he congratulated the Author on having superelevated his curves, but he considered that the Author had not increased the superelevation as much as was desirable. When traversing the A9 road he had not known who had been responsible for the construction of a portion of it to which he had referred¹ in a Paper on "Bituminous Road Surfacing," but, having tested the road practically, he had commended the scientific banking on 5 miles of that road immediately south-west of the city of Perth, and some time afterwards a letter

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¹ Public Works, Roads and Transport Congress, 1929. Final Report, p. 256.

had appeared in the technical Press giving the amount of super-elevation for various curves. In the Table on p. 116 of the Paper under discussion the superelevation was given for radii of 400 and 500 feet. For the A9 road he had nothing directly comparable, but for a 450-foot radius on another Perthshire road the superelevation amounted to no less than 21·6 inches, as compared with the 7·5 inches which would be the corresponding superelevation in the present case. To take identical cases, the last radius mentioned in the Table was 600 feet, and for that radius the superelevation on the A9 road was 15·4 inches, as compared with the 6 inches given in the Paper. That was due to the different speeds adopted in the formula on p. 116. The speed taken by the Author was only 15 miles per hour. Applying the formula to the superelevation of the other road, he found that the speed taken in that case was between 25 and 26 miles per hour. The engineer of that road had stated in the technical Press that, although the cross fall in places was severe, no complaints had been received from drivers of horses. In view of that, and in view of his own experience on the road, he thought the superelevation described by the Author might with advantage have been increased. As the speed-limit had recently been abolished, it was probable that higher speeds would prevail in the future than in the past. It was also known that the wear and tear on roads which took place at bends had been due in large measure in the past to the fact that the roads had not been adequately, if at all, superelevated. Why was it necessary to have a gradient of 1 in 10·5 at one point, and why had that gradient been left in? Perhaps it could not have been avoided. He congratulated the Author heartily on the concrete raft and on the novel features there introduced. The Author had stiffened the edges of his slabs, which seemed to be the tendency of American practice to-day; the Americans designed their slabs with a view to increase the resistance to bending at the edges. The Author had done it in a different manner by putting in beams longitudinally and transversely, and those beams, in addition, acted as underdrains, and would no doubt give very satisfactory results. The Ministry-of-Transport Committee on Experimental Roads had found from recent experiments on concrete foundations that the best sections were those that had the best-drained foundations. As the representative of The Institution on that Committee, he was glad to have the additional information which the Author gave. The Author mentioned the planting of certain trees, but did not say where they were placed. He hoped the silver birches had been placed at the outside of the bends, because if they were so placed motorists would be assisted at

Mr. Frank.

Mr. Frank. night in taking curves, the headlights rendering the light-coloured trunks of such trees clearly visible. He congratulated the Author on the economical manner in which the work appeared to have been carried out, especially as a relief scheme.

Mr. Cook. Mr. F. C. Cook remarked that the road was part of a scheme, for which Sir Henry Maybury had been responsible, for a loop road connecting ultimately Edinburgh, Perth, Inverness, Fort William, Glasgow, and Edinburgh again. The total length was about 400 miles, of which 300 miles had been, or was being, reconstructed. The Author referred to the use that he had made of the road surface already compacted. The capital value in this country of the pre-existing road-crusts—often, as the Author had shown in his Paper, the result of the accumulation of metal throughout centuries—was perhaps not realized. It would be a pity, from the economic point of view, if the idea of making the best possible use of such foundations were to be abandoned, and he was glad to say that road-engineers were generally agreed as to the advantage of utilizing them. Their existence was perhaps one reason why in this country advantage had been found in the use of such materials as bitumen and asphalt, which lent themselves so readily to superimposition on an existing foundation. He could not say that he agreed with Mr. Frank's views about superelevation. He thought, indeed, that the Author's 16 inches of superelevation with an 18-foot carriageway on a radius of 200 feet was as much as was reasonably practicable. Anything beyond that would probably result in something approaching instability in the case of a horse-drawn vehicle, particularly one which was inclined to be top-heavy. Superelevation was a very difficult matter for road-engineers. It seemed to him almost impossible to lay down any very definite rules with regard to it, for the conditions were so different from those obtaining in railway practice. Road-engineers had to deal with varying weights and varying speeds and with both horse and motor transport of all descriptions, and, above all, they had to work with a great variety of surface materials, the coefficients of friction of which differed widely. The railway-engineer, on the other hand, dealt always with steel rails and with speeds under direct control. The Author's formula, based on empirical considerations, for the widening of curves, was a matter that would repay investigation, and it would be desirable to arrive at more definite conclusions if that were possible. Certain features of the reinforced-concrete raft were of very definite interest. There could, he thought, be nothing more suitable than reinforced concrete for the peat subsoil with which the Author had had to deal, but he was not sure that it was right

to assume that concrete roads need necessarily consist of slabs, Mr. Cook. especially in lengths as short as 40 feet. Joints between slabs were, he thought, admittedly a line of weakness. Such deformation as had been noticed very often started at the joints, and investigations had shown also considerable curling of the corners, due to temperature-changes. That had been dealt with in a Paper¹ submitted to The Institution by Messrs. Batson and Wood, of the National Physical Laboratory, on tests carried out at the instigation of the Ministry of Transport. There was a good deal to be said for a more continuous form of construction in the case of concrete roads, provided some very definite effort was made in the direction of securing rigidity at all joints, whether expansion joints deliberately constructed as such, or contraction joints put in to control and guide as far as possible the effects of temperature-changes. He could not quite follow Section BB in Fig. 6, and he would be glad to know the reason for tying the slabs in that way. He would have thought that the beams at the edges of the slabs would have prevented any lateral movement or tendency to slip, and he could not quite see what purpose the hooks served. Why had it been necessary to cover the whole surface with a cold-emulsion dressing? It seemed to him that, apart from looking after the joints, it was superfluous to cover a concrete road with a surface dressing. He thought a concrete road should be left to carry the traffic until its surface was in such condition that the application of a wearing carpet was justified.

Professor F. G. ROYAL-DAWSON, referring to the subject of Professor
Royal-Dawson. alignment, remarked that on the road described in the Paper the usual system of circular arcs connecting straight lengths had been adopted, and the curves ranged from 200 feet radius upwards, though very few were sharper than 300 feet radius. The Author said he had motored over all but the sharpest curves at a speed of 35 to 40 miles per hour without discomfort; but Professor Royal-Dawson felt sure that on some of the sharper curves at that speed many motorists "cut the corners." That colloquial expression might be expressed scientifically as an instinctive and perhaps unconscious following of the transition curve suited to the speed and centrifugal force. His remarks were directed not against any road in particular but against the prevailing disparity between the motorist's natural path and the general alignment of road curves. *Fig. 8* represented a right-angled bend in a road laid out to a circular arc. A motorist approaching from the lower end started

¹ R. G. C. Batson and S. A. Wood, "The Deformation of Concrete Road Slabs." Inst. C. E. Selected Engineering Paper No. 108. 1931.

Professor
Royal-Dawson.

his transition from about the point A, and described the path indicated by the dotted line, reaching a minimum radius at the centre B. He did not do that to shorten the distance, but because he felt instinctively that the curvature of the road was not suited to the purpose of diverting his car through an angle of 90 degrees at the speed at which he was travelling; and if conscientious scruples, or a white line, or the fear of oncoming traffic, influenced him, he kept to the left-hand side, and, in so doing, he had to reduce speed or run the risk of side-slipping. The principle which Professor Royal-Dawson was expressing had been accepted on railways for many years past, and had become more or less standardized; but on roads, although the idea had crept in of recent years in France

Fig. 8.

and in America, it was still in a very elementary stage in this country. There was little or no literature on the subject, so that many engineers, who would perhaps agree that the principle was correct in theory, would dismiss it as being of no practical importance. Most of what literature there was on the subject of transition curves emanated from America. There empirical formulas for railway-curves were based on superelevation and not on the centrifugal factor; and in the same way they had crude formulas for road transition curves, based again on hypothetical superelevation treated as a gradient, and with no reference to the centrifugal factor, which ought to be the basis. The fallacy of basing transition

curves on hypothetical superelevation had been shown in The Institution 22 years ago¹ by Messrs. Spiller and Shortt in a discussion on railway transition curves; but the view persisted, even among some railway-engineers, that the transition curve was merely a desirable adjunct to superelevation, instead of being of paramount importance, superelevation taking a secondary place. It could not be too strongly emphasized that the purpose of a transition curve was to enable the centrifugal force to take effect gradually, quite apart from superelevation. As a corollary, a curve which could not be given any superelevation was more in need of easing at the ends than one which could be superelevated. Those were Mr. Shortt's own words used 22 years ago, and, though they were then applied to railways, they now applied with increased force to roads, especially in view of the higher speeds now attained on roads, and particularly because the superelevation could never be more than a fraction of what was required for the actual speeds attained. In the road described in the Paper the superelevation was about 1 in 20, whereas the centrifugal ratio was 1 in 4, so that superelevation counted for very little. The more important side of the question was the transition, in the interests of both safety and comfort. There was a definite measurable relationship between a given speed and the corresponding maximum safe rate of change of direction, which meant a definite scale of transition. That relationship was independent of superelevation. It was possible to lay out a road to suit a given standard of uniform speed—barring traffic-checks, of course—by following a definite set of rules. That process did not depend primarily on a predetermined minimum radius or a predetermined centrifugal ratio. The angle of deviation or bend was a vital factor. As an instance, a standard speed of 60 miles per hour was not incompatible with a minimum radius of 1,000 feet, provided the angle of bend was at least 40 degrees. If it was only 10 degrees—a very slight deflection—the minimum radius approached by a transition curve must be not less than 2,000 feet, the underlying principle being that a vehicle at a given speed required a definite time-rate of application of centrifugal force up to the maximum provided for. At 60 miles per hour on a minimum radius of 1,000 feet the centrifugal ratio was about $\frac{1}{4}$; that ratio must be acquired in a certain minimum time, which was 8 seconds, and that could be attained only in a transitional bend

Professor
Royal-Dawson.

¹ J. W. Spiller, "High Speed on Railway-Curves." Minutes of Proceedings Inst. C.E., vol. clxxvi, p. 75. W. H. Shortt, "A Practical Method for the Improvement of Existing Railway-Curves." *Ibid.*, p. 97.

Professor
Royal-Dawson.

of 40 degrees. If an attempt were made to put a 1,000-foot radius in a 10-degree bend, even with a transition approach, the time-rate would not be suitable, and the application of the centrifugal ratio of $\frac{1}{8}$ would be too sudden; hence a radius of not less than 2,000 feet was necessary, and that precluded a higher centrifugal ratio than $\frac{1}{8}$. In that case, supposing only 1,000 feet radius were provided, a motorist would either make his own transition curve by utilizing the crown of the road where there was no traffic, or, if there was traffic, he would have to reduce speed suddenly. If he did not reduce speed, hugging the left-hand side of the road might result in side-slip, which also might occur from reducing speed too suddenly. The figures in the following Table were approximate, but gave a good idea of the working of the transition curve:—

Speed.	Centrifugal Ratio.			
	One Fourth.		One Eighth.	
	Angle of Bend.	Minimum Radius.	Angle of Bend.	Minimum Radius.
	Degrees.	Feet.	Degrees.	Feet.
60	40	1,000	10	2,000
40	65	425	16	850
35	76	315	19	630
30	90	250	22	500

In all these cases the centrifugal ratio ultimately reached with the wider deflections was $\frac{1}{4}$, and it required about 8 seconds to attain that ratio, whatever standard of speed was employed. The transition was so graduated that in 2 seconds the centrifugal ratio was $\frac{1}{16}$, in 4 seconds it was $\frac{1}{8}$, as shown on the right-hand side of the Table, which was the usual railway standard, and in 6 seconds it would be $\frac{3}{8}$, while in 8 seconds it was $\frac{1}{4}$, which was what was shown on the left-hand side of the Table. That was the ultimate road standard, which was reached only at the end of the transition required. The figures were conservative and might be applied with safety to large vehicles, such as motor-coaches. Light cars might occasionally with impunity describe the transition curve at a higher speed, but only at the risk of side-slip. The need for transition curves was even more important under slippery conditions, such as those due to frozen snow, when a uniform speed, however moderate, was safer than a fluctuating one.

Mr. Husbands. Mr. H. W. S. HUSBANDS remarked that it would be interesting if the Author could give some particulars with regard to the

construction of the old gravel roads, which he said had formed so Mr. Husbands. satisfactory a foundation for the new work. It would also be interesting to know how Telford had surmounted the difficulties at the marshy ground where the Author had adopted a concrete raft. Apparently Telford's road was still in use when the reconstruction was begun. The type of cheap culvert made of corrugated iron surrounded by concrete had been used in India for many years, but he had not seen it used for small sizes with ordinary uncorrugated sheet iron, presumably because in India it was cheaper to adopt a flat top for such sizes. With regard to deviations and regrading, vertical curves had been adopted in almost every case, but, beyond finding that the curvature ranged from 3 degrees 12 minutes (about 1,700 or 1,800 feet radius) to 20 minutes (about 15,000 feet radius) he could not see any sign of standardization. In two cases there were no vertical curves. One was a very small deflection of only 7 minutes, but the other was nearly 1 degree, and in the other cases the deviation for which the curve had been given ranged from about 40 minutes to 3 degrees 40 minutes. In both cases where there was no vertical curve it happened to be a re-entrant angle, so that there would be no tendency to jump. He was much interested in the method of widening the curve by an inner circle, and he wondered what effect that had on the centre-line of each half of the track, which was obviously some composite curve. With regard to transition curves, the difference between a railway-train and a motor-car, had, of course, to be borne in mind. A train had to travel on the track laid for it, but a motor-car could make its own curve, and a motor-car was in fact bound to follow some kind of transition curve, because it could not slue its wheels round suddenly to the angle required to run on a curve of, say, 300 feet radius. It had to do that gradually, and therefore it traversed a transition curve. If the motor-car had a track which was a circular curve, it could not run exactly on that track, and must go off it on one side or the other to some extent.

The AUTHOR, in reply, thanked the members for the way in The Author. which his Paper had been received and particularly Sir Henry Maybury, Sir Murdoch MacDonald and other speakers for their complimentary remarks. It had been stated that Telford's roads cost £600 per mile, as against a cost of £8,390 per mile in the case of the road described in the Paper. When the standard to which that road had been built, its width, and the bridges and drainage were considered, as well as the difference in the costs of material and labour, and the relative values of money then and now, he thought it would be admitted that £8,390 per mile was an extraordinarily low figure

The Author. for the construction of a trunk road to modern requirements. Some of the speakers, he thought, had been rather severe in their criticism of two of the large bridges. After all, the appearance of a bridge, pleasing or otherwise to the eye, was entirely a matter of opinion. He would content himself by saying that he had had nothing to do with the design of those bridges. The pitching or block-stone bottoming was handset and was laid vertically in courses across the carriageway, all interstices being wedged and filled with quarry shivers. If the setting and wedging were properly done, no rocking occurred when the bottoming was rolled. Pitching had been used instead of concrete because the former was so much cheaper. The sub-foundation, by which he understood Mr. Frank to mean the subsoil, on which the road was constructed, was mainly well-compacted gravel. It was owing to climatic conditions that the surfacing was made with a matrix of 10 per cent. of bitumen and 90 per cent. of tar, because tar macadam made with a higher bitumen content would be too "tacky" in the high altitudes through which the road ran, and would be very difficult to spread on the ground. He did not agree with Mr. Frank's remarks on superelevation. He had travelled over the A9 road in Perthshire, to which Mr. Frank had referred, and in his opinion the superelevation there was excessive. The important point in connection with superelevation was that on an interurban road, and in a district such as Perthshire, it was necessary to consider not only the motorist going at 40, 50 or 60 miles per hour but also the horse-drawn vehicle and other vehicles moving at lower speeds; and superelevation which would be safe at a speed of 40 to 50 miles per hour would be dangerous at 3 to 4 miles per hour, especially in frosty weather. Dealing with the case of the curve of 450 feet radius, cited by Mr. Frank, with its 21.6 inches of superelevation on 18 feet width of carriageway, that meant that an object 3 feet in height measured from the road surface would be 3.6 inches out of plumb, which was an undesirable condition. On that same road the Author had heard of an instance where sacks loaded upright on end on a horse-drawn lorry had actually fallen off when the lorry was proceeding round one of the curves, much to the alarm of a passing motorist. If too much superelevation were given on a curve, a vehicle must increase its speed in order to proceed in safety and comfort, and the result might be, as for instance in the case of a scheduled motor-bus service, that a higher speed would be necessary to round a curve than was maintained on the straight road. It was not possible to provide superelevation to suit all speeds, and it seemed better to provide moderate superelevation to assist the faster vehicle, rather

than the theoretical superelevation for the faster vehicle, which would be a source of danger and inconvenience to the slower vehicle. It was undoubtedly preferable that the faster vehicle should reduce speed rather than that the slower vehicle should be obliged to accelerate in order to proceed safely round a curve. The reasons for not altering the gradient of 1 in $10\frac{1}{2}$ on the old road were that there was only a short length of it, on a perfectly straight piece of road, and that to improve the gradient would have meant a cutting of several thousand cubic yards of rock. It had therefore been decided that such improvement would not be worth the expense. The trees at the roadside were planted about 10 feet from the edge of the carriageway in most places. The ground was very irregular, and the trees and shrubs were planted not in straight lines or avenues but in clumps here and there. The outside lines of sharp curves were defined by guard-post and rail fencing, painted white, which showed up very plainly in the lights from motors at night. There was no doubt that a concrete road expanded and contracted owing to changes in temperature and in climatic conditions, and that, unless means were provided to deal with those effects, cracks would appear in the road. In this country it was generally considered that a concrete road expanded and contracted about $\frac{1}{8}$ inch per 100 feet of length. The longer the slab, the more stress must there be at the middle of it during contraction and expansion. It seemed therefore reasonable to deduce that two $\frac{3}{8}$ -inch expansion joints should be provided in a length of 100 feet of reinforced-concrete road, in bays of 40 feet to 60 feet, if transverse cracks were to be avoided. The hooks shown in the cross section, connecting the twin beams together, had been put there principally for the purpose of holding one slab to another vertically, although they also helped in holding the beams together laterally. If the deeper beam settled, or if the shallower beam lifted, the hooks would ensure a corresponding movement in the adjacent beam. As to the reason for covering the concrete road with bitumen, he was inclined to agree with Mr. Cook that a concrete road should be simply a concrete road; but some trouble had been experienced with abrasion at the centre joint, which had been repaired by filling it with bitumen. When it was completed the appearance was rather unsatisfactory, and it was as much for the sake of appearance as for anything else that the road had been coated with bitumen. The abrasion did not appear to have developed since the repair was completed. With regard to Professor Royal-Dawson's interesting observations on easement curves, transition curves as applied to railway-construction were necessary, but the necessity did not apply equally

The Author.

The Author. to road-construction. In reconstructing main trunk roads in this country there were many fixed points through which the road must pass, and many others which had to be avoided, and those determined to a large extent the alignment of the road and the positions of curves. Cases occurred, such as that of reverse curves of, say, 275 feet radius each way, superelevated 12 inches, between the tangent-points of which it was desirable to have a minimum length of 150 feet of straight road, in order to avoid an immediate reverse and to provide a sufficient length for the run-off from the superelevations to the normal cross section of the road. In many of those cases, where the middle points of the curves were near each other, transitioned curves might overlap at their ends, or unnecessary additional expenditure on construction might be incurred by the introduction of easement curves. He would not care to put in a transition curve with the idea that it would dispense with superelevation, because with superelevation the resistance to the centrifugal force was increased; but he agreed with Professor Royal-Dawson that a curve which could not be superelevated was more in need of easing at the ends than one which could be superelevated. The two subjects of superelevation and transition curves, although closely related, were not identical, nor were the two things equally necessary in road-construction. The object of superelevation was to counteract the effect of centrifugal force, which for a given radius and speed was determinable and constant, and against which the driver of a vehicle had no power; therefore superelevation must be provided on a curve. Transition was used to avoid a too sudden change of direction; but the motorist, not being confined to a fixed track as on railways, and with the ample unit width (10 feet) allowed for one line of traffic on most main roads, together with the additional width provided on sharp curves, could, without going outside his own portion of the road, choose his own route round a curve so as to make the changes of direction as gradual as possible, rather than adhere rigidly to the circular curve; so that transition curves for road work were not essential. For the greater part of its length the old road consisted merely of the native gravel left in its original position, on which subsequent surveyors and others in charge of the road had put successive layers of gravel or metal until it had become a compact structure. Over the peat bog where the concrete raft had been built, Telford's method had consisted of dumping dry material on the peat and dumping road metal on that. In those days loads were light and speeds low, and as the road had sunk more metal had been put on, as occasion demanded. He had watched the road before

reconstruction and had observed that if a vehicle of 2 or 3 tons in weight went over it the road was deformed in a series of waves during the passage of the vehicle, but regained its original form almost immediately. The vertical curves had not been standardized but varied according to the angle of deflection. The omission of the two vertical curves in the profile, referred to by Mr. Husbands, was an oversight. The effect of widening on the inner side of a sharp curve was that the tangent-point at both ends was moved farther away from the intersection-point, thus lengthening the curve, the centre line of each half of the road was altered from a circular curve to a flatter compounded curve, and the width of each half of the road was gradually increased from the new tangent-points to the middle point of the curve; and so a vehicle was afforded greater latitude in negotiating the curve. The Author.

Correspondence.

Mr. M. B. BUXTON remarked that it was satisfactory to note from Mr. Buxton. the statements at the end of the Paper that an effort had been made to preserve the amenities of the countryside. The scenery of the country traversed by this road was some of the finest in the British Isles. The fact that money had been spent on planting shrubs and trees, etc., gave official sanction to that course, and on similar work in the future engineers should consider it a duty to follow the excellent example thus set. On the other hand, it was a matter of sincere regret, not only to inhabitants of the district but also to visitors from England who were bold enough to venture into those wild Highlands, that the beautiful stone arch bridges, which harmonized so well with their surroundings, had been ruthlessly destroyed and replaced by others of concrete which disfigured the landscape. That was nothing short of a calamity. It was to be hoped that no engineer or Government authority would ever again be responsible for such a disgraceful massacre of charming stone bridges.

Mr. J. E. HARRISON remarked that those having experience in Mr. Harrison. the location and construction of railways and roads in the rougher parts of the Highlands—commercial enterprises where the study of economy was a prime factor—must be struck with the high cost of the works described, especially when the cry for economy was everywhere heard. In making comparisons, present-day high costs generally, in relation to the past, had to be kept in view; but there were also circumstances that favoured cheaper costs in this instance,