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The design and construction of concrete roads overseas †

by

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Discussion

Dr A. R. Collins, introducing the Paper, drew attention to an error in Table 1, p. 29, in the column headed "Joint spacing". In the particulars given for Germany the wording should be "Expansion joints not *more* than 160 ft with dummy joints not *more* than 33 ft between".

Mr F. N. Sparkes (Head of Technical Services Division, Road Research Laboratory, D.S.I.R.) referred to an informal international committee of engineers from several European countries which had been formed as a result of discussion at the Tenth International Congress of the Permanent International Association of Road Congresses held at Istanbul in 1956. Representatives of seven countries had got together with the idea of having a small body of people who could carry out a really detailed study of each other's practices and methods of design to compare and contrast the reasons for those designs.

159. The members of the committee did not represent their countries in any way, but were all engineers of very wide experience in both practice and research on the subject of concrete roads. A report had been prepared as a result of the examination of these detailed methods of design and it was hoped to publish it in the near future. Some of the main conclusions had been very similar to those of the Authors.

160. For instance, the thicknesses of concrete used for design purposes for given weights of traffic were similar in these seven European countries. For a particular set of conditions of soil and traffic, the design thicknesses ranged from 20 to 24 cm—a relatively small variation compared with some of the other variations in design which had become all too evident in the discussions. These thicknesses were expected to provide adequate service; but, since the members of the committee had not agreed on the expected life of the road, or on the exact nature of the traffic which was going to use the road, or, in fact, on what constituted failure, it had not been possible to arrive at a definite thickness which could be used in all conditions.

161. It had been agreed, however, that what was now wanted was information on the nature and volume of the traffic using the roads, its distribution across the road, and the nature of the permissible wheel loads used; that was where discussion had broken down in trying to reach precise agreement on the question of thickness. Mr Sparkes thought that the question of the thickness of the concrete had been about the only point on which the committee had reached any substantial measure of agreement. In almost all other respects there were large differences of opinion.

162. There was wide variation in the adopted distances between expansion joints as the Authors had pointed out, from a distance of about 35 ft in Belgium up to almost

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complete omission in Denmark. In other countries distances of the order of 150 ft and 200 ft were common.

163. Opinions had been divided on the need for reinforcement but the informal committee had found that in Britain considerably more was used than in any of the other countries; quite a number used none at all. He thought that the heavier reinforcement used in Britain obviated the need for major repairs or reconstruction after 20 or 30 years (the period at which major reconstruction was often required with unreinforced roads). It was possible, Mr Sparkes believed, to use this reinforcement to increase the length of the slab, cut down the number of expansion joints, and omit contraction joints. He felt that these reasons justified the use of more reinforcement.

164. Very large differences were found in the specified strength requirements of the concrete, and in this respect Britain did not, apparently, show up very well. The normal British minimum specified strength was of the order of 4,000 lb/sq. in. at 28 days. Most of the Continental countries used a figure of about 6,000 lb/sq. in., and in Belgium the figure was 8,300 lb/sq. in. at 56 days. It might be that the association in Britain of weaker concrete and heavier reinforcement helped to cancel out these variations.

165. The thickness of the base also varied very considerably—from zero to 80 cm.

166. These conclusions showed wide variations in many aspects of design, but the Authors had said that while concrete road design and construction differed in various countries in some important details, there were no differences in principle. So far as he could see, a comparison was possible only on thickness. Would the Authors elaborate on what they meant when they said that there were no differences in principle?

167. One of the impressions which he had received during the discussions with the foreign engineers was that there was a tendency in the United Kingdom to think that there was a best design of joint, a best quantity of reinforcement, a best spacing for expansion joints, and so on. He thought it was more likely that there were many solutions to each of these problems and that there might be many satisfactory ways of coping with them. For example, it was bitter experience in Britain that sleeper beams beneath expansion joints could cause serious trouble, but contemporary Dutch engineers would say that they had used them for the past 20 years under the heaviest traffic in Holland and that the roads had been perfectly satisfactory. Thus, differences of approach existed, but the Dutch might be right in using their sleeper beams in the conditions in which they used them, just as British engineers might be right in using dowel-bars and omitting the sleeper beams. If that point of view was accepted, it showed why the Authors had not tried to draw conclusions from the data which they had collected.

168. The question was now "What next?" A great deal of information was available, and it was in many ways conflicting. If the Authors could point to any factors which were common to all the countries it would at least be a starting-point for the further consideration of the subject, and it would help to crystallize ideas on certain aspects of design. So far as the informal international committee to which he had referred was concerned, it was proposed to give further consideration to such items as methods of construction, comparisons between roads and runways, prestressed concrete, and a few other relevant matters; but perhaps the most important thing which they would consider concerned experimental roads so far constructed in the different countries. Information on this subject was being collected for discussion, by the international committee, in May 1958 in London.

169. It seemed to be logical from this to try to co-ordinate the construction of experimental roads in these countries and for each to study a particular set of variables, but each having a common factor—a strip of road built into the experiment to a common standard. This should make comparisons possible in different countries and under different traffic and soil conditions, and perhaps provide some points of contact from which progress could be made in the future.

170. The great difficulty in trying to settle questions of design was that concrete roads normally lasted for such a long time that progress was necessarily rather slow. It might, however, be of interest in the meantime to note some of the suggestions for

future research which had arisen from the discussions of this informal committee. There was a need for much more information on the relative merits of flexible and rigid bases beneath the concrete slab, and much more information about the effects of repeated loading, especially on corners and edges. There were a number of other factors of that sort which could form the subject of future work.

Mr J. M. Fisher (Technical Adviser, John Laing & Son Ltd, London) believed that most of those present would be familiar with the provisions of Road Note No. 19, which made recommendations regarding slab thicknesses and weights of reinforcement to be used for various categories of traffic. They would also be aware of the fact that there had been issued recently an Addendum⁴³ to Road Note No. 19, which made alternative recommendations showing closer agreement with practice on the Continent. Briefly, the new recommendations reduced the length of slab between joints (whether contraction or expansion joints) and reduced the amount of reinforcement which was required. No concessions were made on the thickness of slabs. Although these revised proposals still seemed to some engineers to be conservative when compared with foreign standards, they would in large measure have the effect of reducing costs, which had been one of the main reasons for their introduction. In order to find out whether or not this conservatism was justified it would presumably be necessary to wait for 40 or 50 years, since this was the expected life-span of concrete roads.

172. In the meantime, the relative costs of concrete roads and roads in other forms of construction still showed a discrepancy which could only occasionally be compensated for by the reduced maintenance costs of concrete roads.

173. The recent behaviour of the seals of expansion joints between long concrete slabs with no intermediate joint, which had been laid in the past few years, was giving cause for concern. In many of these joints the seal had been completely broken and there was a strong risk that water would find its way through the joint to the formation, so that the consequence of this broken seal might be serious. Frequently, joints were sawn between 120-ft-long slabs; they were designed to be about 1½ in. wide and filled with a sealing compound. As the slabs closed up the joint seal assumed a rivet-shaped cross-section, which became detached from the concrete when the slabs shortened again. The result was a completely broken seal, which had been observed on a number of roads and runways.

174. The reasons for these failures seemed to be (a) the movement at the joint was too great to be accommodated by the grades of sealing compound currently used, and (b) a good bond, capable of resisting high-tensile forces at the interface between seal and concrete, could not be obtained under site conditions. A common feature of all these failures was that they had occurred in sawn joints, but whether or not there was any significance in the fact that they were sawn was not known at present. The Continental practice of using reasonably wide spacing of expansion joints and close spacing of dummy joints reduced the total movement of individual joints and made any shortcomings of the sealing compound less evident, but a form of seal which would remain completely effective over a number of years, whatever the movement of the joint, would be of great advantage and was widely sought.

175. On the subject of the riding quality of concrete roads, the figures quoted by the Authors for the riding quality of roads abroad showed the general standard of excellence which had been obtained on concrete roads, particularly in California. Whether roads of such low *q*-value as those in California showed any significantly better riding characteristics, even in badly-sprung vehicles, than those with somewhat higher *q*-values was open to question, but many engineers in Britain were, rightly or wrongly, not well disposed towards the methods by which these very low *q*-values were obtained. He believed that they would prefer to have roads of not the highest obtainable riding quality—if such methods had perforce to be accepted—but made in accordance with what they considered to be good practice.

176. Could the Authors give some information on the skidding resistance of roads finished in the manner which gave such a smooth profile?

Mr J. G. Smith (Assistant Chief Engineer, Ministry of Transport and Civil Aviation) wondered how the milages of concrete roads constructed in other countries compared with the total milages of roads in those countries. At the International Concrete Road Congress held in Rome in October 1957, some information on this point had been given to the Congress in a Paper⁴⁴ entitled "Trunk roads" by Damm, of Germany, which the Authors would recall. This showed that in the countries of Western Europe the proportion of concrete road mileage in the trunk-road and motorway system varied from 0.5% in France and Norway to 22% in Holland. Apart from Holland, Germany with 10% and Belgium with 19% were the only two countries with percentages exceeding 10.

178. A striking feature of the present Paper was the great difference in important matters of design and construction between the countries concerned. There seemed to be an almost equal division of opinion on whether or not reinforcement should be used. Furthermore, if reinforcement was used there was a variation from about 3 lb/sq. yd in the Scandinavian countries up to 8 lb/sq. yd in some American States. On the matter of joint spacing there was considerable difference of opinion as to whether or not expansion joints were required.

179. With regard to concrete strength and concrete mix designs, it would be seen from Tables 4 and 5 that the requirements for cube crushing strength varied from 4,000 lb/sq. in. in the U.S.A. to about 6,000 lb/sq. in. in Western Germany and the extraordinarily high figure of more than 8,000 lb/sq. in. in Belgium. There was also the important difference in construction practice between that in the U.S.A., where the work was based on the mobile Paver mixer, and the more general practice elsewhere of using central batching and mixing plant, with, however, the further exception of the system in Western Germany, with the bridge-type mixer running on rails.

180. In considering British practice in relation to these variations elsewhere, it seemed that, as might be expected, this country followed a middle-of-the-road course. The latest design recommendations, in Road Note No. 19 and its Addendum, seemed to be well in line with current thought in Britain. It appeared to be surprising that other countries had not adopted the British recommendation for the classification of the design according to the expected volume of commercial vehicles, which seemed to him to be a more desirable arrangement than the German system of basing it on the classification of the road type (see § 26).

181. There was one point of detail on which the Authors did not seem to have commented, namely the practice of darkening concrete surfaces. There had been some work of this kind done in Western Germany, and some of the urban expressways in the U.S.A. had darkened concrete surfaces. The main factors in its favour were the reduction of glare, amenity considerations, and the benefit of contrast between the white line markings and the marginal strips. In the United Kingdom glare would not seem to be important, but the other two factors were worthy of consideration. Had the Authors any information from their investigations as to current thought, particularly in Western Europe, on this point?

182. The United Kingdom was much too dependent on foreign-made spreading and finishing machines. There was urgent need for the fullest development of concrete-road-construction equipment by British manufacturers to secure the further progress of British concrete techniques. The transformation in the methods of flexible construction since the war had been brought about mainly by the rapid development of the manufacture of suitable plant in Britain, and this served to emphasize the leeway still to be made up in the concrete field. It was not to be expected that concrete roads would be satisfactorily developed in Britain so long as their construction depended largely on the importation of machines from the Continent.

183. As a matter of interest it might be mentioned that Dr Kunde, of Germany, in another Paper⁴⁵ to the Rome Congress on motorways in Europe, stated that when the first German motorway construction began in 1933 the provision of bitumen surfacing for a large proportion of the roads had been envisaged, but the idea had been abandoned because it would have necessitated mechanization, which had been impossible at that time with the practice of using hand-pitched bottoming. Clearly the Germans did

not regret their decision, but one wondered whether or not, if the present methods of flexible construction had been available, the same decision would have been taken. The recent announcement that the St Albans By-pass, a 12-mile length which would form part of the London-Birmingham motorway, was to be constructed in concrete, would perhaps stimulate interest among plant manufacturers, since the work would provide invaluable information on modern concrete construction techniques on one of Britain's most important motorways.

Mr B. F. J. Bradbeer (Assistant County Surveyor, East Sussex County Council) said that to the uninitiated the discussion so far might appear to suggest that there was yet no satisfactory answer to any of the problems involved. He did not think that was really the case so far as practising engineers were concerned; there were some good concrete roads in Britain and during the past 10 years pilot schemes had been carried out with official cognisance and under observation by technicians of the Road Research Laboratory, from which very interesting and helpful reports had come to hand. British engineers need not be ashamed of their efforts to keep level with the rest of the world in their ability to make good concrete roads. At one time their efforts had undoubtedly been hampered by ignorance, but the position had been very much improved of late years.

185. He noted that in the countries dealt with in the Paper there had been a total abandonment of the former iniquitous principle of the concrete raft, that purely hypothetical structure which was to bridge over all the engineer's difficulties. Now they all knew and practised the principle of preparing the bases and earthworks in such a way that they would properly support the concrete slab. It was on that basis that the latest recommendations had been made by the Road Research Board in recommending the empirical method of road slab design and it was difficult to see how that could be improved upon in present circumstances.

186. Engineers in the United Kingdom were limited in the first place by economics. Machinery and plant for building the road required a large capital investment and the availability of materials and their price also entered into the question.

187. For those engineers who had been abroad to learn all that was possible from what was being done in other countries, the Paper would answer many questions on points of detail to which it was not otherwise possible to obtain satisfactory replies.

Dr R. H. H. Kirkham (Head of Concrete Section, Road Research Laboratory, D.S.I.R.) said that in comparing the designs used it was important to try to make the comparison on the basis of performance under traffic. Germany and the U.S.A. were the two foreign countries with long-term experience of concrete roads under heavy traffic. Their designs had been modified on the basis of this experience and were generally stronger than those elsewhere. In the Scandinavian countries, on the other hand, the designs were comparatively untested.

189. It had already been stated that the greatest difference in design was concerned with reinforcement. The Authors suggested that this was affected by economic considerations, and he agreed that that was so, but he thought that it was noticeable that Germany, which had the greatest European experience of heavily trafficked roads, used reinforcement, and the Authors pointed out that in the U.S.A. reinforcement was used in areas where the densities of the population and of heavy industry were high and where the heaviest traffic might therefore be expected. For heavy traffic it was reasonable to conclude that reinforcement was necessary. The quantity of reinforcement, however, was open to argument. Although in America the quantity might be calculated from the stress in the steel and the frictional restraint of the subgrade, there was little evidence in practice of failure of the steel, and it seemed probable that the width of crack which could be tolerated was more important than the steel stress. Information about the width of cracks, apart from surface width, in concrete roads was almost non-existent, and it was not possible, therefore, to produce a design method based on the

width of cracks. This might be one of the reasons why many of the design methods used in Europe were empirical.

190. In the recent Addendum to Road Note No. 19 two designs were now given, in one of which there was relatively heavy reinforcement to reduce the number of joints to the minimum and to give a very long life free from maintenance, while the other included dummy joints so that the lightest weight of reinforcement which would give satisfactory performance could be used. The weights were those considered necessary to prevent deterioration of the cracks under heavy traffic. Some freedom to interpolate between those two designs could be permitted, but it was unlikely that intermediate designs would be used, since in most cases designs would be based on the minimum quantity of reinforcement or on the widest spacing of joints. Any theoretical design methods would therefore be very little used. For roads including dummy joints the weights of reinforcement now suggested for use in Britain were only a little heavier than those used in the U.S.A. and in Germany.

191. It was suggested in § 62 that continuously reinforced slabs had shown promise; but a study of the conclusions reached in the tests carried out in Belgium, Germany, and the U.S.A. showed that in many cases there were doubts about the long-term performance of this type of construction, and the only roads which had given satisfactory performance were those in Indiana with a weight of reinforcement of 50 lb/sq. yd. In more recently constructed continuously reinforced roads lower weights, up to 30 lb/sq. yd., had been used, but in some the condition of the cracks after a period of up to 3 years had given rise to doubts about their satisfactory long-term performance. Two roads, with slabs 3,000 ft or more long, were constructed in Britain in the summer of 1957. One had cracked with moderately closely spaced hair cracks about 12 ft apart; in the other, after 6 months, the cracks were widely spaced and tending to open. It might be expected that the performance of those two slabs might be different, and it was obviously desirable that there should be further experiments with continuously reinforced slabs, particularly in order to examine the effects on the width and spacing of the cracks of the strength and quality of the concrete, the weight of reinforcement, and the type of base.

192. It was also important that there should be some further research into the effect of the proportions of the concrete on the performance of the road. In the Paper it had been possible to compare the concrete used only on the basis of strength, but in road work there had been a tendency for engineers to become a little too strength-conscious in the past 10 years. Differences in strength were often produced with differences in mix proportions, which would have a considerable effect on the strain at which failure took place and on the creep of the concrete. The ability of the concrete to deform to accommodate small permanent deformations of the subgrade was one of its most important properties for road work, but it was not, unfortunately, possible to assess this from existing data.

193. The differences in construction technique were also interesting. It was noticeable that the two countries with the longest experience of large-scale concrete road construction used travelling mixers in preference to a central mixing plant; the use of travelling mixers would be expected to lead to better riding qualities, but there were so many differences between the procedures used that it was difficult to be certain that any particular change would result in a higher standard. There must in the same way be some doubt about whether or not the better standard of riding quality which could be claimed for American roads could be attributed only to the use of more workable concrete with a scraping straight-edge or longitudinal float. On some airfields recently constructed in Britain a concrete comparable to the American had been used. Finishing with a scraping straight-edge had resulted in an average q -value never less than 40 in/mile. If a riding quality better than this was required, careful examination of all the differences in technique would, he thought, be necessary. This emphasized again the difficulty, which he was sure that the Authors had appreciated, in drawing conclusions from a survey of practice. Their survey would, however, be most useful in suggesting the range within which controlled experiments were most desirable.

Mr C. F. Armstrong (Senior Engineer, Ministry of Transport and Civil Aviation) observed that although the Paper dealt with concrete roads overseas it was a useful exercise for those concerned with drawing up specifications for trunk roads in the United Kingdom to see whether or not the practice proposed to be followed here lined up with what was being done abroad. At first glance the most encouraging conclusion to be drawn from the Paper was that within a reasonable range of tolerance the variations between countries were so numerous that almost every aspect of practice in Britain tied in with what was being done in one country or another overseas. On closer examination it was clear that the recently-issued Ministry of Transport specification embodied many of the features regarded as representing the best overseas concrete practice. These included: concentration near the top of the slab of mesh reinforcement to control crack width; tests to be carried out on cores cut from trial slabs and elsewhere; emphasis on sawn joints; concrete as an alternative design for carriageways carried on high embankments; acceptance of two-lane slab widths; acceptance of air entrainment; and the requirement of close tolerance for surface regularity.

195. He drew attention only to what appeared to be some of the more important constructional features mentioned in the Paper which were of interest in the United Kingdom.

196. First, there was the great measure of agreement on the value of dowels in expansion and contraction joints, and the movement towards standardization of the method of prefabricating joint assemblies.

197. Next, he noted that most countries found it desirable to add a sufficient thickness of base to reach the full depth of frost penetration over frost-susceptible soils.

198. Reference was made to the extra steel used near the edges of slabs in Germany, the Scandinavian countries, and Switzerland. He had noticed this also in Austria in 1957, two mats being used over the 7½-m slab so that the closer spacing of reinforcement was automatically provided near the longitudinal joint in the slab as well as at the edges.

199. There was reference to concrete roads on high embankments (§ 80). Embankments were now to be constructed to specifications designed to guard against differential settlement, so that there was no longer justification for the view sometimes held previously, that concrete was an unstable pavement for use in such circumstances.

200. Although core-cutting was stated to be a requirement where the slab was suspect, only Belgium specified it as a regular procedure. The Ministry of Transport emphasized the value of the testing of cores and definitely required them to be cut from all trial slabs.

201. It was very surprising that no country except Great Britain surface-dressed the formation. In the uncertain climate which Britain shared with certain other European countries this was an obvious safeguard when dealing with cohesive soils, and it had been found very successful recently in experiments on the Ashford By-pass and at Alconbury Hill on the Great North Road. Nevertheless it was essential, in any case, to isolate the surface from construction traffic until further work was ready to proceed. If, in addition, contractors would provide themselves with a mobile canopy or tent, such as the Authors had described, this would protect the unrolling of the underlay, the placing of the joint assemblies, and the concreting operations. Thus these two features—surface dressing and the provision of the canopy—would in combination be a great advance towards keeping the work moving in showery weather. In Austria the canopy was a definite requirement in the specification for motorways, both for those reasons and for protection from the sun and drying winds.

202. If in America the success achieved in regard to surface regularity was due to the scraping straight-edge, was not it desirable that British engineers should seriously consider modifying mix design to enable such a method of finishing to be used? Good machine-laid flexible surfacings imparted a characteristic steadiness to a moving vehicle, and the aim should be that a passenger would not be able to tell, without looking, whether he was being driven on a concrete or on a flexible road. Even with the most recently constructed lengths of concrete road in Britain that was still not possible. Sawn joints seemed to be eliminating trouble at those places, but there was still much to

be learnt in methods of compaction, in mix design, and in finishing techniques, or perhaps in the combination of those factors.

203. The slip-form paver⁴⁶ seemed to be a promising development to reduce the cost of concrete roads. If the forms had vibrators attached to them that should enable the vertical faces of the slab to stand up even better.

204. Finally, the Paper omitted (probably because of space limitations) mention of concrete maintenance. Detailed evidence would be of particular advantage in enabling a really definite check to be made between alternative tenders for construction in rigid and flexible materials respectively. It was not sufficient to say that concrete roads generally had a low maintenance cost, without taking into account the cost of lengths which had failed or which for one reason or another had had to be surfaced.

Mr P. H. T. Gooding (Director of Information, Cement and Concrete Association) said that he had seen the concrete roads in all the six countries mentioned by the Authors and had also seen many of the concrete roads built in Britain over the past 30 years. He had found the Paper of particular interest from that point of view.

206. The bankettes in Austria, which the Authors had stated were finished with a rough concrete, had ultimately been finished with concrete setts made with white cement, which showed up very well from the traffic point of view and also gave a very effective overall appearance to the road.

207. He endorsed, from personal experience, the high praise of the Californian road surfaces. Whether driving over them in an American car or in an old English car with no shock absorbers the results were the same; it was possible to drive for miles without any shock, bump, or sway. Another impression which he had gained in America, and particularly in New York, where he had gone over the whole of the thoroughways and parkways, had been the immense capacity of the concrete road to carry heavy traffic over a very long period.

208. On the subject of embankments, wherever he had been he had tried to get information about whether or not the country which he was visiting used concrete on embankments, or what were the objections to doing so, and he had not been able to get any response whatever. The attitude adopted by some engineers in the United Kingdom was simply not understood.

209. With regard to reinforcement, his impression was, whatever might be said in the Paper, that the different countries generally were turning towards the use of reinforcement and were tending to use it more and more. Some remarks had been made about the quality of the roads in Britain compared with those abroad. He recalled that there had been a ban on the use of cement for roads which had lasted for many years after the war. When comparisons were made with the position abroad, it should be borne in mind that in the United Kingdom there had been a lack of opportunity. In spite of that he would say that the roads of East Sussex, built before the war, would stand comparison with any others anywhere else. He thought, too, that some of the airfield runways built since the war, the road at Oxtown, and Alconbury Hill, should give everyone complete confidence for the future with regard to riding qualities, general appearance, and everything else.

Mr J. M. Watson (Superintending Civil Engineer, Air Ministry) referred to the Author's comment that it was largely owing to the great quantity of concrete work which had been done on airfields during and since the war, that the techniques in Britain were up to date as compared with other countries. It was interesting to consider some of the ways in which airfield concrete-pavement techniques had diverged slightly from road practice in Britain, and he would try to give a brief account of them.

211. For the most part, airfields had used unreinforced concrete; only one complete reinforced concrete runway had been built in the past 15 years or so. It had also become airfield practice, generally, to lay a course of lean concrete as a base under the pavement slab; this was usually of a thickness of the order of 4 in. and extended under the whole of the high-quality concrete slab. That, in his opinion, had proved

to be a very wise decision. It meant that on a clay site, as soon as the excavation was completed, the working course could be laid quickly; from then on the work would be independent of the weather. Those who had worked on clay sites knew what could happen if they did not render themselves independent of the weather very quickly. The lean concrete course allowed the contractor's plant to work through the job without reducing the subgrade to a sea of glutinous material into which to pour the concrete—which had happened in earlier days when speed had been more important than quality. It also provided a load-transfer device at every joint, which was necessary in an undowelled unreinforced slab. On the other hand, sleeper beams under joints had not proved to be of the value expected, and he believed that Dutch engineers had now decided to abandon the practice of using them and intended to lay a continuous base under their roads.

212. The layer of lean concrete also allowed some slight reduction in the slab thickness. This might emphasize another difference in the approaches to airfield work and road work. For airfield construction the strength of pavements had been estimated by plate loading tests, generally increasing the test load until a corner cracked off. By repeating such a test in several places a very fair estimation of the strength of pavements had been obtained and this 4-in. lean concrete base on a heavy clay site had been found equivalent to about another 2 in. of good-quality concrete on, say, an 8-in. slab. It also had the effect that if there was a leaky joint, or if cracks developed in the slab, the base was not immediately susceptible to moisture and there was no danger of "pumping" developing.

213. The use of 20-ft lanes was another difference in the approach to airfield construction. That dimension had been determined largely by the width of the laying plant available. It had been found that 20-ft bays almost invariably cracked into 10-ft squares if the slab was less than about 10 in. thick. So 20-ft lanes were divided by contraction joints into either 20-ft-sq. bays or 10-ft-sq. bays, according to whether or not the slab was more than 10 in. thick.

214. For curing, it seemed that a slightly different approach from both European and American practices had been developed. The use of a sprayed membrane, followed by protection from excessive heat or cold, had been adopted. It was considered necessary that this spray should be applied mechanically, because application by hand lances was so haphazard that the least breeze—and there was often more than a breeze on an airfield—blew the material away. It was not possible to be sure that the spray was adequately and evenly applied unless it was mechanically fed and the nozzle was held close to the pavement. It was applied immediately after the work on the surface was complete; this was a distinct advantage over curing by wet hessian, which could not be laid on until such time as it would not mark the surface.

215. A mix with a minimum cube strength of 3,500 lb/sq. in. had been adopted; that was very similar to road practice, but in order to ensure that good riding quality could be obtained, the aggregate/cement ratio and the sand content had been specified so that the mix was a plastic one and amenable to being worked on the surface. It was clear, however, that it should not be worked by hand tools or small tools, which did more damage than good. For a tool to be really effective it had to be of the order of 10 ft in length and worked transversely. The result was that there were now lengths of up to a mile of concrete pavement in which it was not possible to find more than a $\frac{1}{16}$ -in. gap under a 10-ft straight-edge. That gave a riding quality which was of the order of that of a good machine-laid bituminous road—a very satisfactory riding quality.

216. Mr Watson did not agree that the method of specifying the riding quality by specifying the level of the forms was satisfactory. If it was specified that the forms must be true to $\frac{1}{8}$ in. in level it should be borne in mind that the forms were 10 ft long, and there could be a rise of $\frac{1}{16}$ in. or a fall of $\frac{1}{16}$ in. in every 10 ft, with a very undesirable effect. It was necessary to specify that the overall variation in level of the pavement must be within $\pm \frac{1}{8}$ in. or $\pm \frac{3}{16}$ in. of the plane shown on the drawing. If this was complied with, the requisite riding quality would be obtained. It required that the forms also be set by dumpy level as near as possible and trued up afterwards by a stretched line,

or something of that nature. The slight errors which could occur in setting by level must be corrected by means more accurate than a levelling staff, and a stretched line would do this.

217. Speaking briefly of expansion joints, Mr Watson said that he considered that the time had arrived when they could and should be generally eliminated in motorway and airfield pavement construction.

Mr P. L. Critchell (Manager, Sales Development Department, Expandite Limited) referred to the effect described by Mr Fisher and said that the gap between joint filler and concrete often continued right to the bottom of the slab. The reason was, he felt, that the large spacing between joints resulted in more movement than the jointing materials could satisfactorily accommodate. Moreover, the method of construction, employing, as it did, such large equipment for placing, spreading, and compacting the concrete, meant that the filler board had to remain rigid during construction but, as soon as the paving had been inserted, the same filler board must be readily compressible, and that, he suggested, was an impossibility.

219. With regard to the sealing compound itself, the problem was perhaps not quite so difficult to solve. In the Paper mention was made of the new cold-poured synthetic rubbers, which undoubtedly were being developed to such an extent that it appeared that considerable movement could be accommodated by these materials. The straight synthetic rubbers, however, while giving an apparently good performance, would, if maintained in an extended condition over a long period of time (during the winter, for example), slowly peel away from the joint, although under normal testing conditions in the laboratory to British Standard or Air Ministry conditions they performed with flying colours. In America, however (and he would like to have the Authors' comments on this) very much softer sealing compounds were used than in Britain. His firm was engaged in selling joint-sealing compounds to the American forces overseas and to American specifications and had quite a fair export market in America, which indicated that there were British-made materials which would do the same job that the American materials did. That led him to believe that there might be extra conditions to cope with in Britain which were in excess of American conditions. For instance, there might be more grit on roads remaining from surface dressings, and so on. The soft compounds to American specifications, being readily deformable, would naturally accept grit, and grit in the joints would undoubtedly cause spalling, which in turn would lead to poor riding quality.

220. The continuous method of construction enabled very good riding quality to be obtained with sawn joints; not only did those sawn joints lead to problems when a single saw-cut was used, as in dummy joints, but also during the sawing operation a fine slurry of cement and water was worked into the walls of the joint. That slurry was almost impossible to remove with present equipment, and it would be interesting to know whether or not appropriate equipment existed elsewhere to cope with this situation.

Mr V. H. Pontin asked if it was usual to have a sliding membrane between the base and the top surface. On airfield construction he had seen a plastic layer put between the two surfaces so that the reduction of the frictional resistance would reduce stresses set up by changes of temperature.

The following contributions were received in writing.

Mr W. J. O. Scott (Principal Scientific Officer, Road Research Laboratory, D.S.I.R.) observed that Mr Fisher had expressed doubts as to whether or not the riding surface quality of concrete roads for which the values of the irregularity index q were very low was significantly better than those characterized by somewhat higher values. By that, Mr Scott presumed, he implied those values associated with the best recent British machine-finished concrete road and runway surfaces, for which the overall mean values of q were of the order of 40–60 in/mile for major lengths of around one mile. Values of q down to less than 30 in/mile had been recorded on certain British bituminous roads (resurfaced) and runways, and Mr Scott assured Mr Fisher that their riding surface

227. In Table 11, Mr Osborne gave three examples of recent concrete roads in Britain, which, when compared with Table I, appeared to indicate that British practice was nearest to that of America.

TABLE 11

Road	Sub-base	Slab thickness: inches	Reinforcement (top only): lb/sq. yd	Joint spacing: feet
Oxton By-pass extension	5" shale	8	9.69–11.69	97–113
Reconstruction of Fosse Way	3" old tarmac on 9" unrein- forced slab	6	7	90
St Albans By-pass (to be built)	7" granular material	11	9.32	160 (winter) 240 (summer)

228. Mr Armstrong of the Ministry of Transport had mentioned that the Ministry had recently amended their specification for roadworks by improved sections on construction of sub-base, flexible surfacings, and concrete carriageways but it was of interest to note that no change had been made in clause No. 1702 or Table B for proportion of mixes, or the low minimum strength of concrete. This clause still gave no scope for concrete mix design adjustment to suit economic use of aggregates with varying grading according to localities.

229. Concrete quality must be considered a prime factor in concrete pavement design and practice and there was now a growing appreciation of the need for specified concrete compressive strength higher than 4,000 lb/sq. in. at 28 days. From Table 5 it would be seen that, ignoring Austria (4,900 lb/sq. in.), the minimum strength requirement for European concrete main roads ranged from 5,600 to 7,300 lb/sq. in. (56 days converted to 28 days). Everyone experienced in the supervision of concrete works was aware that a strength of 4,000 lb/sq. in., with a water-cement ratio of 0.55 maximum, could be regularly obtained in a 7-day test for the Ministry of Transport Class B (vibrated) concrete (4:1 to 5:0:1). It would therefore appear that a poor standard of workmanship was expected, with consequent uneconomical mix of concrete. The corresponding 28-day strength should therefore be 6,000 lb/sq. in. a more realistic figure, which compared favourably with the average of 6,450 lb/sq. in. specified above for European concrete.

230. Another factor in specifications for concrete minimum strengths, which so far as Mr Osborne was aware was now omitted, was the need for specifying the average crushing strength of works cubes which would give the required minimum figure. This important point, affecting the strength of concrete roads and essential for complete concrete control, was referred to generally in "The vibration of concrete".⁴⁸

The Authors, in reply, said they were pleased to hear their general conclusions endorsed by a number of speakers.

232. The informal committee on concrete road design had already done much useful work and the results of its activities over the next few years will be of great value to road engineers in every country.

233. Mr Sparkes had quite rightly emphasized the danger, of which the Authors had been aware when preparing the Paper, that a design detail or method of construction might be quite satisfactory in one country and a complete failure in another. It was hoped that the work of the informal committee in collecting data regarding the similarities and differences in conditions and methods of road construction employed in the different countries would help to explain these differences in results. However, some of the differences of this kind were more apparent than real and were often resolved by the

TABLE 12.—TYPICAL DESIGNS FOR ROADS CARRYING HEAVY TRAFFIC

Country	Base thickness: inches	Slab thick- ness: inches	Reinforce- ment: lb/sq. yd	Spacing of joints: feet	
				Expansion	Contraction
Britain	6	10	8½	240	80
Austria	2 + F*	9	4½	99	33
Belgium	9	9	0	33–44	0
Denmark	4 + F	8	0	0	20
			3¼	250	50
Germany	6 + F	9½	3¼	165	33
Holland	36	9	0	120	20
U.S.A., Bayshore Freeway, California	4 soil-cement + 22 granular	8	0	0	15
U.S.A., Ohio Turn- pike	6	10	5¼	0	61½
U.S.A., Pennsylvania Turnpike	6	9	4½	900	46½
U.S.A., West Virginia Turnpike	15	9	0	0	18

* F denotes a layer of frost-resistant material to bring total construction thickness to equal depth of frost penetration.

with old road systems or undeveloped countries in which the roads were mostly unsurfaced would naturally have a small percentage of concrete surfaces while those where most of the roads had been built during the present century would show higher figures. The proportion of roads now under construction by different methods formed a better basis of comparison though even here the results were much affected by factors quite unrelated to performance and cost.

241. Mr Smith had also mentioned the remark by Dr Kunde that the relative degree of mechanization had been an important factor in the original German choice of concrete for the Autobahn system. That surely was merely saying that the German engineers had done what all engineers did in choosing the most economical satisfactory method of construction. The mechanization of flexible construction methods had naturally changed this situation but it was interesting to note that most German post-war motor-road construction had been in concrete.

242. The general increase in spacing of expansion joints which had occurred in recent years had focused some attention on joint-sealing compounds. Mr Fisher had observed that some failures of materials, presumably all complying with B.S.2499, had been noted in the past few years. Improved sealing compounds with greater bonding properties and permitting larger movements were now in use in America and would probably be introduced into the United Kingdom in the near future. Mr Fisher had commented that the continental practice of using reasonably wide spacing of expansion joints and close spacing of dummy joints reduced the total movement at individual

passage of time. For example the sleeper-beams joint mentioned by Mr Sparkes was, as Mr Watson had said, now being abandoned in Holland.

234. The only point of query raised by Mr Sparkes was in the Authors' statement that there was no difference in principle between the different countries and it might be useful to explain what was meant by the statement made in the Paper. Concrete roads in all countries consisted of slabs, either reinforced or unreinforced, laid on a base and divided into lengths by joints. However, variations in the thickness of the various parts of the road, in the spacing of joints, and in the use or otherwise of reinforcement were not regarded by the Authors as differences in principle. In their view this would have required some basic difference in approach to design, for example, as in a road in which the slab was in some way fixed to the subgrade and, therefore, requiring no joints, or where it was supported by piles.

235. Mr Sparkes had also asked if the Authors could point to any common factors existing in the different countries that would act as a starting point in comparing designs and methods of construction. There were in fact quite a number which appeared reasonably readily from an inspection of the tables given in the Paper.

236. There appeared to be two main methods of designing concrete roads. The first was the empirical method, of which the German recommendations were a typical example, consisting of a ready-made precalculated code setting out designs for roads of different categories, while at the other extreme, there was the American method, in which the recommendations specified basic data and design methods from which the engineer calculated the dimensions of the road to suit the traffic intensity expected. The British method lay somewhere between, though it was perhaps a little more logical than the purely empirical method in that the road classification for design purposes was based on traffic intensity and not on its category as a highway.

237. Table 12 had been prepared to assist in a comparison of designs used in different countries. It showed the main dimensions for a road carrying heavy traffic according to each of the European codes and (since there was no equivalent standard in the U.S.A.) the same data for some typical American roads. Although the definition of heavy traffic might well vary from country to country it could be seen from Table 12 that the slab thickness did not often vary greatly from 9 in. There were, however, considerable variations in base thickness which might indicate the varying effect of frost penetration or might be the result of some basic lack of knowledge on this subject.

238. Another point of difference concerned the omission or use of expansion joints. In some countries and in some American States expansion joints were used only at the abutments of bridges; in other countries expansion joints were used at comparatively close intervals. This matter had been commented upon in the Paper and all that could perhaps be added here was that it might be that the expansion joint might be completely omitted if the contraction or dummy joints were properly made and sealed, but half-hearted attempts to reduce the number of expansion joints might lead to failure. There might in fact be no satisfactory arrangement between the two extremes of having frequent expansion joints or none at all.

239. There was also considerable variation in practice regarding reinforcement. Designers in both Europe and America seemed to be equally divided on the question of whether reinforcement should or should not be used. However this might not be a purely technical matter, for economy might well be the deciding factor. It was interesting to note that in the United States, the States in which reinforcement was normally employed were mostly those in which steel was cheap. The considerable variation in weight of reinforcement used in the different countries was more difficult to explain. It might be that the engineers in those countries using the heavier weights were more conservative or that they expected a longer life from their roads, or it might even be merely a matter of habit.

240. Mr Smith had commented on the percentage of the total road systems in various countries that were of concrete construction. Comparisons of this kind were, however very unreal for there were many factors that affected the results. For example, countries

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with old road systems or undeveloped countries in which the roads were mostly unsurfaced would naturally have a small percentage of concrete surfaces while those where most of the roads had been built during the present century would show higher figures. The proportion of roads now under construction by different methods formed a better basis of comparison though even here the results were much affected by factors quite unrelated to performance and cost.

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joints. The recently issued addendum to Road Note No. 19 gave alternative design recommendations similar to this continental practice and if these were widely adopted, as would seem certain because of the economies in reinforcement weights that followed, it would be likely that troubles with sealing compounds would in time be reduced.

243. Mr Osborne was clearly of the opinion that road concrete used in the United Kingdom which was usually specified as having a minimum compressive strength of 4,000 lb/sq. in. at 28 days, was inadequate for the purpose. Dr Kirkham on the other hand thought that there had been a tendency for road engineers to become too strength conscious in the past 10 years. Because of the empirical methods of slab design in use, it was impossible from data available to determine the effect of strength of the concrete on the performance of the road but full-scale trial roads incorporating concretes of different strengths had already been made in the United Kingdom and we would no doubt know the answer in due course.

244. Plastic membranes such as those described by Mr Pontin had been used on a trial basis on road and airfield projects in the United Kingdom. Laboratory experiments indicated that the frictional resistance between the top of the base and the underside of the slab could be reduced by interposing a layer of plastic film and that two layers of film were even more effective. The Authors did not know the extent of the application of this technique abroad but considered that properly applied it could be advantageous, although it must be remembered that any reduction in subgrade friction brought about increased movement at joints, a result that might not always be welcome.

245. Several observations had been made on the comparisons between the riding quality of concrete and bituminous surfaced roads. Mr Fisher had questioned if small differences in the values of the irregularity index q had much significance when roads such as those in California were under discussion. Mr Scott was of the opinion that a riding surface with q -value of 30 in/mile was noticeably better than one with a value of 40–60 in/mile. It was useful to have Mr Scott's confirmation of the important conclusion that in California there were extensive miles of concrete road where the riding quality was as good or better than the best surface anywhere else in the world. It followed from this that the construction methods used in California merited careful study and Mr Scott had pointed out that the most obvious differences between the technique used in California and elsewhere, was the adoption of a float finisher with a long wheel base. This machine was mechanically propelled and consisted essentially of an 8-in.-dia. roller, placed transversely, and carefully positioned adjustable hardwood floats so arranged that every part of the surface was covered many times during the four to six passes of the machine that were usually made.

246. Mr Fisher had questioned whether the use of this machine resulted in roads with low skidding resistance, but the Authors were not able to provide any data on this point. It could be presumed, however, that since the same methods of finishing had been used for a number of years, there was no criticism in California on this score. Experience and experiment in the United Kingdom had indicated that the skidding resistance of a concrete surface depended more than anything else on the choice of the correct grading of the coarse particles of sand, and the exposure of these particles to traffic was not incompatible with the achievement of a very smooth profile. The Authors wholeheartedly agreed with Dr Kirkham's warning of the danger of drawing conclusions from a survey of practice. They had, however, discussed the Californian roads with engineers who had seen them under construction and had travelled over them and it did appear that the adoption of the float finisher was largely responsible for their excellent riding quality. It should be remembered, however, that the concrete mix had to be designed around the machine and was very much more workable than the material commonly used in this country.

247. Mr Armstrong had asked whether it was not desirable that British engineers should look more closely into the scraping straight edge even if it meant modifying their mix to enable this device to be used. The Authors endorsed this view because it seemed very probable that the use of the scraping straight edge would remove the short minor irregularities of small amplitude referred to by Mr Scott as causing vibration in cars.

248. Mr Smith had mentioned the practice of darkening concrete running surfaces in Western Germany and U.S.A. In Germany, the Authors had found a very sharp division amongst highway engineers as to the value of these darkened surfaces and it was difficult to quote much in their favour. Glare was reduced but as one German engineer had put it, the need to wear sunglasses on the 45 days of the year during which the sun shines was no great hardship and was greatly offset by the safer driving conditions provided by light-coloured concrete during 365 nights of the year. If the road safety engineer had his way, it was clear that he would build light-coloured surfaces and obtain a contrast with the verges or hard shoulders by changes in texture which were more effective than colours.

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