so far as the relation of the margin to the carriageway affects the degree of elaboration of surface-water drainage.

On the country roads, the raised margin, with or without kerb, is generally accepted as current good practice, even where no footpath or other track has to be accommodated. The merits of this lay-out, as they are preached, are that traffic does not damage the margin and that surface-water is contained in the channel and can be collected without softening the margin by percolation.

The validity of the first reason is open to serious question. Some road engineers believe that a flush margin, suitably stiffened for a few feet on either side of the carriageway, should be provided as a safety zone for traffic in difficulty due to risk of collision, etc.; this principle seems to be followed as general practice in America, and in fact, where it is not provided a warning sign with the appealing wording "*soft shoulders*" is sometimes displayed.

With regard to the drainage factor, if such flush margin falls away from the road the carriageway water can be dissipated continuously throughout its length to be soaked up by the margin or, if a surplus does accumulate at the back of it, to be disposed of by a shallow spoon drain tapped at appropriate places for outfall. The fear of the softening of the margin is probably a bogey anyway and has proved to be so in the Author's own area.

The principle can be applied to well made embankments and, in the Author's experience, the water from the carriage does not mount up or accumulate at particular places to such an extent as to provide the slightest risk of damage.

The effect of such a policy is to provide considerable economy in the cost of surface-water drainage works and to give considerable relief with regard to the provision, off the highway, of elaborate outfalls, as well as a general relief to the adjacent surface-water drainage system in the shape of ditches, streams, etc.

Discussion

Mr. Floyd, in opening the Discussion, said that it was the business of a body such as the Institution to explore periodically the work that its members did. Sometimes a Paper would break new ground, whilst at other times reliance had to be placed on a certain spontaneity, and he hoped that on the present occasion spontaneous points of view would be put forward which would be useful to many members (and to himself in particular) in sorting out their ideas on a matter which many of them were finding extremely difficult. It might be said that a certain doubt about what one happened to be doing at the moment was one of the mainsprings

of progress. An attitude of satisfaction with present practice and a disinclination to be dissatisfied and critical would never lead to fresh ideas. As long as road engineers were satisfied with such road fixtures as concrete pavements, and so on, and were quite certain that they were the last word in practice, they might not make much progress and might even fail to see an obvious development.

With regard to concrete roads and his relatively mild doubts about them, many people who had read his Introductory Note seemed to think that he was rather like Saul among the prophets, in reverse. He made no apology for having theorized on concrete roads and practised their construction for 25 years, and he thought that in general his experience had been quite satisfactory; but sometimes, under a certain duress, an excuse had to be found for doing something new by criticizing common practice. His comments on concrete roads might be regarded as having been prompted by the fact that he was looking for an excuse, under duress, for constructing other types of road. It was well known that there was very little money available for road work and that the momentum of road work which had been apparent before the war had now disappeared. In his view, it would not start again for a very long time. From 1933 to about 1938, about £250,000 had been spent on improvement work on the roads of West Sussex every year, and even in those days that sum had not gone very far. The cost of road work had now increased enormously and the £250,000 was now £500,000 or more; the Ministry of Transport made grants of up to 75 per cent., but that still left the county of West Sussex to find £125,000 a year if it was to approach its pre-war momentum. That would entail a 1*s.* rate, and he did not know how long it would take to build up such an income.

Those remarks, he thought, applied to many counties other than West Sussex, and thus he had found himself looking into other trends which would possibly be forced upon the counties by circumstances over which they had no control—trends that would be the only alternative to doing so little road work of a permanent character that it would make no alteration whatever to the road system of Great Britain. He felt that it would be useful to discuss that question of a cheaper alternative, more particularly since it might be effected by the use of machinery, such as the Barber-Greene machine and others that he had mentioned in his Introductory Note.

Many of those who had built concrete roads knew that they were very durable indeed. He personally was not always satisfied with the resulting running surface, but he knew that a concrete road would last probably longer than 25 years. He was very doubtful, however, whether, even if the money were available for the purpose, anything effective could speedily be done in that direction. If it was said that the measures outlined in his Introductory Note were makeshift and transitory, his reply would be that at least they were likely to last for 10 years, by which time there might be

more time and money available. Road engineers should now be prepared to explore new methods, and he hoped that, in the ensuing Discussion, points would be made which might even be in conflict with what he had said but which would open up new possibilities.

In the Introductory Note he had made a particular point of the utility of the flush margin and the considerable economy that it effected with regard to drainage. He thought that much of the money that had been spent on elaborate drainage had been spent to no purpose.

He wished to point out that in the Introductory Note he had broached only two aspects of a very wide subject; he hoped that the meeting would understand that the Note was not intended to be exhaustive, and that members would raise a much wider variety of points which had a general bearing on the trend of road construction.

Mr H. E. Lunn said that the first things to be examined in matters such as that under discussion were the fundamentals; the fundamental in the present case was the title, " The Trend of Road Construction." Thus he had first asked himself whether Mr. Floyd was considering what road engineers had to do because they had no money, or whether he was thinking of what they ought to do because it was the proper thing to do, and he concluded, from Mr. Floyd's opening remarks, that he was looking at the problem in both ways; in other words, he had said: " I have done much concrete-road work; I am not sure that there is not a better way, but what I have done is very good," and presumably, if it had been possible, he would have gone on with that class of work. The necessary funds, however, were not now available, and road engineers must find a form of construction which would replace concrete. Mr Lunn himself was in a difficulty in that connexion, since he had no doubt whatever that concrete roads were the solution to the road problem in his county, and it would therefore take a great deal to make him depart from that form of construction. Extensive surfacing work was now being done on carriageways, with thicknesses varying from $\frac{1}{2}$ inch to 3 inches; very good riding surfaces were produced by the use of machinery, but what would those surfaces be like in 10 years time?

He was not in entire agreement with some of the statements made in the Introductory Note with regard to the deficiencies of concrete roads. He had, indeed, many very poor concrete roads in his county, but those had been built in the early days; those which had been built just prior to the last war still provided a good riding surface although none of them, of course, was less than 10 years old.

When road engineers proposed to build new roads, they should take into account the traffic that would use them, and particularly the bogey known as the " heavy indivisible load " which was inflicted upon them from time to time. That was often a tragedy to a road engineer: it had to be routed somewhere, and was often forced to use a road which was unsuitable for it, with the result that damage was done to the foundation of the road. For

that reason he thought that engineers should strive towards rigidity in their road surfaces. They could not, of course, carry out concrete-road work upon the whole mileage of their roads; no doubt the greater part of the road system of Great Britain would never require such treatment, but the roads he had mentioned required a form of strengthening which should, in his view, give additional rigidity to the road surface and the body of the road. In his own county an attempt had been made several years ago to strengthen them by grouting dry granite with cold emulsion. The result of that procedure on the weaker country roads had been so satisfactory that it had been continued ever since and, apart from certain damage that had been done during the war, the roads which had been dealt with in that way were in existence to-day. He thought that that was probably due to the fact that the material used was more rigid than tar macadam.

His remarks so far had been a statement of experience; with regard to trends, however, he hoped that some speaker in the Discussion would indicate how road engineers could enhance the strength of the weaker country roads, as distinct from the more important classified roads, by some rapid method of construction such as that which had been mentioned by Mr Floyd.

Mr F. N. Sparkes hoped that he might be forgiven if he confined himself to joining issue with Mr Floyd on the comparatively narrow subject of concrete roads, which had been much criticized in the Introductory Note.

Mr Sparkes did not agree that "there may be a common agreement that the concrete surface frequently results, after a few years, in a somewhat rough ride." If the road was well designed and constructed there was no reason why its good riding qualities should not remain for very many years (all road engineers knew of concrete roads in Great Britain up to 20 years of age which still possessed excellent riding qualities). Considerable advances had been made in both adequacy of design and quality of construction in recent years, with the result, he thought, that concrete roads would give better performance in the future than some of them had given in the past. American and German concrete motor-roads had stood up quite satisfactorily to fairly heavy traffic for 10–20 years, showing that it was quite possible to make concrete roads which would both last for a long time and possess good riding qualities.

Mr Floyd had also said in his Note: "It is questionable whether concrete construction is going to be speedy enough when large-scale road construction is recommenced." That had caused Mr Sparkes to seek comparisons. Just before the last war, German motor-roads had been laid at the rate of 600 miles a year, and British work on airfields had corresponded to about 2 miles of dual carriageway a week, whilst on the Pennsylvania Turnpike, U.S.A., 150 miles of dual carriageway had been laid in $2\frac{1}{2}$ months. It seemed to him that the speed of construction depended very largely upon the effort that was put into the work.

Mr Floyd had stated that the maintenance of joints in concrete roads was tedious and expensive. Perhaps it was at present, but could not machines be used for that class of work ? The Americans had machines for cleaning out joints and re-sealing them ; if the work were done every 3 years, the cost would be only about 1*d.* a square yard per annum, which was not unduly expensive. Mr R. M. Finch, O.B.E., M.I.C.E., had stated[1] that he " had checked the maintenance costs on two housing estates of very similar type and mileage, and had found that £18 had been spent during the past 12 years in maintaining the one with concrete roads, whereas the one with tarmac roads had cost £150 per annum to maintain." Obviously it was possible to criticize those figures, but Mr Sparkes thought that, if they made an effort, road engineers could maintain their concrete roads adequately at a relatively cheap cost.

Mr Floyd had referred in his Note to the cost of construction of new concrete roads as being very high. That was well known to be true, but Mr Sparkes suggested that the initial cost of the road should not be the sole criterion. The main consideration should be the overall cost of the road during the whole of its life, and he thought that the fact that the Germans had laid so many miles of concrete motor-road, and that the Americans had laid on their main highways 79,000 miles of concrete road, compared with 51,000 miles of bituminous road, showed that the Germans and Americans had found that the initial cost was not an overriding factor in determining whether or not to construct a concrete road.

The object of the present Discussion was to produce constructive suggestions, so he would like to indicate a way in which he thought concrete-road construction might be considerably improved in the future. There should be a still better appreciation of the relation between the concrete surface and the soil underneath. That would have a twofold effect; first, a much better performance would be obtained from the roads, and, secondly, in very many cases it would be possible to produce a road of given performance at a very much lower cost if attention was paid to the nature of the foundation or if the existing foundation was built up to give an adequate support. He thought that the latter would be done chiefly by an extended use of base courses beneath the concrete. For very many years 8 inches of reinforced concrete had been laid on 3 inches of ashes, under all manner of conditions, and he thought it hardly surprising that a certain amount of trouble had been experienced. Heavier construction was required in some cases, but a considerably cheaper form of construction would be effective in many other cases.

A further development in concrete-road construction would be, he thought, a reduction in the number of joints and an improved method of constructing them. Work was being done at the Road Research Laboratory towards those ends.

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[1] R. M. Finch and R. R. W. Grigson, " Maintenance of Roads, with Particular Reference to Mechanical Aids." I.C.E. Road Paper No. 28 (1949), p. 54.

A much better riding surface could be obtained on concrete roads if greater attention was paid to the spreading technique in front of the compacting machine and to the setting of the formwork. Formwork which was satisfactory only for light machines had been used also for very heavy machines, and he thought that that was one reason why certain concrete roads laid at the present time had unsatisfactory riding qualities.

Mr D. J. Maclean said that his main interest in the construction of roads was in their foundations, so that he could claim a certain degree of neutrality in the matter of the nature of their surfacings. He would, however, like to congratulate Mr Floyd on his courage in making the suggestion that the modern trend in road construction should be towards bitumen and tar roads, instead of the concrete roads which had been the principal form of construction for 30 years. Few engineers would disagree with Mr Floyd's statement that concrete roads had not in general given the satisfactory service which was expected from them when they were first adopted. Mr Maclean thought that it was important that the reasons for that should be clearly appreciated.

The Road Research Laboratory had made a considerable number of investigations into the causes of defects in concrete roads, and in nearly all cases the trouble had been found to be in the foundation and not in the concrete itself. That seemed to be attributable to the fact that a standard foundation of 3 inches of compacted ashes had been used, irrespective of the nature of the subsoil and the intensity of the traffic using the road. It had been found that, for a heavily trafficked concrete road constructed on a clay subsoil, a foundation of at least 8 inches of well compacted granular material was required, even where an 8-inch-thick concrete slab was used. He considered that, if more satisfactory service was to be obtained from concrete roads in the future, it would be necessary to permit more flexibility in the design in order to take proper account of the variations in subsoil and traffic conditions. That would also apply in the case of bitumen- and tar-surfaced roads, and in that connexion he was unable to agree with Mr Floyd's suggestion for an 8-inch macadam foundation for such roads. In heavily trafficked roads founded on clay subsoil it was possible that the macadam foundation under a bitumen-surfaced road would need to be greater than 16 inches in thickness. He thought, however, that many engineers would now accept the use of the California-bearing-ratio method, or other accepted methods of design, for estimating the thickness of the foundation required for such roads.

Mr Maclean thought that Mr Floyd's proposals for constructing macadam foundations mechanically merited very careful consideration. The Road Research Laboratory had recently constructed an experimental road in which crusher-run stone was placed mechanically by a Barber-Greene spreader as the foundation of a bitumen-surfaced road. It had been found that the fines tended to segregate from the coarser material and that it was preferable to use a single-size material and then to blind

with the fine material. It was too early yet to say whether that form of construction was likely to be successful, but promising results had so far been obtained.

Mr Floyd based his argument for a lighter foundation for bituminous roads on the belief that surface irregularity was caused mainly by impact forces exerted by vehicles. Such experimental information as existed on that subject suggested, however, that impact forces on most modern roads were likely rarely to exceed the static forces by more than 20 per cent.

It seemed that there were three principal causes of surface irregularity of bituminous roads :

(1) plastic deformation of the subgrade—that was, the soil foundation beneath the road ;
(2) compaction of the surfacing and foundation material by repeated static loading produced by traffic ;
(3) volume changes in clay subsoils due to seasonal variations in moisture-content.

Plastic deformation of the subgrade could be avoided by the use of a foundation of adequate stability, and, as he had already mentioned, that could be reasonably well assured by the use of one of the accepted methods of pavement design. Surface irregularity due to the compaction of the surfacing and foundation material by traffic could be largely prevented by adequate compaction during construction. Surface irregularity caused by seasonal changes in the moisture-content of clay subsoils was the most difficult condition to eradicate economically. Owing largely to two severe droughts in the past 3 years, the damage caused to roads by that effect had assumed very serious proportions, but it appeared fairly certain that, even under more normal climatic conditions, it was probably the primary cause of surface irregularity on many roads in Great Britain. It had been established that trees and hedges in close proximity to the road could cause considerable changes in the moisture-content of the soil beneath the road, and they should be regarded as contributing quite largely to surface irregularity in bituminous roads.

Mr Maclean thought that the seasonal volume change in clay subgrades was a trouble which could affect both concrete and bituminous roads, and it was probably one of the chief causes of the deterioration of the riding qualities of concrete roads, to which Mr Floyd had drawn attention in his Note.

He doubted the value of Mr Floyd's suggestion for flooding macadam foundations with a pre-mixed earth slurry, because the soil matrix between the stones would probably remain too wet to form a useful bond—in Great Britain, at any rate. The principle of obtaining a dense and stable interlocking mixture of stone, sand, and clay had, however, been applied with considerable success in other countries, notably in Scandinavia, where considerable mileages of unsurfaced roads had been laid by the use

of mixtures of the three materials in accurate proportions. In such cases the materials were pre-mixed at a central plant, a moisture-content being used that would give a dense material when the material was compacted. He felt that such methods might with advantage be more widely used than they were at present, since the operations involved were economical and comparatively simple.

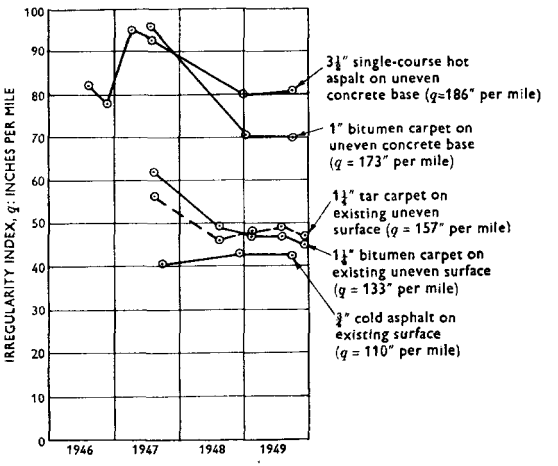
Mr Floyd had mentioned the possible use of stabilized soil for foundations; Mr Maclean considered that that form of construction, also, should be much more widely used than it was at present. In recent years a considerable area of soil cement—more than 500,000 square yards—had been successfully constructed in Great Britain; the advantages of low cost and speed which the process possessed had been very apparent.

Finally, with regard to the use of flush margins for roads, he thought that there was little doubt that softening would occur with many soils, and might possibly encourage the seasonal volume changes in the subsoil to which he had already drawn attention; but the provision of an impermeable surface to the margin might limit that form of trouble.

Mr W. J. O. Scott said that the increasing mechanization of bituminous surfacing was a prominent feature of current practice; it generally resulted in a good running surface and was frequently an economic necessity. A point in that connexion which gave rise to considerable misgiving, however, arose from the suspicion, which was not unnatural, that, where a machine-laid carpet was placed directly upon an uneven foundation or an existing uneven surface, the irregularity of the base would reappear in the course of time, at least partially, as the result of subsequent differential compaction. Some information bearing on that point, which of necessity was only recently becoming available, would therefore be of interest. The results, so far as they went, tended to refute that suspicion.

Fig. 1 showed the relations between surface irregularity and time of several typical surfacings. All the examples were normal surfacing or maintenance works, comprising a hot and a cold asphalt and a few typical carpets on various bases, most of which were distinctly uneven. It would be seen that in most cases, after a slight initial reduction of irregularity, very little change had occurred. (The slight increase in the early stages in the case of the hot asphalt was attributable to the fact that in that particular case the surface had been finished with a generous dressing of pre-coated chippings of large gauge. The fact that all the chippings did not stay in place accounted for a slight increase in irregularity in the early stages, which was not actually associated with any changes in the body of the surfacing itself.) If differential compaction occurred it seemed reasonable to presume that it was more likely to occur during the early life of a surfacing; the inference suggested by the absence of change in irregularity was that compaction was almost complete very early in the life of the surfacing—in fact, practically at the time of laying. Those results were not so numerous as he could wish, but were reassuring. As a

*Fig 1**



IRREGULARITY/TIME RELATIONSHIPS FOR MACHINE-LAID BITUMINOUS SURFACINGS

corollary they also suggested that, in cases where noticeable irregularity developed, lack of stability of the material was to be suspected rather than the reappearance of underlying irregularity. In all the cases shown, the carpets had been laid on stable bases, and, although in other cases instability of a base such as had been mentioned earlier in the Discussion might give rise to irregularity, in those the conditions had ensured that any effects of time in the surfacings were isolated.

With regard to concrete roads, he wished to refer briefly to joints in general, and to give some recent information about their effect as a contributory source of irregularity on concrete surfaces. Those results also tended, on the whole, to be reassuring.

Table 1 referred to the results obtained on a number of concrete roads, and indicated the proportion of the total irregularity which was attributable to joints. That proportion of the total length of surface which might reasonably be regarded as liable to be affected by the presence of the joints, and which would have contributed its own quota of irregularity in proportion to that found elsewhere if the joints had not been present, was shown for comparison. All the roads concerned were of post-war construction and all except one were machine-finished. The assumption that a joint might affect 12–18 inches of surface on either side of it was based on the experience gained in analysing profile-records. In several cases the proportion of irregularity due to the joints was similar to or smaller than the proportion of the length of surface affected, whilst in certain cases it was greater. In brief, joints were generally responsible for only a modest

TABLE 1.—PROPORTIONS OF TOTAL IRREGULARITY DUE TO JOINTS ON CONCRETE ROADS *

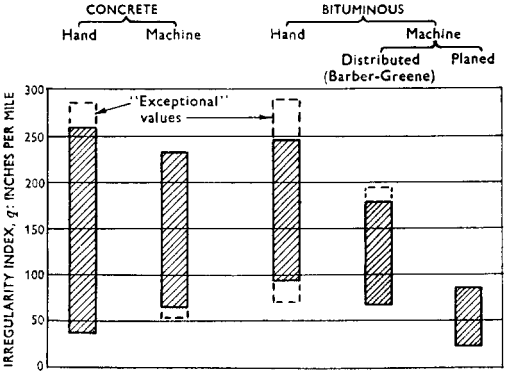
Road Ref.	Interval between joints : feet	Percentage of total length associated with joints (on basis that introduction of a joint affects 12–18 inches of surface on either side)	Percentage of total irregularity due to joints (determined from analysis of profile-records)	Index of total irregularity, q : inches per mile
B	20 (5 dummy to 1 expansion)	10–15	11	132
B	40 (2 dummy to 1 expansion)	5–7½	6·6	111
B	60	3½–5	7·5	94
B	60	3½–5	2·7	103
C	30	7–10	12	123
D	45	4½–7	18	117
E	45	4½–7	14	127
F	45	4½–7	5·9	155
G	20 (5 dummy to 1 expansion : estate road)	10–15	20	107
H	15 (hand-laid, alternate bay)	13–20	7	80

proportion of the total irregularity and in no case were they a major source of unevenness. The variability of the ratio of actual irregularity to "justifiable" irregularity certainly gave no grounds for complacency, but the proportion of satisfactory results suggested that the trend of technique was satisfactory and that, although construction in concrete had its share of problems, fear of the consequences of introducing the necessary joints need not constitute a prejudice against it. He thought it should be realized that joints in concrete roads were liable to make an exaggerated impression on the average observer. A visible impression at each successive joint as it was traversed, combined sometimes with an audible impression and added to the expectancy created by a sometimes all too obvious vista of approaching joints, could foster the belief that joints were a major or even a preponderant source of irregularity. Whilst that might have been more or less true in certain cases in the past, it was evidently not so now. A greater interval between joints naturally reduced the likelihood of their causing irregularity and, combined with the generally less obtrusive appearance of modern joints, also diminished the likelihood of an unfavourable

impression being created. These considerations were, of course, supplementary to other reasons for increasing joint spacing as far as possible.

Riding quality was, naturally enough, a frequently quoted criterion of the relative merit of different surfaces; Mr Scott felt, therefore, that it was worth while to draw attention to the very wide variations in riding quality which, in fact, were found on different examples of all the main forms of surfacing. *Fig. 2* summarized the considerable number of results that had been accumulated at the Road Research Laboratory for the main classes of surfacing, as defined by material and basic process, namely, hand- and machine-finished concrete, and hand- and machine-laid bituminous surfacing, the latter being sub-divided into Barber-Greene and planed work. With such wide ranges in almost every class and extensive overlap

*Fig 2**



SUMMARY OF IRREGULARITY DATA FOR THE PRINCIPAL CLASSES OF SURFACINGS

between classes, it was evident how individual engineers, notwithstanding very considerable experience, might be acquainted with sufficient examples of roads in the various categories to appear to justify certain conclusions which, however, turned out to be very different from the conclusions arrived at by others. The only definite conclusions that could be drawn—and even those had to be qualified as being in a broad sense—were that planed surfacings, as a class, were better than the other main classes, and that Barber-Greene-machine-laid bituminous surfacings, as a class, were better than hand-laid ones; the latter was an admissible conclusion by reason of the fact, not clear from the diagram, that most of the irregularity indices in the Barber-Greene range were below 120 inches per mile. Mr Scott suggested that, despite the unsatisfactory examples of various types which all engineers could cite, the important conclusion was that good results were possible from any class of work, except, perhaps, hand-laid bituminous work

THE INSTITUTION OF CIVIL ENGINEERS

ROAD ENGINEERING DIVISION MEETING

Tuesday, 10 January, 1950

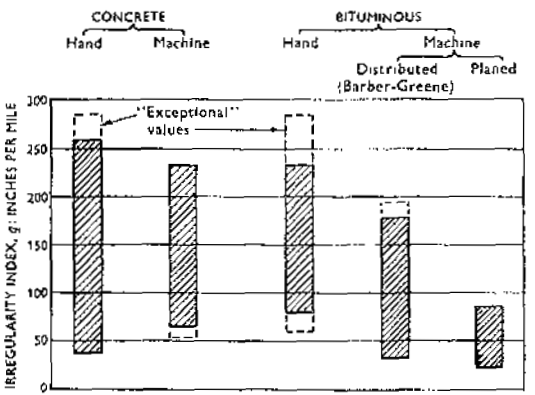
Discussion on

" The Trend of Road Construction "

CORRIGENDUM

The revised illustration shown below should be substituted for *Fig. 2*, p. 16.

*Fig. 2**



SUMMARY OF IRREGULARITY DATA FOR THE PRINCIPAL CLASSES OF SURFACINGS

which, in any case, for well known reasons, was becoming obsolescent except for minor works.

Mr J. McC. Lee said that he wished to consider the important question of dealing more expeditiously with the strengthening and maintaining of the many miles of Class III and lower-quality roads in Great Britain. In that connexion various suggestions had been made in the Introductory Note; Mr Floyd had referred, for instance, to the mechanical spreading of macadam and the use of 2-inch to 4-inch stones, and had contemplated the use of spreader boxes. Although Mr Lee himself had had no experience of using a spreader box for that purpose, it seemed to him that a spreader box was a very unwieldy instrument: it ran on skids and a considerable tractive effort was needed to draw it. He thought that the difficulty of drawing it over the rather rough formation of a road of the kind in question would probably rule it out.

Considerable thought had been given in East Sussex for some time to the problem of spreading macadam. Experiments had been conducted with various methods, and one instrument which seemed to be promising was the auto-patrol grader, which was equipped with an engine of about 90 horse-power, and had a blade, controlled from the driver's cab, that could be put into almost any desired position. That machine had been used in conjunction with a scarifier which had been built on the back of a heavy caterpillar tractor—also a powerful machine of 90 horse-power or more. The road had first been scarified with the tractor, and had then been graded with the auto-patrol grader. Experience in East Sussex with that machine had so far been fairly limited, but the indications were promising, the chief result that had been found being a saving of labour amounting to about 60 per cent. The largest of the jobs done with the machine was a length of about $\frac{1}{4}$ mile; the cost of the work on a job of that nature had been almost exactly the same as that of hand methods, but, in addition to the drastic saving in labour, there had been a considerable increase in the speed with which the work was done.

Mr Floyd had referred in his Note to a method of stabilizing macadam after it had been laid, and Mr Lee was surprised that the use of 1,000-gallon tanks of cold emulsion was not mentioned. In East Sussex those large tanks had been used and had provided a very speedy method of doing the work. Strictly speaking, however, the road should be closed while the work was being done; with a succession of tanks it was possible to deal with great lengths of road, but traffic using the road before the rolling was done and the chippings were applied had a detrimental effect on the running surface.

Chippings had been applied successfully in East Sussex by utilizing on the back of lorries exactly the same attachments as were used for gritting after normal surface dressing. Mr Lee thought that a similar type of apparatus could, with advantage, be used for the rapid and economical spreading of $2\frac{1}{4}$-inch-down stone. He believed that an attachment of that

nature would enable the material to be spread in an even layer over the road ; experiments along those lines were being made in East Sussex but had not yet progressed very far.

Mr B. F. J. Bradbeer said that he wished to deal with the trend of new construction as distinct from that of maintenance. He had wondered at first how far back to go in the study of that trend, and at a hint from the Introducer his thoughts had gone back to the older roads which had been inherited and to the people who had built them and the way in which they had been built. The work had been done, of course, largely by pick and shovel and by the hand-pitching of stones, and the haulage had been done by horse and cart. It became clear that the men concerned, working so close to the ground for so long, had acquired a high degree of individual skill in making use of local soils and rocks, which indeed they were forced to do if only by lack of long-distance transport. It was recorded about 100 years ago by Samuel Smiles that many of the men engaged on the work became highly individually skilled workers and obtained a great knowledge of " the nature of the soils and rocks, the tenacity of the clays and the porosity of certain stratifications."

As to the extent of the work on which those men were engaged, it was known that they had borne the brunt of the labour on many miles of the roads which existed to-day and that in the main their work was good. The same men turned their attention to canal building, which also called for a very conscious knowledge and technique in the handling of soils in order to make the canals watertight, and to the construction of railways, involving large earthworks and tunnels and some structures which in those days were considered daring in the extreme. As a mark of their boldness, it was recorded that, in the 25 years following the construction of the Manchester and Liverpool line in 1830, they succeeded in constructing 7,000 miles of new railway works. If that effort were translated into terms of what could be done now if opportunity offered, he suggested that it could be faced with equanimity and courage so long as those concerned did not forget " the nature of the soils and rocks, the tenacity of the clays and the porosity of certain stratifications," especially since advantage could now be taken of the modern science of soil mechanics. He thought that in the construction of new roads those points would largely determine the choice of the materials of which the roads were to be constructed. There were numerous recent cases which showed that concrete, even over 21–23 inches of macadam, was not efficacious upon certain soils. Those were perhaps extreme cases, but, in the expediency of the present time, might not road engineers again borrow from the railway builders of the past in overcoming the difficulties encountered in a large programme of road work ?

Speaking as one who had been engaged as a young man on railway work and had seen many of the very old and interesting contract documents for railway construction, he was reminded that the old railway engineers,

when they built lines involving many great cuttings and embankments, provided in their contracts for only temporary ballasting of the track, believing that in future years they might need to attend to certain parts of the line and would then add ballast as required. He suggested that that might serve as an example to road engineers of the present time, in that, in any new road construction, they might well make use of the spreader box or Barber-Greene machine or some other method for putting down a temporary running surface, which, when more funds became available, might be followed by a more durable surface, which Mr Bradbeer, after many years' experience of reinforced concrete, considered should be of that material. He was convinced that a reinforced-concrete road would have a longer life and would be cheaper to maintain than any bituminous road of the same dimensions.

Mr E. B. Hugh-Jones said that it might be of interest to the meeting if he referred to some experiments which he had seen recently and which he thought illustrated a trend to which reference had already been made in the Discussion, namely, the stabilization of soils more or less as they were found. He believed that the present trend was to stabilize whatever material occurred with tar, bitumen, cement-quarry waste, or other material, in the top 6 inches, and then to apply a macadam top with a Barber-Greene machine. He had seen some experiments originating in Africa with a binder which was completely new to him, namely, the waste from sisal or groundnuts. It was used not only for stabilizing the ground but also for building huts. About 5 per cent. of it was mixed in and then the ground was rolled and surface-dressed, producing a very good surface. The pectin from the waste was utilized, a certain amount of cement being used not as a binding agent but simply to add finely divided calcium to the pectin to make an insoluble pectate. He could not say at present whether that binder would be suitable for roads in Great Britain.

Mr J. W. Henderson said that for the past 4 years new construction had been confined largely to the unclassified road, rather than the county road or main road, on which very little work had been done.

The unclassified road, or estate road, with which he personally had been chiefly concerned recently, lent itself to considerable experiment. The building of new towns entailed the construction of up to 30 or 40 miles of new roads, spread over perhaps 20 years, and considerable experiment would be needed to determine the right type of construction for those roads. In the present Discussion that subject had been only lightly touched upon. He had experimented in the construction of a normal concrete road on 3 inches of clinker, removing the subsoil if it was unsuitable and replacing it with up to 12 inches of compacted gravel. He had also gone to the other extreme of providing a stabilized soil where he had been able to do so. The curious result was that there was very little difference in the cost between a construction consisting of 8 inches of reinforced concrete on 3–6 inches of compacted hoggin, and one consisting of stabilized hoggin or

soil, particularly in the case of a small road. On a larger road the latter method might entail a saving if the right combination of materials could be found. The similarity in cost was largely due to the fact that, in the case of the stabilized construction, there had to be some form of support on either side which the concrete construction did not require.

There had been no reference in the Discussion to the unsolved problem of stabilizing the trenches in carriageways, particularly at the construction stage. That was the greatest difficulty with which the developing engineer was faced ; if the soil was a clay, as indeed it was in the majority of large-scale development which was taking place at present, whether he adopted a concrete construction or stabilized soil he was in difficulties, since settlement would occur and the capital cost would be increased. Mr Henderson said that he mentioned that subject in the hope that there was someone present who might have had some experience of overcoming the difficulty of stabilizing trenches. He was referring not only to the shallow trench for the electricity undertaking, but also to the deep sewer trench or water trench. Was there a machine on the market which could back-fill the trenches adequately to ensure that the cost of the trench when it was filled in was the last cost ?

Mr E. H. Frankland said that Mr Floyd had referred in his Note to the influence on the trend of road construction of financial restriction ; road engineers were largely confined to dealing with roads already in existence, and he thought that the trend of road construction would be towards investigating methods of dealing with them. A considerable number of the concrete roads in Buckinghamshire could not be regarded as entirely satisfactory, and it was necessary to find some way of improving them. There were in the county some heavily trafficked concrete roads which, although they had given good service during the past 10 years, had now reached the stage when they were rapidly deteriorating. They had been treated by placing over them an adequate cushion of coating material, which would have the effect of reducing the load of the traffic on the sub-base ; it had been found from experience in Buckinghamshire that, if a concrete road deteriorated badly, the cost of breaking up the concrete and replacing it was prohibitive.

The most reasonable way to improve the existing road network was by widening out and haunching, and it seemed possible that there was scope for machinery that could very quickly produce a haunch in an existing road.

Mr M. J. Tomlinson, referring to the question of the construction of embankments, said that he thought that future trends would emphasize the superiority of the scraper type or similar tractor-drawn plant. At one time embankments had been constructed almost universally by means of the ordinary mechanical excavator, the material usually being tipped by end-tipping methods. That method had resulted in some cases of very noticeable settlement, involving maintenance of the embankment over a very long period. By the use of tractor-drawn equipment or bulldozers

for spreading the soil in very thin layers, however, it was possible to construct a high embankment with practically no settlement. A further advantage was that tractor-drawn equipment spread and compacted at the same time. His firm had constructed a high clay embankment in the Middlesbrough area, the only plant used being lorries for dumping the material and bulldozers for spreading it in thin layers. Lorries bringing in the fill material were carefully routed by means of obstructions to cover systematically the whole fill-area on their outward and return trips, in order to obtain the maximum compacting effect from their wheels. That embankment, which was about 20 feet high, had now been in existence for nearly a year, and settlement had been negligible.

A future trend should certainly be towards more care in embankment construction, particularly from the point of view of spreading and compaction.

Mr D. H. Little said that a most pressing need was for a definite method for the design of roads.

He would like to refer to some experiences in the rapid construction of naval air stations during the last war. The standard specification for the runways was 7 inches of hardcore on 3 inches of ashes, topped with tar macadam. When tested under static loading, those runways invariably gave a high standard of performance; they could withstand a heavy load simply because they had a flexible top. When a hurriedly laid concrete runway broke up, the only practical course was to lay on some tar macadam and so hide the concrete; surprisingly, the experience of runways so treated was that they gave a high standard of performance.

His Department had just completed the construction of a very large concrete runway. It was not yet in full use, but already certain people who had driven along it in cars were disappointed with the running surface. Perhaps that was due to the purely visual impression of undulations created by the joints.

He himself considered that a concrete runway was an unsatisfactory engineering proposition, since the difficulty of weakness at the edges and the corners had not yet been overcome. That weakness of edges and corners was in such marked contrast to the strength of interiors that it seemed basically unsound to use a medium of so wide a strength range—especially as edges and corners formed such a large proportion of the surface.

Mr L. R. Robertson said that he wished to make further reference to the subject of back-filling of trenches, which caused much trouble in the construction of housing-estate roads. He had not yet been able to find a complete solution to the problem, but he had adopted a procedure which had been fairly successful where the clay was at a moisture-content slightly lower than the optimum. The excavated clay lay in a windrow alongside the trench, and the workmen, on the day before back-filling, broke up the clods of clay and roughly screened the material to about $\frac{3}{4}$-inch to 1-inch size. A Proctor test was carried out on the clay, to determine the optimum moisture-content, which was generally uniform throughout the site. It

was then possible to estimate the quantity of water which should be added to render the clay most suitable for compaction. The water was poured over the pile from a watering-can and mixed in roughly. By the next morning the water had permeated the windrow and the back-filling was then carried out. The clerk of works ensured that it was done in 6-inch or 9-inch layers, thoroughly compacted with a power rammer.

With reference to another difficult problem that he had encountered, it was held by scientists that a clay formation should always be sealed off as soon as it was excavated. On a large motor road, no doubt, that procedure could be fairly easily carried out, but, on a housing estate, the excavation had to be done with a scraper, and it was necessary to excavate all the roads—a total of perhaps 20,000 square yards—almost at the same time, in order to keep the costs down; it was not possible to construct one road at a time. The problem was thus to seal off all the clay, since the surfacing could not proceed at anything like the speed of the excavation. It was not sufficient merely to cover the clay with ashes, nor, on a normal fairly small housing estate, was it possible, on financial considerations, to cover the clay immediately with rolled concrete. He had read descriptions of the prefabricated bituminous surfacing which had been used on the clay airfields and roads in Burma, but he believed that that required extensive organization, more appropriate to large motor roads than to small housing roads. Moreover, the work had to be done in small strips, so that a fairly smooth formation was necessary. He had considered the possibilities of tarpaulins, but they were too expensive to be left permanently in position. He wondered whether plastics, or possibly a very thin layer of rubber, would provide a solution. Something was needed that would exclude water and that could be put down immediately the scraper had passed, probably to become a permanent part of the formation. Once the housing construction had been completed, a very light road would suffice for the traffic which would use it thereafter. A very strong surface was required, however, for the lorries delivering materials to the houses while they were being built; such a surface could not be obtained unless the clay formation was in the hard condition in which it usually was when first excavated. If it could be kept in that condition no trouble would be experienced.

The Chairman, in summing up the Discussion, said that Mr Floyd had suggested in his Note that concrete roads had not proved to be as satisfactory as had been expected, and that a little more thought might now be given to the possibilities of the older method of flexible construction. In that he supported Mr Floyd, without for one moment admitting that concrete roads were not often very good examples of engineering work which had given sterling service. It would be ridiculous, too, to suggest that concrete would not be used for roads in the future, but he confessed to some slight feeling of disappointment with that form of construction, which he thought was shared by many road engineers.

When concrete was first used for road construction, it had been regarded as a cure for subsoil difficulties. In many cases, when a flexible sub-base had been put down on clay, the clay had been found to work up through the sub-base, and it had been thought that that difficulty could be overcome by laying concrete in the form of large slabs. Since then, those concrete roads had been subjected almost to a test to destruction: maintenance work on them had had to be abandoned for 6 war years, during which time they had had to carry the equivalent of 30–40 years' normal traffic, much of it heavier than that for which they had been designed owing to the heavy units used by the army.

Many concrete roads did well in the first years of their life but not so well thereafter, and it seemed paradoxical that a form of construction which, it was thought, would last for ever appeared to be liable to deterioration, whereas the flexible form of construction, if a good job were made of it initially, seemed to improve with time.

In the circumstances, a return might be made in suitable cases to the flexible form of construction, especially for new major roads, and road engineers would then have to consider what was the best way to put down a flexible road. One possibility seemed to be to lay a flexible top by Barber-Greene machine and the flexible base with some other form of machine which need not be so complicated as the Barber-Greene. He had done that himself on a small scale, and there was no doubt about its success: if the work were properly designed the method would be satisfactory. Whether it could be carried out as quickly and as cheaply as construction in concrete was a matter that manufacturers might look into, for it was a production problem.

The Chairman confessed to some feeling of doubt whether, when a thin surfacing was provided, it was wise to use a porous material which allowed water to penetrate directly into a new foundation. Perhaps there should be a retrogressive trend towards the use of a waterproof wearing course for roads.

*** **Mr T. U. Wilson** observed that the trend of road construction seemed to be largely influenced by national economics and by the development of mechanization both of the vehicles using the roads and of the machines available for road construction. In the present circumstances, restrictions were necessarily imposed both on finances and on the use of certain commodities, such as cement, for road construction. Consequently improvisations were made and recourse was had to the use of local and natural materials. Similarly, the shortage and cost of manual labour induced an increasing measure of employment of mechanical aids. It was possible that the combination of these factors might in no small measure direct the trend of future road-construction methods in Great Britain.

*** Mr Wilson was unable to attend, and submitted this contribution in writing on the day of the meeting.—Sec. I.C.E.

Primarily it should be recognized that, whatever type of road surfacing was adopted, the provision of an adequate and stable foundation was essential. Recent research and progress in soil mechanics had provided modern scientific methods of compaction of the subgrade and, coupled with the advance of soil-stabilization methods, led to a greater degree of uniform foundation strength, which might tend to revolutionize future types of superimposed construction. Road foundations of hand-set stone pitching, after the Telford pattern, had been generally displaced by mechanization and the difficulty of obtaining skilled labour for the work. In addition, shortage of manual labour and the mechanization of quarries prevented the selection of stones of the requisite sizes before primary crushing.

A well made concrete road on a stable foundation had the advantage of providing good riding qualities, as compared with other forms of construction, and might in the future be relegated to act as a foundation to other types of surfacing. Apart from present restrictions in the use of cement and the problem of efficient compaction of the sub-base, a decision to adopt concrete roads was prejudiced by other factors, such as probable future damage by service openings and reinstatements, mineral subsidence, frost action, and the slipperiness of the surface under adverse weather conditions. Nevertheless, concrete roads lent themselves to mechanical methods of construction, as instanced by the German *Autobahn* construction, especially where an entirely new road was being constructed with a uniform width of carriageway.

Hardcore foundations, with or without binder element, had largely replaced hand-set pitching since the advent of the mechanization of quarries and methods of laying. It seemed likely that that form of foundation construction would be developed, particularly for the widening and strengthening of existing roads, since it utilized local natural resources.

It might well be that the efforts of road engineers would, for some time to come, be confined largely to the improvement of the running surfaces of the existing road system, to the exclusion of entirely new road construction, so that the trend of road construction would require to develop in the direction of improved and economical running surfaces and lasting non-skid properties, having regard to such problems as the oxidation of tars and bitumens under atmospheric conditions. In that respect, further development was urgently required in the shape of more modern methods in surface dressing works, especially in conditions of inclement weather and intense traffic. This trend of development might take the form of a substitute for tars and bitumens, using other industrial by-products to provide natural stone-coloured roads instead of the traditional black.

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