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Discussion.

The Author introduced the Paper with the aid of a series of lantern-slides.

Mr. G. T. Bennett observed that the correct alignment and appearance of a road from the point of view of the driver was very important, particularly as the driver's vista would be greatly widened when the future motorways were constructed.

Could the Author, from his experience in the use of the method described in the Paper, lay down rules to serve as a guide in the preliminary choice of gradients and alignments? It would not always be possible to use the Author's methods on ordinary road works, but designers should learn the lesson with regard to ordinary roads as well as motorways. They would not always need to draw three-dimensional perspectives on exaggerated scales, and would welcome some simple rules which would indicate what to avoid when drawing two-dimensional plans.

The Author had stated that the picture drawn eventually would be the driver's view of the road from one point only, and that from another point the road might not look so well. Apparently, therefore, it would be necessary to draw an almost infinite number of pictures in order to be sure that the road was entirely satisfactory. That might be an exaggeration of the position, but further enlightenment would be of value. Was the introduction of superelevation as an additional complication a serious matter or not, and would the transition curves themselves present a further difficulty when they were added?

Mr. E. C. Boyce considered that the Author had rendered a valuable service by bringing the Paper before the Road Engineering Division. Some mystery had existed about that method of dealing with road alignments and, frankly, Mr. Boyce could not say that he was very much wiser after reading the Author's explanation of the three-dimensional approach.

It was obviously necessary to ensure, in the location of new roads, that the tangents, both vertical and horizontal, should coincide; but it was

undesirable to go to extremes in that respect, because the correct proportions would be lost. For example, if there were very long horizontal curves on a new road, and the inference was that the vertical curves should be very long, the result would be to create enormous embankments and cuttings; but Mr. Boyce understood from Mr. Aldington's Paper that that was precisely what the Ministry of Transport desired to avoid. It appeared, therefore, that to take long, sweeping horizontal curves would defeat the object of ensuring that a free-flowing alignment was achieved. To go to the other extreme, if there were long lengths of straight and very short curves, the fitting of a vertical curve to a horizontal curve was quite a simple matter but would be completely against the whole principle of the free-flowing alignment. Mr. Boyce considered, therefore, that to follow, though not slavishly, the lie of the landscape would represent a happy compromise at which to aim.

There was only one particular point on a road from which a particular effect would be seen. In driving along the road in a car the effect was continually changing, so that at only one precise point would the driver experience the optical illusion of the road being out of sweep curvature. Mr. Boyce had walked about on the German *Autobahnen* when with the party who reported on them in 1946, and they had found one or two places where alignments of the kind which the Author had illustrated were encountered, but the effect was only instantaneous and from one particular point; as soon as the party got into a car and drove along, the whole aspect changed and the fault disappeared. He could not believe, therefore, that the matter could be very important on a road intended essentially for motor vehicles. If the road were intended for people to stroll about on on Sunday afternoons the position might be different, but in fact the whole effect of the objectionable alignment was lost an instant after it had been seen. Mr. Boyce considered that too much attention should not be paid to the importance of that aspect of the matter.

With regard to the question of balancing cut and fill, he understood that that was not now regarded as very important, because it was possible to bring in as much extra filling as was needed to ensure that the alignment was satisfactory! What would the planners have to say, however when enormous borrow-pits were dug all over the countryside in order to create beautiful free-flowing embankments?

In combining horizontal and vertical curvature there were two variables. It was necessary to start somewhere when locating a road, and in Great Britain the designer would be tied very tightly in regard to the horizontal alignment and would have certain fixed points from which he could not depart. It would, therefore, be necessary to start with some kind of horizontal alignment and then try to fit the vertical alignment to it.

Fig. 6 showed the proposed Severn bridge as viewed from Road A.38, north of Almondsbury. That happened to be in Mr. Boyce's own county of Gloucester, and he knew the view from Road A.38 across to the river

Severn very well. He was convinced that the Severn bridge could not be seen from the road in the way shown on the drawing; the angle of the bridge as shown was quite wrong, and it would appear to be miles away from the road—much farther than was shown in the drawing. The towers in the drawing would not be visible, except perhaps vaguely in the distance. Two very high pylons, which took the Electricity Board's cables across the river Severn, were about the same height as the towers of the Severn bridge would be, and he judged the effect from those towers and how the bridge would be seen from the road.

The Paper was very important and valuable and contained much matter for discussion and analysis so that practical conclusions could be reached.

M. R. A. Abbott inquired whether the Author could give some information on his method of applying superelevation and incorporating it in his design. Apparently he achieved a smooth-flowing centre-line, which was really more of a reference line, about which he applied superelevation; but when that was done certain kinks would be introduced, although probably they would not be so obvious as the kinks resulting from certain combinations of vertical and horizontal curvature. Was it possible to overcome that?

Mr. Abbott agreed that the designer should have at his disposal some means of verifying that the alignment would prove satisfactory from a three-dimensional aspect; but he was not convinced that the method described was the most satisfactory approach. He feared that the production of the drawings and the calculations involved would take considerable time. The full-line diagram showing curves and verges would probably take three or four days, but that might be an over-estimate.

With regard to the selection of view-points, it would be necessary either to make drawings every 300 or 400 feet along the road or to assume where the kinks would occur and hope for the best. A scale model was a more satisfactory method of approach. Road models which had been described in the past had admittedly involved the permanent requisitioning of a large building, and a large outlay on apparatus, but it was not difficult to overcome that.

Recently Mr. Abbott had been experimenting with a short length of model which consisted of a series of stands, rather like shop display stands, each one of which could be represented as a cross-section of a road. With that, $\frac{1}{2}$ mile of road could be set up in 4 or 5 hours to a scale of 3 feet to 1 inch; with a smaller scale, $2\frac{1}{2}$ miles could be set up with the same number of units, and the total cost of the complete apparatus should not be more than about £150. The advantage of that model was obvious. It could be viewed from any desired point—from the driver's viewpoint or any other—and adjustments could be made. A permanent photographic record of any point could be obtained, and diagrams which were exactly similar to those of the Author could be produced in 15 minutes with an

ordinary photographic enlarger. If such a method were readily available and did not occupy permanent space, would the Author regard it as more satisfactory than the purely graphical method?

Professor F. G. Royal-Dawson considered that the Author's process of obtaining perspective "pre-views" of a proposed alignment was ingenious; but if it were merely for the purpose of revealing optical defects, anyone accustomed to location work in the field would anticipate many of those defects and take steps to rectify them straight away. Professor Royal-Dawson had dealt with the question in a nutshell on pages 93 and 94 of his recent book.¹

A typical case was a change of gradient within the limits of a horizontal curve. If that could not be avoided, one method of dealing with it would be to make the length of the vertical curve as nearly coterminous as possible with that of the horizontal curve. That, however, was merely a general idea, and each case would have to be dealt with on its own merits. A very simple drawing-office method was to plot the horizontal curve to a fairly large scale on a sheet of paper, and bend the paper to give more or less the vertical contour; then, by running the eye along the whole curve from start to finish, facing the direction of travel, and keeping the eye as close to the surface of the paper as possible, in order to represent the eye of a motorist, a constantly-changing perspective view would be obtained right along the line, so that the perspective aspect at any point in the line could be seen at a glance, without any necessity to make a special diagram of it. That method, although simple, usually gave as much information as was required and could be recommended for ordinary cases, whether the Author's method was afterwards applied or not.

Mr. H. N. Ginns observed that the subject of the Paper should be examined in the light of the fact that very few road engineers in Great Britain had ever conceived road design from the point of view advanced by the Author. The work of Cardell and Howarth, and the ideas of Hugo Koester on the *Autobahnen*² had opened up a new approach to road design.

He had some grounds for saying that, because at one time he had looked through profiles and tentative plan lines of many of the new motorways. The drawings had been prepared all over the country, in county offices, consulting engineers' offices, and the offices of the Ministry of Transport, and in not many cases—perhaps in none—was there any evidence of the application of the new aesthetic ideas. Some of the simple necessities were not there, and often the plan line was not shown against the section.

In making that statement, Mr. Ginns did not wish to appear disparaging; those drawings were perfectly good, sound road drawings in the light of the knowledge then available and from the engineering and planning point of view they were what all road engineers would have done:

¹ "Vertical Curves for Roads." Spon. 1946.

² *Die Strasse*, Aug. 1940.

but at that time the Author was working very hard at his new technique of perspective drawings and studying the effects of the new aesthetic approach. If that new technique were applied to the roads shown on those drawings—which were very sound roads, capable of carrying traffic for many years—there would be a difference in finish and in polish; the roads would be not simply engineering structures but also fine engineering structures.

That was clearly illustrated by *Figs 4 and 5*, which showed the crossing of a river valley. That was an actual case, and had not been introduced just to illustrate the point. It could not be doubted that anywhere along that stretch of road, and from whatever point it was viewed, the final line in *Fig. 5* would be better than that in *Fig. 4*.

The reason for the lack of knowledge on the subject was not far to seek. Apart from the relatively large volume of work carried out immediately after the first World War, when about 300 miles of roads were built, he believed only three jobs exceeding 15 miles in length had been carried out from 1925 to 1939, namely, the Edinburgh-Glasgow road, the Liverpool and East Lancashire road, and the Kent Coastal road. All the rest had consisted of short by-passes, 5 or 10 miles long. In the middle of the period a financial crisis had arisen, and from 1936 onwards people were beginning to think about rearming. At no time since motor-cars came on to the roads and the Road Board was formed had road engineers in Great Britain had a fair run; they had always been faced with some crisis or another and that was the real reason why they now found themselves confronted with something quite new to them in the aesthetic approach.

Another reason was that, although many English engineers went to Germany to study the *Autobahnen* before the war, it was not until the middle of the war that Lorenz, Koester, and others had published Papers. At that time people in Great Britain were too busy to worry about the aesthetics of road design, and it was astonishing that the Germans should have done so in the middle of the war. After the war those Papers were sent to England, and then Cardell and Howarth, Aldington, and the Author got to work. A debt of gratitude was due to them for the pioneer work done on the subject.

The Author had stated that few young engineers had had the opportunity of doing road work. Mr. Ginns hoped that they would have more opportunity in the future, but many people felt very despondent about that. It had been hoped that after the conclusion of the war a burst of new road work would occur, like that which followed the first World War, when Aldington and others were sent off to Kent or some other part of the country and told to build a road, and within a month had started to do so. The 300 miles of road built after the first World War might not be up to modern standards, but they carried thousands of tons of traffic.

Young engineers should follow the method described by the Author step by step and should study the whole subject carefully. If that were

done, there would be no reason to regret the present interim period during which no work was going on, because it could be turned to advantage, so that when eventually the roads were built they would be models of their kind.

Mr. B. G. Combridge observed that he attempted always to visualize road location schemes by the simple process of reconnoitring the country and looking at the plans and sections long enough to be able to have a mental picture in three dimensions.

Fig. 7 (b), Plate 1, illustrated what would be generally agreed to be the ideal, of the horizontal and vertical curves being coincident in length; Fig. 7 (a) showed the short vertical within the longer horizontal; and Fig. 7 (c) showed the short horizontal within the longer vertical. Had the Author made any perspective drawings of that kind where the horizontal and vertical curves were staggered so that, instead of the one being wholly within the other, the vertical curve would start first and then the horizontal; the vertical would then finish, and finally the horizontal? Could the Author show any drawings of that kind, or describe what the effect would be?

Figs 9 showed that, whether in horizontal or in vertical curves, a divergent angle smaller than about 20 degrees was fraught with danger, because any unfortunate feature round the corner could not be hidden. What convenient limit to such a divergent angle would the Author suggest?

Mr. J. C. Howard observed that there was in existence a 1948 provisional edition of the Ordnance Survey to a scale of 1:25,000 (about $2\frac{1}{2}$ inches to the mile). On those sheets contours were shown at 25-foot intervals, and he had already found them very useful in location work and in drawing provisional preliminary longitudinal sections in rolling country.

He agreed with Mr. Boyce that many eminent British road engineers were already co-ordinating horizontal and vertical curves, and some of them had done so for a number of years. The practice was becoming increasingly common, but hitherto no really satisfactory way of dealing with it visually existed. In order to test the convenience of the Author's method of construction, he had recently drawn a perspective for a length of about 1,200 yards, showing just the four lines of a dual carriageway, and had been surprised to find, after 2 hours' preliminary scrutiny of the Paper, that he was able to get perspectives similar to those shown by the Author in from 4 to 6 hours. He believed that to set up any kind of a model would take at least 6 hours, in order to be sure of the levels; accuracy in levels was necessary in a profile as well as in a perspective, because to get the perspective effect on a model it was necessary to bring one's eye close down to the strip of paper, cardboard, or other material, where slight inaccuracies would appear to be magnified.

It was obvious that the vertical curve in Figs. 7 should have a length equal to or greater than that of the horizontal curve, but never appreciably less, unless there were prohibitive considerations. Actually, he had found

places where the horizontal and the vertical curves were perforce not coincident, and he had not been able to detect any appreciable optical illusion on his own perspective drawing in one such case ; he had, however, had the combination of vertical and horizontal curves in mind when the profile was drawn. What degree of accuracy was required in making up those perspective drawings ? He calculated that the perspective shown in the Paper would be roughly 8 inches by 4 inches on the finished article, and he suspected that close accuracy was required to show, at all events, minor optical illusions. For the purposes of the Paper, the cases discussed by the Author were rather flagrant ones and were therefore easy to detect.

Figs 8, Plate 2, were particularly interesting, because it was obvious that views in both directions might be necessary in some cases. It was significant that the optical illusion appeared from both ends, although it was more accentuated from one end than from the other. Mr. Howard did not think that it would be necessary to take views from both directions in all cases.

The method also appeared to be a very rapid way of dealing with malalignments arising from the imposition of superelevation on a profile on a local bend. It might be possible to obtain a bigger perspective, to show up any minor errors in ordinary cases, as distinct from the extreme cases given by the Author.

The choice of position of the eye seemed to be important ; but it was obvious that the eye should be roughly in line with the road.

It should be noted that the various lines which were required in the perspective should be drawn on the plan at their correct distance relative to each other measured to the offset scale of 1 : 500.

Professor R. G. H. Clements observed that, in glancing through the Paper, he had not been able to find an example sufficiently bad to support the case which the Author was making for three-dimensional projection of the road ; therefore he wished to give an example which had occurred in some work which he had undertaken about 25 years ago in connexion with a length of road of about 15 miles in Kent over undulating country.

Although on that road and in the work generally everything possible was done to create a standard of perfection by easy curvature—no horizontal curve was to have a radius of less than 1 mile and no vertical curve less than $\frac{1}{2}$ mile, and transition and visibility were all considered on the drawings—although the conventional longitudinal section and plan drawings looked nearly perfect, when the work was done the effect could serve as an awful example. The work involved cutting into the high points and filling in the hollows ; in other words, a series of easy gradients was established, and it was believed to be completely successful, but when the work was done the folds in the ground showed themselves as in *Fig. 10*, terminating in a ridge.

For 20 years he had tried to teach three-dimensional projection in road work, but he did not consider that the type of projection evolved by

the Author would answer the question. First, the Author invited acceptance of a snapshot presentation at a given moment ; he relied on a certain aspect at selected points along a road, whereas it might present an equally offensive appearance from the other end. For simplicity, the Author had confined himself to the road line ; and he had stated that one line was bad, having an intervening straight portion between the two curves, whilst another was good because that straight portion had been removed. That might be all right from one particular point of view, if one could train one's mind to accept that presentation and it was regarded as the complete

Fig. 10.

answer to the question ; but Professor Clements did not think that it could be so regarded, at least in the present state of knowledge. Moreover, that type of isolated picture did not present what a road engineer did when he aligned a road, and had to construe it as a completed route. Eventually, therefore, it would seem that the Author's method would have to be changed into a form in which it would be possible to get a three-dimensional projection over a substantial length of the road, not over only one small part, and so that it could be interpreted from each end. The question was whether it was completely satisfying aesthetically if traversed in either direction.

Again, the engineer had to carry out his work and settle the longitudinal section and plan in relation to the quantity of material which he had to move. He could not shut his mind to cut and fill ; otherwise, his work as a whole would not be economical. Therefore, it was obvious that the question of aesthetics could not be considered in vacuo, but should be related back to the landscape into which the structure had to fit ; and the

more perfectly it fitted the landscape the more aesthetically perfect would it be.

With those two points in mind, the Author should be complimented on ventilating a subject about which too little was known and much had still to be done. Professor Clements believed that the solution lay in treating the whole length of the road, dividing the longitudinal section and the plan into constant intervals, and plotting not in perspective but according to the type of polar diagram shown in *Fig. 11*. If the points shown were

Fig. 11.

plotted in relation to a datum-line, the interval being constant, it was merely necessary to plot the A- and B-axes of those two points, and it might be possible to resolve it into a true polar diagram in which, the interval being constant, an alignment for the road would be obtained which, by its constancy, would indicate whether it was good or bad. That was for the future, but he was sure that it could be achieved.

Mr. E. R. Gambrell suggested that a combination of paper and model was really needed. Attempts were being made to devise a model

which would not cost £150, as stated by Mr. Abbott, but could be made by any local handyman from plywood and spare cycle parts and would render it possible to set up the profile and the plan of a road for a distance of about 4,000 feet on a base of roughly 8 feet and to a horizontal scale of 1 : 500. The difficulty at the moment was to find material sufficiently rigid to give the true longitudinal section as drawn and sufficiently pliable to go between fixed points and yet retain its shape. It had been objected that the distortion was noticed only for an instant, but that would be obvious from the model and, if necessary, the three-dimensional drawing could be made. It was possible with the model to follow the line of route as if riding in a car, and to see it from both ends at one setting up.

An advantage of the three-dimensional drawing, for local authorities, was that when big schemes were being considered it was very useful to produce a drawing which the councillors could examine, whilst the engineer's report would be helped by drawings of that nature, which were accurate and not merely draughtsmen's sketches. If a combination of the model and the three-dimensional drawing could be used, that would go a long way to provide a solution for the bad cases of malalignment which were so frequently seen.

The Chairman observed that the bottom right hand illustration of Figs 8, Plate 2, showed the amended line, after working out the perspective drawings. The horizontal line or the plan line—apparently as amended—came off the straight, and a series of radii—100,000, 35,000, 100,000 and 16,000 feet—were shown, whereas the original line showed a straight and one curve of 16,000 feet radius. Normally objections to compound curves existed, for various reasons, and perhaps in that particular example the difficulties in the appearance of the road might have been overcome if a regular curve had been adopted, instead of the compound curve.

The problem of the co-ordination of the horizontal and vertical alignment of high-speed roads was of considerable interest to highway engineers, because they hoped for an opportunity of building some high-speed roads. In his introduction, the Author had referred to the Ministry of Transport proposal for 800 miles of motor roads. The Special Roads Bill had received a Second Reading, and when that became an Act it would enable the Minister at some time to carry out the work.

The problem of alignment and appearance had disturbed the Chairman about a year ago. As one who in the past had had a good deal to do with railway location work, he had believed that similar ideas to those adopted in railway location and alignment could be quite easily applied to highway work; but in railway work fairly flat curves and gradients were used. The difficulties with roads, where curves were sharper—they might not be in the new motor roads, but the gradients would be—were not found with railways. The combination of a sharp gradient and a curve not in the same plane led to serious objections in the appearance of the road.

The Germans had encountered that problem in the first motor roads

they had built. *Figs 9* illustrated the appearance of a road which had been worked out in theory after the road had been built. Traffic could pass over that road in safety and at speed, but its appearance was disagreeable and, to a certain extent, irritating. That was undoubtedly a disturbing influence on a driver. A lack of harmony in the lay-out was an irritating factor, and anything which had that effect upon a driver was bad. The appearance of roads, therefore, particularly in hilly country, and the correlation between the vertical and the horizontal, was very important. In flat country those difficulties presumably would not arise, for the obvious reason that everything was in the same plane.

A lull would occur before the building of any major road could be undertaken, but when the new roads came to be built he felt certain that those responsible, as sensible men and as engineers, would take the fullest advantage of all the research work which had been carried out on the subject of alignment, so that the new roads would have no disturbing features and would be a credit to the country.

He hoped the Author would continue his research work and would be able to obtain access to all the literature available, most of which came from German sources. The Chairman believed that the mistakes in grading and alignment which had been made in British roads had been made everywhere. He had recently seen some photographs of roads built in America which had exactly the same defects as were evident on the early German motor roads.

* * * **Mr. W. T. Shaddock** observed that the co-ordination of horizontal and vertical alignment of roads for the purpose of overcoming an optical illusion brought to his mind the adoption of entasis by the Greeks for the purpose of obviating the illusion of hollowness in the design of the doric columns of the Parthenon. Such a development in the aesthetic treatment of roads was comparatively new and was largely due to the conception of the single-purpose road. But it was interesting to note that, in their Final Report published in 1931, the Royal Commission on Transport emphasized the importance of improving highways from the aesthetic point of view and, although they certainly had in mind particularly the construction of well-proportioned bridges and the use of adventitious aids such as the planting of trees, they used the phrase "dignity of alignment." Before the war Mr. Shaddock had had occasion to examine, on behalf of The Institution, some of the published German records of work on the construction of the *Autobahnen*. A noteworthy feature of the early work was the attention given to the aesthetic, as distinct from the utilitarian, aspect of design, but his impression was that even at that time more concern had been felt for bridge elevations than for the alignment of the motorways, and that it was only later that the latter had begun to receive recognition as being a matter of importance aesthetically. The probability that at some future date motorways would be constructed in England had

* * * This contribution was submitted in writing.—Sec. I.C.E.

again raised the question of amenity. But, however much amenity had been sought after for its own sake in the distant past, in the present age aesthetic treatment had come to be closely scrutinized on financial grounds, and a refinement of design such as the co-ordination of horizontal and vertical alignment of roads might prove to be no exception if, as appeared to be the case, it was likely to result in increased expenditure. It would be interesting to learn whether any investigation had been made into the effect of such co-ordination upon the cost of construction in specific cases and whether estimates had been made of the anticipated savings, if any, in vehicle operation on account of easier gradients, which could be set against increased capital outlay.

The Author, in reply, thanked the speakers for their comments. If the Paper had served to bring home the need for a study of the subject it had been worth while.

He considered that the true value of a model would never be realized unless it were made so that it would track a small cine-camera, rendering it possible to simulate on the screen the movement of the traffic over the road in a continuous picture. Funds might be provided to set up one such model in the country, and he hoped that the Chairman would think kindly of that suggestion.

A road model setting out the road in six lines—not four, because it was necessary to put in the outer margins as well as the carriageway edges—would form a great aid to knowledge of the subject. In the meantime, all county councils and all people working on road alignment could not hope to set up those models, and perhaps the Paper might help road designers who could not set up models to answer criticisms made by their councils or (in the case of consultants) their sponsors, and enable them to present their answers to questions about alignment.

He hoped, with the Chief Engineer's permission, to adopt Mr. Bennett's suggestion and to present the limitations, and the points which should be looked for, in the form of a small document which might be a kind of *vade mecum*.

Mr. Bennett had asked whether the number of pictures might not be infinite. The pictures were constantly changing, but if too many were made for one piece of road it might be concluded that what looked good on the first picture would continue fairly good throughout its visible length.

With regard to superelevation and transition, from the aesthetic point of view it was unwise to stick slavishly to a given radial acceleration. The Germans had found that if they developed superelevation at an increasing gradient, greater than 1 : 200, they were asking for trouble, and eventually they decided not to increase the approach gradient by a greater degree than 1 : 200, and to have it flatter if they could. If the criterion were accepted that the superelevation should be developed throughout the length of the introductory transition curve and that the above variation in grade should not be exceeded, then it was necessary to depart from a

fixed figure for the radial acceleration. Drawings made so far bore out that point and the ultimate result of investigations would probably be that the length of the transition would be dictated by aesthetic limitations.

Mr. Boyce and the Author saw things from different angles at the moment, but the Author hoped that, in a spirit of compromise, they would come together before the end. Mr. Boyce considered that the tangents should coincide. That was one of the criteria given in the Paper, but the Author was not pedantic about it. It was a question of intelligent application. When traversing curves which had fairly large displacement, what happened round the corner from the aesthetic point of view could not affect the view on the approach to the corner, so that changes were possible in a horizontal curve without upsetting aesthetics. What was out of sight was out of mind and, so long as the change in the horizontal curve was made gently and in what might be regarded as a good and persuasive manner, he did not think it necessary to worry about the effect, or to feel that every vertical curve should be made the length of every horizontal curve. Aesthetics could apply only to what was seen at one time.

Mr. Boyce was perhaps dealing with an existing plan line laid down about 2 years ago, and trying to apply the principles to that line. That was difficult. It was obvious that, if those ideas were to be applied, it would be necessary to start almost *de novo*. It was now possible to make use of an aerial survey, and from it to plot the contours over a fairly wide strip—which would be laborious by hand but could be done in 3 months from the air for 100 miles of road with a sufficiently reasonable degree of accuracy; and then it would be possible to build up the picture as one went along, and to move the plan and profile lines together to give not only a good line but also a very economical line from the point of view of cut and fill. Curve to curve working together was capable of a far greater degree of movement than a straight and a curve. If the radius of one curve were increased or decreased, a very different approach to a point was obtained while keeping to a tie-point at the other end, so that if the two were applied together from the beginning, some of the difficulties which seemed to arise at the moment would be overcome.

With regard to the balance of cut and fill, the Author had already said that if one re-started at the beginning it was possible to balance cut and fill more closely than appeared possible in trying to fit the method to an existing plan line.

The view of the Severn bridge and the line of the road and the towers were drawn by the perspective method with particular care for accuracy. The intervening countryside, which Mr. Boyce did not recognize, was added by artistic creation.

The Author hoped that it would be possible to solve the problem of the development of superelevation in a short time. It was possible to produce two diagrams such as *Figs 4* and *5* in about 12 hours, and the time might be shortened when one became used to the method. It

was not clear whether Mr. Abbott, in referring to a scale model, meant one developed from aerial photographs in full detail or the ordinary line model which other speakers had mentioned. It was possible to produce from an aerial survey an accurate scale model of the countryside with a photograph skin accurately fitted and the detail brought down by stereoscopic study. That could be done for £40 to £45 a mile, and a great deal of information could be gathered from the model. It gave an appreciation of the country which could not really be gained even from walking over it. A public exhibition had recently been opened in Berkeley Square House in which one such model, fully developed, with houses and trees put on, and so on, was exhibited, showing how an aerial survey could be developed to help.

Professor Royal-Dawson was one of the pioneers of methods of three-dimensional study, and had presented many ideas on the subject. The Germans made considerable use of gradient models. Those models stood up a little stark, and it was difficult to mask the depth, but they served a very useful purpose and were well worth trying out. The Author hoped that an opportunity would be taken of using them.

In reply to Mr. Combridge, it was impossible to give any ruling or any drawing which could make it possible to say that one particular stagger would look good and another bad. In the case shown it was a combination of two radii. In so far as the divergent angle was concerned, the alignment

Fig. 12.

which Professor Clements had illustrated was very disturbing, but a very disturbing effect could also be obtained with a straight line of road, as shown in *Fig. 12*, as could be seen in England even now. In pleading for a large enough angle of divergence on the road line, Professor Clements had raised a point with which the Author was in hearty agreement.

The Ordnance sheets to which Mr. Howard had drawn attention had been used on preliminary location, but, in deciding upon a line which could be followed, 25 feet was found to be too great an interval to allow of further development without considerable out-door work. The Author suggested that that stage should be followed by an aerial survey, in which it was possible to have contours at intervals of 5 feet if desired. He had found that a 10-foot interval gave sufficient accuracy to make it possible to determine the line closely without much outdoor work until a firm line was arrived at; then the minimum of outdoor levelling would be required, and probably, over most of the line, only one set of levels would be necessary.

The size of the picture of the Severn bridge produced in the original drawing was 30 inches by 12 inches. The accuracy of plotting could be

quite good at that size. In a drawing of that kind about 6 miles of road was in view. The towers were 420 feet high, which was a very considerable height, so that even from the distance from which the drawing was made they would appear as quite tall structures.

Views from both directions were essential. It was necessary to see that the alignment did not look bad from the opposite direction. It was necessary to consider what a driver would see at a point 12 feet from the carriageway over which he was travelling, at a height of approximately 4 feet.

Professor Clements had given a very graphic description and illustration of a point, not brought out in the Paper, which needed to be emphasized. The Author did not think that cut and fill would be increased if the method were used from the beginning. He would keep in mind the desirability of a continuous profile, and would study that question. If it were possible to develop a model with a moving camera on it, that should meet the case equally well, because it would provide a continuous view.

The Author agreed with Mr. Gambrell that a combination of paper and model was needed, because even when a model had been made only an engineer could appreciate it, whereas a drawing on the flat would generally be appreciated by those to whom one might have to propound one's scheme.

The simplest way to answer the Chairman's question about the curve was to say that the illustration was extracted from German work. It had to be, because there were two illustrations of German roads, and so it was analysed through from the German illustrations. That meant that there were balancing curves on each side of the centre radius. In English practice the compound curve would be avoided, but it had been necessary to adhere to the German solution; otherwise there would not have been much point in including the original photographs.

In reply to Mr. Shaddock, no controlled investigation of the effect of co-ordination of alignments on the cost of construction had been made but no reason was seen why there should be any increase: in fact, a reduction should accrue owing to the greater flexibility of alignment which was possible.

In reply to the request made by Mr. Bennett, the following notes had been prepared to indicate how, in practice, the desired results could be achieved. The Author wished to apologize for the inclusion in the notes of already established practice in location work, but he considered that to be necessary in order to emphasize the process advocated.

FLOWING ALIGNMENT.

The Phasing of Horizontal and Vertical Curvature.

(1) The proposals for a system of motorways and the adaptation of certain trunk roads for long-distance traffic have emphasized the necessity for introducing a technique of highway design which will pay full regard to amenities and aesthetic principles. This technique is, in brief, the correct phasing of horizontal and vertical curvature to give "Flowing Alignment."

(2) The basic engineering principles, such as the balancing of earth-works, still apply; the technique is merely a development of these principles to ensure that after construction a pleasing appearance of the road ahead is given to the road user, and this is achieved by modifying or adjusting the general alignment of the new road to obviate the appearance of "kinks" or optical malalignments.

- (a) Perspective views of the road ahead should have either background or continuity. It is important that the road should not form part of the horizon; it should (i) disappear into cutting, or (ii) be visible ahead with each section obviously in continuation of that preceding. In order to preserve an unbroken background, major changes in direction should, as far as possible, be reserved for negotiating ridges in cutting, broad belts of woodland, etc.

It follows from the above that flat curves and straights should be reserved for embankments or where the road profile approaches or coincides with the ground profile.

- (b) Horizontal and vertical curves should be as long as possible; it is imperative that short curves and straights should be avoided.
- (c) The lengths of adjacent curves should be of the same order.
- (d) Small changes of direction should be avoided to obviate the consequent disjointed appearance and lack of continuity in perspective of the road ahead.
- (e) On the level terrain long straights are permissible, but these straights should be sited so as to give a view ahead of some feature, not necessarily centrally situated, such as a cathedral tower, a wooded copse, etc. This will relieve the monotony associated with the straight road.

In level country the water table will usually preclude the new road passing under railways; consequently there will be raising of the profile, and it will be for consideration whether changes in direction should be located at such changes in profile and so accord with free-flow principles. On the other hand, care should be taken to preserve the continuity of the

line of route, and this will usually be achieved by ensuring that the horizontal curve is of sufficient length.

- (f) Curves of the same or opposite sense, which are visible from one another, should not be connected by a straight. It is better to introduce a flat curve or to extend the transition curves to a common point and thus obviate the "hardness" otherwise likely to result.
- (g) The effect of the foregoing generally will be to fit the road into the landscape. Cases will arise, however (say when the new road is raised in profile to give the necessary headroom over a railway), where the vertical alignment will tend to be out of harmony with the terrain by the introduction of a "false brow" unless at the same time the necessity for the brow is made obvious, for example, by the provision of parapets. It is important that in all cases the purpose of any feature tending to obtrude on the landscape should be evident: where it is not evident the profile should, if possible, be adjusted to remove the feature.

A particular case to avoid is where a false brow tends to become evident immediately before the road enters a cutting.

(3) From examination of Ordnance maps, etc., followed by a walking reconnaissance, the key points and the general alignment of the new road, with possible variation, will be determined.

(4) The next stage is to obtain information along the general alignment as under:

- (a) Contours as 1/2,500 Ordnance Survey sheets at a suitable vertical interval (10 feet in rolling country is usually sufficient, but 5 feet is sometimes necessary, for example, in or near built-up areas). To cover contingencies, contouring over a width of $\frac{1}{2}$ mile on either side of the line (and its alternatives) should be carried out.
- (b) Correction of the Ordnance Survey sheets within say $\frac{1}{8}$ mile of the line and its alternatives. Aerial survey is the cheapest method for obtaining the information in (a) and (b) and is also the most expeditious for lengthy surveys.
- (c) Demarcation on 6-inch Ordnance Survey strip plans, over the contoured area, of areas subject to flood, with an indication of maximum flood-levels.
- (d) Delineation on 6-inch Ordnance Survey strip plans, over the contoured area, of estate and land units (farms, cemeteries, commons, Trust lands, etc.).
- (e) Preliminary soil survey, including general information regarding depth of rock, water table, etc.
- (f) Ground profile prepared from contoured Ordnance Survey sheets.

- (g) Economic gradient lines for the treatment of earthworks, having regard to (e) above.
- (h) Longitudinal sections of all roads crossing the new road (prepared from contours and such spot levels as are available).

(5) It is now possible to develop the plan line and profile, by the adjustment and readjustment of each with the other, under the limitations imposed by factors such as soil conditions, land units, balance of earthworks, etc., in accordance with the principles outlined below (7). (Minor adjustments in earthworks quantities should be effected after the finalizing of the plan and profile by modifying the slopes of embankments, or cuttings and/or daylighting where appropriate).

(6) The essence of the technique for achieving flowing alignment is to consider the new road as a problem in three dimensions. Emphasis is accordingly placed on the moulding, one with the other, of the plan and profile, since it is only in this way that the best results can be achieved. It does not necessarily follow, however, that no useful purpose is served by adjusting (i) the profile in such cases where the plan line is fixed, such as perhaps by a S. 1 (3) Order made under the 1936 Trunk Roads Act, or physical limitations imposed by the terrain; or (ii) the plan line where the profile is fixed, say, by the location of railways athwart the plan line. The adoption of the principles outline below will in such cases do much to remove the optical deficiencies otherwise likely to result.

(7) Attention was drawn in paragraph (2) to principles to be observed in considering the general alignment of the new road. In the main these principles are common to both general and flowing alignment and their observance in the early stages will greatly facilitate the development of the latter. The principles peculiar to the achievement of flowing alignment are :

- (a) The ultimate aim of flowing alignment is harmony in perspectives and it is important in all cases that the appearance of the road to users in each direction should be kept in mind. It is stressed that the effect to be attained is one of perspective, and hence an alignment which is hidden, say by a bridge or other obstruction, is not of serious consequence.
- (b) The changes in horizontal and vertical alignments should be phased to coincide wherever possible; that is, the vertical curve should extend from the commencement to the end of its corresponding horizontal curve.
- (c) The alignments referred to above may be straights, circular arcs with or without transitions, or compound curves, but flexibility can most readily be achieved by the free use of curves in preference to straights.
- (d) The case will frequently occur where it will not be possible to produce a coincidental curve for the profile without the intro-

duction of reverse curves. These are, of course, permissible but, when introduced, it is important that they should be continuous and of similar radius and length.

- (e) It is important that, subject to (a), balance be preserved throughout in the choice of radius and length of curves and that adjacent curves of greatly dissimilar radius and/or length be avoided. This will apply particularly in the case of the vertical alignment.
- (f) The choice of a particular curve at the commencement of operations may well affect the choice of the curve or curves some distance ahead, and it follows that a system of trial and error must be adopted from the outset.
- (g) Subject to (h) the road profile should not be made subordinate to profiles of structures forming part of the road. Minor hog-backs over bridges will mar the appearance of the road as seen by road users, because of the short length of curve involved, and should, therefore, be avoided.
- (h) The length of road across major structures such as large bridges and long viaducts should permit the vertical rise necessary in certain types of structure to develop the full aesthetic value of the structure in elevation. Care must be taken to see that the horizontal and vertical alignments coincide in their extent.
- (i) In those cases where the central reservation is varied in width because of the proposed construction of the two carriageways at different levels or on different plan lines, or from any other cause, the vertical alignment of each carriageway should be phased with its corresponding plan line. Any change in width on the same vertical plane should be effected on a horizontal curve and its commencement should coincide with the commencement of the curve.
- (j) Abrupt development of superelevation will introduce a visual kink in the alignment. Care should be taken that the rate of climb to full superelevation does not exceed 0.5 per cent. variation from the general gradient at the point in question.

Flowing alignment is the natural result from the phasing of curves in the horizontal and vertical alignments; it is controlled by all the various factors referred to in (5) but, nevertheless, it will be possible to make a choice from a number of variations and arrive at a result which will give the desired harmony, not only in the road itself, but also with the economic and other factors involved.