

## Discussion.

Dr. Stradling. DR. STRADLING, in exhibiting some lantern-slides illustrating the Paper, said that in submitting it the Authors had taken advantage of the invitation extended to them by The Institution to bring forward for discussion investigations which were still unfinished. The Authors were anxious to bring the work to the notice of The Institution because they felt that the next step must be taken by practical engineers, and they hoped to induce engineers who were concerned with road-problems to utilize the apparatus which was now available for them. They therefore wished to make that apparatus as widely known as possible. It was practical, easily handled, and simple to understand, and it should be of very great service to the road-engineer. There was, however, little more work that the Road Research Laboratory could do on it until its use could be extended over a wider field ; they would like to persuade engineers throughout the country to adopt it.

Referring to *Fig. 3*, he mentioned that the road whose properties were represented by curve (3), which was labelled "Bad," had previously been the subject of complaints, and had to be put right. Roads of that type were fairly rare, most roads giving results coming between curve (2) and curve (1).

With regard to Table II, it would be observed that the sideways-force coefficients were found to be lower in summer, when the tests were made during showers, than in winter, when the roads had more continuous washing by rain.

Referring to the discussion in the Paper of the relative merits of the "sandpaper" and the rougher types of finish, he suggested that in that connection the practical experience of road-engineers would be of great value. If, as the work described in the Paper appeared to indicate, the liquid film on the surface of the road was the cause of slipperiness, then it would appear that with a given amount of film the chances of getting solid friction were very much higher with a rough surface of, say,  $\frac{3}{4}$ -inch chippings than if the film were spread over a relatively smooth surface. It could not be assumed, however, that that would necessarily be the case. Since the date on which the Paper was originally to have been presented,<sup>1</sup> his colleagues in the Ministry had shown him a road which had a surface of  $\frac{3}{4}$ -inch chippings, and yet had a poorer sideways-force coefficient, as

<sup>1</sup> 21 January, 1936.

measured by the machine described in the Paper, than other roads Dr. Stradling. which, judged by the eye, seemed very much smoother. On looking into the matter, the trouble appeared to be due to the fact that the actual chippings themselves were smooth and flat, so that the surface gave the impression of consisting of a miniature series of cobblestones. It seemed therefore impossible to lay down any definite general rules for the attainment of a non-skid surface, but he thought that the chance of non-interference by a lubricating film must be relatively higher with a very rough surface, provided that the chippings were of suitable shape.

He would like to emphasize that any county or city engineers who adopted the machine could rest assured that every assistance would be given to them by the Road Research Laboratory.

Mr. BIRD exhibited and explained two cinematograph films illustrating the testing-apparatus in use. Mr. Bird.

Mr. F. C. COOK remarked that those who had been concerned with road administration for a long period would well remember the time when the dust nuisance was the chief problem. As so often happened, the solution of that problem had introduced another, and it was the necessity of measuring the slipperiness of various road-surfaces, following on the application of impervious, smooth surface coats, which led the Ministry of Transport to approach the National Physical Laboratory about 8 years ago and ask them to design the machine which was described in the Paper. He was told that in 1930 Messrs. Bradley and Allen had expressed their willingness to present a Paper describing that machine to The Institution, but the Paper was not in fact presented, presumably because at that time it was thought that the subject was not of sufficient general interest. It was a welcome indication of the change of outlook and of the appreciation of the fact that scientific principles should be brought to the solution of road problems that the present discussion was taking place. The first machine was used with success over a period of some years, that success being largely due to the skill of Mr. Bird. The results which the machine gave were singularly in accord with practical experience of road-conditions.

He would like to stress the Authors' suggestion that a machine of the type in question ought to be regarded as a normal item of the plant of, at any rate, the larger highway-authorities. The Paper mentioned several respects in which such a machine would be useful to them, but there was another to which reference might be made, namely, that it would enable a road-engineer to rebut, if necessary, with some degree of certitude the statements, often misleading, which were made concerning the alleged slipperiness of a particular road, often as the result of observation which was prejudiced or misleading.

Mr. Cook

It would also enable the road-engineer to obtain a really accurate picture, based on scientific data, of the extent of the problem of road-slipperiness in the area for which he was responsible.

With regard to the extent of the problem, two years ago the Ministry of Transport conducted investigations into all cases where road-conditions were alleged to have been the cause of fatal accidents. In the year in question there were 6,942 fatal accidents, and of those 149 were alleged to be due to skidding. All those 149 cases were investigated by the divisional road-engineers of the Ministry, and it was shown that in 82 of them the diagnosis might be regarded as correct, so that 1.3 per cent. of the total number of fatal accidents in that year could definitely be attributed to skidding caused by the road-surface. He mentioned those figures with some reserve ; firstly, because they might be thought to lead to some degree of complacency in the minds of road-engineers, which was not in fact the case ; and, secondly, because the dividing line between a fatal and a non-fatal accident was very fine indeed, and might be considered to depend either on the interposition of a merciful providence or the skill or good fortune of the individual concerned.

It was perhaps true to say that in no aspect of road-engineering had a greater advance been made in recent years than in the provision of a non-skid surface. In the early days of water-bound roads coated with an impermeable smooth surface there were many complaints of slippery conditions, and in 1929, after consulting many highway-engineers, the Minister of Transport issued a circular in which it was suggested that use should be made of larger-grade chippings than had previously been the case. On the whole, the results were excellent, and he thought it would be agreed that there had been a very marked improvement in the technique of surface-dressing, certainly within the last 5 or 6 years. An extended life had been obtained, and surface-dressing was no longer regarded as an annual process ; a life of 2 or 3 years or even more was now obtainable. Further, the area of road-surface dressed in each year was becoming less and less, owing to the method which was now being adopted of securing a non-skid surface by the application of a thin surface-coat, possessing an inherent non-skid property of its own, which would remain non-skid for a considerable number of years. The Ministry of Transport, with the co-operation of highway authorities, had laid no fewer than forty sections of roads of that character in different parts of the country, formed of thirty different materials. There had been occasional failures, but on the whole the results were extremely promising. It had to be remembered that, besides bad road-surfaces, there were other factors which tended to induce skidding. Those factors included the

alignment, grading, and particularly the camber of the road, the Mr. Cook. design of the vehicle, the type and condition of the tire, the characteristics of the driver, and the effect of the conduct of other road-users upon his actions.

Although great advances had been made in the production of reasonably non-skid surfaces, the root cause of road-slipperiness had yet to be determined. The Paper indicated that the presence of a lubricating film was undoubtedly the principal agent in that respect, but its composition and source had yet to be discovered. If it were due to exudation of the binder, what were the characteristics which caused it, and how could they be eliminated? If external sources were responsible, was the film due to the deposition of soot or of dust, to attrition of the road-surface, or to attrition of the tire? The engineer could not determine such questions for himself; they were essentially matters for laboratory investigation, and Dr. Stradling was now carrying out at the Road Research Laboratory investigations which should be very helpful in those directions.

Further progress in the production of safe road-surfaces was largely in the hands of road-engineers and of manufacturers of road-material, and he could not express too strongly the gratitude of the Ministry of Transport and of the Road Research Board for the whole-hearted co-operation which they had afforded in dealing with the problem in question.

Mr. T. PEIRSON FRANK remarked that the Paper stated:—"A Mr. Frank. measuring instrument, however, can at the best only give a numerical value." He would submit that the machine could do a little more than that, and thought that the words "fair comparative" might be added, so that the sentence would imply that the machine in question could "give a fair comparative numerical value." He suggested that the machine enabled an engineer not only to compare one section of a road with another, probably under somewhat similar climatic conditions when the lengths were near together, but also to compare the same section of road at different times during an extended period, so that it should be even more useful than might be gathered from the introductory portion of the Paper.

The Authors stated that the ideal road-surface would have characteristics similar to those shown by curve No. 1 of *Fig. 3*, and added, "but road-engineers require to know how far they can let an otherwise satisfactory surface deteriorate". He thought the Authors would agree that the deterioration referred to was not disintegration but deterioration from the point of view of skidding tendencies, due probably in many instances to temperature-changes, sometimes called hardening-out or rolling-out of the road-surface. He wondered whether some of the excellent surfaces in the Highlands of Scotland

Mr. Frank.

were not due in some measure to the fact that they were not subjected to extremes of temperature such as were experienced in the south of England. He believed that the British Standard Specification permitted the use of varying percentages of bitumen so as to suit different climatic conditions. When he had been located at Plymouth, he had had a number of experiments made to try to get as safe a bituminous mixture as was conveniently possible according to the temperatures there prevailing.

He believed that he was right in saying that the particular road referred to on p. 450 as giving a very low sideways-force coefficient was by no means in common use, and that the same remark applied to the old compressed rock-asphalt surface mentioned in Table II. He thought that such low coefficients could almost be disregarded so far as present-day practice was concerned. It would appear that the fifth surface mentioned in Table II would come first and the fourth would come second as to quality. He would like to suggest that tests should be made on bare and on treated wood paving.

He understood from Dr. Stradling's remarks that the sideways-force coefficient would be lowest immediately after a slight shower which had followed a long spell of fine weather. That being so, he suggested that motor-vehicle designers should make arrangements to collect some of their "trade wastes"—oil, carbon, and other products discharged from the exhaust.

The last part of the Paper mentioned the importance of the siting and planning of roads. Roads were usually constructed with a camber, which did not provide the safest and most satisfactory surface upon which vehicles could travel. On such a cambered road it was sometimes inconvenient to drive near to the curb, particularly on the outside of a bend, when the tendency to side-slip was increased, and the object of the driver in general was to travel on the crown of the road. It might be safer, and probably more economical, if new arterial roads were laid out so that the vehicle was always travelling on a suitable cross-fall, and not on a barrelled road-surface. The cost of drainage-systems might be reduced, and driving, especially at night, would be made a little more comfortable and convenient if that type of road were more generally adopted.

Mr. Bailey.

Mr. T. H. BAILEY remarked that the selection of the best materials for road-construction and repairs, and especially for non-skid carpeting, was of great importance. In recent years many products, claimed to be non-skid, had been put on the market. The binding materials for those preparations were in many cases similar, but the success of the non-skid carpet depended much more on the quality of the aggregate used. It was essential that the stone should be of a high crushing strength and of a coarse-grained fracture. In many

cases the stone used was of a low crushing strength and not of a Mr. Bailey. coarse-grained fracture; in time such stone became pulverized under the weight of the traffic, and eventually formed a smooth, treacherous surface which also often became greasy. If the carpet used was of a fine-grained fracture, the stone became polished under traffic and tended to become slippery. Dolerite-olivine granite was a satisfactory stone for the purpose; typical samples had a crushing-strength of 14.6 tons per square inch, and the grain of the stone was coarse. The grading of the aggregate should be regulated according to the conditions which it had to fulfil. For re-surfacing roads which had become slippery owing to the poor quality of the materials with which they had originally been laid, a coat of carpeting composed of aggregate ranging from  $\frac{3}{4}$ -inch down to  $\frac{1}{8}$ -inch chippings, with a certain amount of dust introduced as filler, had been found to be satisfactory, and to retain its non-skid properties after years of traffic. For the reconstruction of worn roads a carpet approximately  $1\frac{1}{2}$  inch thick, composed of  $1\frac{1}{4}$ -inch to  $\frac{1}{8}$ -inch aggregate, with the requisite quantity of dust introduced as a filler, had given excellent results. The roads had remained non-skid for motor traffic, horses and cattle, and it had not been necessary to tar-spray them since they had been laid. A point which was often overlooked with regard to non-skid carpeting was the colour of the aggregate used. If it was of a dark colour, the road-surface always remained dark, which was detrimental to night-driving. A carpeting laid with the stone to which he had referred, after being subjected to traffic for approximately 6 months, assumed the original grey-green colour of the granite, and that fact considerably added to the safety of night driving.

Mr. W. J. HADFIELD expressed his appreciation of the way in Mr. Hadfield. which Dr. Stradling had brought about collaboration between the practical engineer and the scientist.

Referring to the subject of road-accidents, Mr. Hadfield was very glad that attention had been drawn to the small proportion of road-accidents attended with fatal results which took place owing to defects in the road-surface; that was, however, no reason why endeavours to obtain a safe road-surface should be relaxed. The causes of accidents should be removed, and the road should be absolutely safe.

The machine described in the Paper enabled the engineer to measure the slipperiness of a road-surface in definite units. Through the kindness of Dr. Stradling, the machine had been sent to Sheffield for a time, and Mr. Hadfield, speaking as a practical man who had an idea of the condition of his roads, said that the tests made with the machine had confirmed his own views on the roads tested; in

Mr. Hadfield. consequence, he had a good deal of confidence in the machine. What he was afraid of, however, was that if a standard of safety expressed as the sideways-force coefficient were set up, it might prove to be a two-edged sword, and engineers might one day find themselves asked questions in court about the machine and whether the safety-point had been reached. At the present moment no safety-point had been specified, but by the time the machine was in common use such a point would have been laid down.

A great deal depended not only on the construction of the road and on its condition from a structural point of view, but also on its condition from the point of view of cleanliness. It would be possible, as the Authors had said, to have a road which, when clean, was quite safe, but when dirty was far from safe. He had never regarded cleansing as being a very interesting branch of road-work, but it was very important, and, where a good road existed, it was the engineer's business to keep it clean; that was a condition of road-safety which was not sufficiently considered.

Professor  
Clements.

Professor R. G. H. CLEMENTS remarked that although the percentage of accidents which could fairly be attributed to the condition of the road-surface at the time was now so low as 1.3, that did not absolve the engineer from dealing with the serious problem, which fortunately he always did keep before him, of making all efforts to reduce that percentage still further. The significant feature of the Paper was that a number was now available which could be arrived at in a certain manner, had a definite scientific quality, and did in fact give a close index of the actual surface-condition of the road at the time and under the conditions of the test. He was a little sorry that no attempt had been made, on the basis of the numbers obtained, to classify road-surfaces into groups for the guidance of road-engineers. There appeared to be three clear types: (1) those in which the sideways-force coefficient was high, slightly smaller than 1, whether the surface were wet or dry; (2) those in which the coefficient was high when the road-surface was dry, but fell to a dangerously low value when the surface was lubricated; (3) those, possibly a very small group, in which the surface whether wet or dry had low coefficients. It would be helpful for future surface-construction if some guidance could be given in regard to those three conditions. It was by the engineer attacking those conditions which he knew to be defective, and ascertaining the precise nature of the fault or defect, that information could best be provided and progress made.

It was stated in the Paper that the maximum speed at which tests had been made was approximately 30 miles per hour, which was the safe limiting condition of the present machine. The extension of

the measurement of the sideways-force coefficient to higher speeds was, he thought, of great importance, because it was at those higher speeds that the most critical condition arose. Professor Clements.

One part of the Paper was of special importance, as it opened up a parallel line of investigation, namely, that envisaged by the work of Dr. Saal. The alteration from the dry surface which was safe and gave a high coefficient to the wet surface which gave a low coefficient was due simply to the interposition of a third medium, the lubricating film. The laboratory determination of the characteristics of the film which was interposed between the wheel and the surface of the road was probably a most fruitful line of investigation, together with the measurement or approximation of the quality and the nature of the roughness of the road-surface at a given time with a measurement, if possible, of texture itself. With that there was bound up the film tension of the liquid or lubricating medium, in relation to the surface-tension of the stone or composite material forming the road-crust. The investigation called for by the Authors, namely, the extended use of their piece of scientific apparatus and the analysis of the data which could be obtained by its use under actual service conditions throughout the country, should be paralleled by supplementary investigation of the scientific conditions which arose at the interface between the wheel and the road.

Mr. W. P. ROBINSON, considering the matter from a severely Mr. Robinson. practical point of view, ventured to suggest that the Treasury should at the outset purchase five machines, one to be placed in each of the five highway-divisions of the country and to be available for hiring out by the highway-authorities at a daily rental. He was afraid it would be very difficult for the highway-engineers to persuade their authorities to provide separate machines for their own use, when possibly during the summer there would be no skidding tests to be done. He had been driving vehicles for 40 years, and had had only two skids during the whole of that time, one of which was on a snow-bound road and the other on an ice-bound road; he did not think the problem of skidding was so important as the problem of being able to measure when a road was due for repair. Skidding was probably partly due to the want of repair, and if a method could be developed to determine when a road required resurfacing or repair he thought the problem of skidding would automatically be dealt with.

The Authors had referred to the argument regarding the merits of a "sandpaper" finish and a rough surface. It was suggested that when a film was formed there was more liability to skid on a smooth surface, but did it follow that a rough surface would get rid of that film? Some engineers found that a rough surface provided a

Mr. Robinson. receptacle for water, grease, and so on, and thus increased the liability to skid. There were points on both sides, and practical engineers looked to scientists to use the measuring instrument which had been provided to find out the facts, and thence to deduce what was the best type of surface from the point of view of durability and of reduced liability to give rise to skidding.

Mr. Marriott. Mr. T. G. MARRIOTT said that in his opinion the particular aspect of the road problem which was under discussion had its origin about 20 years ago. At that time road-manufacturers, of whom he was one, were troubled with corrugation, which arose from the following cause. The roads of the country were passing from waterbound macadam to the bituminous surface; in the process of transition mixtures of insufficient stability were used, and surfaces were imposed on foundations which were insufficient, so that the chief difficulty met with was foundation-weakness and corrugation. He mentioned that because he thought that the various road problems were complementary. The difficulty with regard to foundations was quickly removed by the developments in the use of concrete, but the problem of corrugation had then to be faced owing to the rapid transformation from the water-bound to the bituminous type of road. There was such anxiety to avoid disintegration that too much bituminous matter was put into the surface, and that caused the corrugation. At that period there still remained a large volume of horse-drawn steel-tired slow traffic, and the transition between the two types of traffic created a problem which had not yet been finally solved, because there still remained large areas of old-fashioned pavings put down at the period to which he referred which were not yet worn out, but had given rise to the problem of slipperiness.

There were two schools of thought with regard to the prevention of slipperiness, those who advocated the "sandpaper" finish and those who advocated the rough-textured surface. The leading advocate of the "sandpaper" finish was Professor R. A. Moyer, but unfortunately Professor Moyer's data were based entirely on American experience. Mr. Marriott knew something about the conditions in America. In the winter months in any of the big cities of America rain might fall on 20 consecutive days, but the pavements never failed to dry out each day. The problem in England was different; the pavements in London often remained wet for long periods, while in Glasgow they hardly ever dried out from October until March or April. As the dry atmosphere in America caused the pavements to dry out so quickly, Professor Moyer thought that with modern high-speed high-braking-power vehicles a smooth surface was satisfactory. So far at any rate as

Great Britain was concerned, Mr. Marriott disagreed with that view, Mr. Marriott, because of the difficulties caused by the moisture film, which in London was accompanied by soot and was therefore particularly effective as a lubricant. In view of the filth which fell on the London streets a smooth surface was most dangerous for modern high-speed traffic. He thought that by following the British Standard Specifications for bituminous work the new roads would be found to be reasonably satisfactory. In view of that, and with the aid of the Ministry of Transport, he believed that the problem of the old-fashioned smooth type of pavement was being coped with gradually but effectively. As Mr. Cook had indicated, a system was slowly being evolved by which it would be possible to superimpose on any type of surface a pavement so graded that with reasonable conditions of climate and traffic it would afford a satisfactory tire-grip for vehicles.

Mr. H. V. OVERFIELD said that he believed that most skidding was Mr. Overfield, due to careless driving. Roads should be made as foolproof as possible, but reasonable care was to be expected from drivers. He imagined that wet wood-blocks and compressed asphalt, especially in industrial towns and on damp and foggy days, provided probably the most slippery surfaces, but even those surfaces were not quite so bad after a heavy fall of rain.

The results given in the Paper of the road-tests under wet conditions were of the kind that might have been expected, but it would be of interest if the Authors would say whether the roads under test were merely damp or whether they had been washed by heavy rain. He thought that before figures were taken as enabling the value of one surface to be compared with that of another, the road under test should be perfectly true; otherwise the effects of impact might upset the frictional resistance. The results obtained under dry conditions were very surprising, in that the sideways-force coefficients were so very high for all normal clean surfaces. If those figures were the only standard by which the road-surfaces were to be judged, some cherished theories would probably be upset. He did not think, however, that the Authors would claim that those figures did constitute the final standard. For example, he had heard it whispered that one of the roads that gave very good results broke up soon after the test. As an instance of that upsetting of theories, the advantages claimed for lake asphalt (which contained mineral matter in its native state) over the residual bitumens in asphalt cements, and for the so-called "sandpaper" finishes of the fine asphalt toppings which were admittedly giving very excellent results, would be of no effect. He himself still thought that both those materials were preferable to many others in road-surfaces.

Mr. Overfield.

The decrease of the coefficient as the speed increased was important, and it was possible that that was partly due to the rapid variations in pressure and contact between the tire and the road. The pneumatic tire was subject to so many unknown conditions at high speed that he wondered whether the Authors would consider it worth while to make tests with an iron tire or a stiff solid rubber tire. At first sight it might seem a waste of time even to suggest working with iron tires, when their use on the roads was rapidly coming to an end, but he had discussed the point with many horse-owners, and it was claimed quite seriously that horses shod with iron shoes travelled better and more surely on wet roads. The horse-owners also preferred the "sandpaper" finish, possibly because the surface was rather softer than that of many of the harder asphalts. They certainly disliked the hard polished surface in worn granite-dressed roads, and much preferred gravel or quartzite coverings, which were relatively friable. Another curious fact which might be mentioned was that road-rollers with steel wheels had a much better grip than those with cast-iron wheels. With horses and road-rollers, however, the iron or steel came into contact with the road at very low speeds, and perhaps even the suggestions of the horse-owners were not inconsistent with the figures in Table II, where the coefficients were still quite high at a speed of 5 miles per hour.

With regard to the question of surface-texture, he thought it was admitted that a high degree of frictional resistance was required, but it should not be obtained at the expense of other requirements of the road, and that was where the judgement of the practical man was required. The surface should be as smooth as possible for cleanliness and low tractive resistance. Both were fundamental requirements, and a balance had to be struck between the roughness required for frictional resistance and the smoothness which was desirable for cleanliness, especially in towns. Clean road-surfaces were required to reduce the effects of lubricating films, but during rainfall on very flat roads water would form thick films. Good drainage of the surface was necessary, and that called for sufficient but not excessive cross-fall. In that connection attention might be called to certain new road-paving systems where parts of the surface of the blocks stood above the rest. For example, the road in the Mersey tunnel had a surface formed of cast-iron blocks with diamond-shaped projections. From such a surface water would drain away in the grooves, leaving the projections almost dry, and that might help to prevent the formation of film. Personally, he thought it inconceivable that a pneumatic tire could skid on such a surface, because the diamond-shaped projections were forced into the rubber and formed a mechanical bond. An attempt had been made to

attain the same result by making blocks of a fairly hard asphalt with Mr. Overfield. a grooved pattern on the surface. Roads made with those blocks dried very quickly, and even during rainfall the surface remained fairly free of water. He had been told by those who had charge of such roads that they remained very clean under all conditions, but he was not prepared to say that they were practicable for extensive use, on account of their cost.

Skidding was probably due more often to the defective layout of roads than to defects in the surface-texture. Excessive camber and sudden changes in the curvature gave rise to large unbalanced lateral forces. Many curves were deceptive, and an inattentive driver might find himself travelling too fast when he reached the curve. The research work described in the Paper might, he thought, be supplemented by a detailed examination of conditions on curves, and he would suggest that the experimental machine described by the Authors should be fitted with accelerometers, by means of which the centrifugal forces could be recorded, together with the sideways-resistance coefficients. He thought that if the reconstruction of the roads were accelerated and carried out on proper engineering lines, the problem of the slippery road would be solved.

Mr. F. G. TURNER remarked that his daily work brought him very Mr. Turner. much in contact with the Authors, as the great majority of the tests which had been done by them and their staff with the machine described in the Paper had been carried out at his request. It had therefore been agreed that he should wait until the end of the discussion and should then deal with any questions which had been raised with regard to any of the roads referred to in the Paper. Very few points of that kind had been made, but Mr. Frank had referred to the road which was described on p. 450 as being very slippery. That was a road which had been brought to notice as being slippery, and immediately afterwards it was treated and made safe; it was of a special new type of construction which proved unsatisfactory, failure being largely due to unsuitable weather-conditions during construction. The suggestion had been made in the discussion that wood blocks should be tested. The figures given in the Paper referred only to typical examples of roads, and a number of tests had been made on wood blocks.

Mr. Overfield had asked whether the tests were made on roads that were damp or on roads that had been washed by heavy rain. That naturally depended on the circumstances; the machine had to be sent from its headquarters to the road where the test was to be made. Whenever possible the machine would get to the road soon after the rain had started, and in that case the road would only be damp; but occasionally the rain had been heavy enough to wash

Mr. Turner.

the road, and then that factor was noted and allowed for when the results were considered. Mr. Overfield had referred to a rumour that one of the roads that gave very good results had broken up soon after the test ; Mr. Turner had not heard of that rumour.

While the Paper was being read he had heard someone whisper, " Why a smooth tire ? " It might be helpful, therefore, to refer to the way in which he had always regarded the matter. The coefficient was measured between the tire and the road, and the result must therefore depend, and did depend to an appreciable extent, on the condition of the tire. While the test was being made, the wheel was partly skidding and partly revolving, and the wear on the tire was therefore very heavy. He thought he was right in saying that under normal conditions of test on a wet road the life of the tire was about 30 miles. The consequence was that if a treaded tire was used the change in it would be so rapid that it would not be possible to compare any one test with another, and a smooth tire was used for that reason.

It might also be of interest to mention that the tests showed that the lowest figures, with which all those responsible for roads were concerned, were always obtained when a road was tested while it was getting wet, and that was particularly the case after a prolonged dry spell. If reliance were going to be placed on rain, as distinct from artificial watering, to give a wet road, a very definite limit was placed on the radius of action of the machine ; the maximum figure would probably be about 20 or 30 miles. That was one of the reasons why it was desirable to increase the number of machines.

Professor Clements had referred to the question of the maximum speed, and had suggested that the tests had been limited to 30 miles per hour on the grounds of safety. Mr. Turner thought the limiting factor was rather the power required to drive the machine ; the wheel was partially locked, so that the frictional resistance was approximately at its maximum value, and the power required to drive the machine at 30 miles per hour was as much as could be obtained.

Mr. Forty.

\* \* Mr. F. J. FORTY observed that further explanation of certain points regarding the interesting devices developed by the Authors would be welcome. Firstly, in the Paper no account was taken of gyroscopic effect in the case of the motor-cycle and sidecar machine ; it would appear to influence the observed results, and would depend upon the speed of the vehicle. Secondly, there would be transmission of a sideways force to the main frame, which would appear

\* \* This and the succeeding contributions were submitted in writing.—SEC. INST. C.E.

to tend to divert the motor-cycle from a straight path. The natural Mr. Forty. action of the driver was to correct that tendency, and the human element, therefore, would obtrude in the case of different drivers. Thirdly, was it thought that the camber of the road-surface would introduce a variable factor in comparing different surfaces? Possibly some device had been incorporated for counteracting that effect. It would be interesting to know whether the two latter factors had been found to have any effect on the ease of control of the machine.

Mr. G. H. HODGSON observed that the Paper had emphasized the Mr. Hodgson. influence exerted on the finished surface of the road by two main factors, namely, the lubricating film, and the roughness or other attributes of the surface tending to prevent film-formation. Intimately connected with those two factors was the choice of the rock from which the chippings were produced. Chippings should have a rough fracture, should be able to stand up to heavy load without crushing, and should have a good resistance to abrasion. Under wear, the fine mineral matter produced should be coarsely crystalline, and not an impalpable powder. From the study of plaster casts from roads surface-dressed with chippings, it could be seen that such a surface was excellent to prevent film-formation, as much of the material forming the lubricating film could pass away between the chippings to the channels, so that the top of the chippings could give the necessary frictional resistance.

Mr. F. W. VALLÉ-JONES observed that the test-results given in the Mr. Vallé-Jones. Paper did not include figures for iron roads or wood-block paving, which would have been particularly interesting. On account of the small difference found between the frictional resistance of hot-asphalt surfacing treated with pre-coated chippings at the time of laying and after several years of wear, it was evident that the road tested was taking comparatively light traffic. It might be argued that the road chosen for those tests was a good one to be taken as a standard, but it would be unfair to judge different surfacings on those lines unless there were uniformity in conditions of traffic and in the ages of the pavements. Whilst it would be difficult entirely to eliminate the lubricating film which was deposited on roads, it would be possible to reduce it very greatly by more frequent scavenging. From the point of view of cleanliness and ease of scavenging the iron road could not be surpassed. The hot-asphalt carpeting treated with pre-coated chippings used as a surface veneer failed when subjected to heavy horse-drawn steel-tired traffic. The protruding chippings were ground gradually to powder, and in a comparatively short time the road might be rendered useless from a non-skid standpoint. For rubber-tired traffic that type of road had been

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satisfactory so far, but it had yet to be proved whether it would remain non-skid for any reasonable length of time, and examples which had "faced up" in a month or two under heavy traffic were not uncommon. The lubricating film which was formed by rain with solid matter did not, in his opinion, materially affect the non-skid value of a rough road, and its effect on roads properly scavenged would be reduced to a negligible quantity. The same lubricating film on a smooth road, however, produced a very dangerous surface. The index of the value of any non-skid road was best measured by its tendency to polish, which could be better measured in the laboratory than on the road, the road-specimen being treated as a stationary surface and a piece of solid rubber rubbed over it at a given rate either backwards and forwards or in one direction only, a simple but effective test.

One of the speakers had referred to granite chippings having a crushing strength of approximately 14 tons per square inch, which, he stated, had given remarkable results in making a non-skid road. Such chippings could only be used for lightly-trafficked roads. Suitable chippings for general work should have a crushing strength of not less than 20 tons per square inch, and it was possible in England to obtain chippings having a crushing strength of 25 tons per square inch, which were ideal for use in surface-dressing.

It was remarkable that the sideways-force coefficient had been found to be much less in wet weather during summer than in wet weather during winter, and in the Paper no reason appeared to be given for that effect. Would it not indicate that there was a tendency for the binder to exude and play a part in lubricating the surface, and that the proportion of binder should be reduced to a minimum in order to make roads safe? As the sideways-force coefficient was reduced by approximately 50 per cent. when the speed was increased from 5 miles per hour to 30 miles per hour, apprehension might be felt as to what would be the value of that coefficient at 60 miles per hour. He had often drawn attention to the fact that London roads were not safe at speeds of more than 20 miles per hour, and the results given in the Tables confirmed that statement. Were future tests to be limited to 30 miles per hour?

The provision of non-skid roads near main goods-stations presented a difficult problem, as the heavy horse-drawn steel-tired traffic caused considerable damage to any type of thin veneer. Whilst such roads were safe for motor-traffic they could not be said to be safe for horse-drawn traffic. The frictional resistance on such roads might change from month to month on account of the continual grinding of the chippings. On such surfaces horses could slip even in dry weather. The testing of the frictional resistance of the various

types of roads carried out by the Ministry of Transport had presumably been carried out with the vehicle travelling in a straight line, but there could be little doubt that, whilst most surfaces might be safe under those conditions, they failed when vehicles left the straight course.

Mr. J. H. WALKER observed that the majority of motorists would classify road-crusts having untreated surfaces roughly into the following three classes: (1) non-skid crusts requiring neither the sprinkling of sand or gravel in wet weather, nor the periodical superposition of non-skid carpets; (2) crusts which when new were skid-proof, but which sooner or later became more or less slippery; (3) crusts which initially had slippery surfaces. Class (1) included (a) granite setts, where the granite itself was of a non-slippery nature; (b) water-bound macadam, free from any muddy matrix; (c) concrete, with a surface-aggregate consisting chiefly of large granite macadam in sizes ranging from  $1\frac{1}{2}$  to  $2\frac{1}{2}$  or 3 inches. Class (2) included (a) macadam, blinded with fine material, such as old road-scrappings, which in wet weather could work to the surface to form a thin layer of mud; (b) tar-macadam or synthetic asphalt, out of which in hot weather the tar or bitumen could "bleed" to the surface; (c) concrete road-crusts with a small-sized surface-aggregate, from  $\frac{1}{4}$  to  $\frac{3}{4}$  inch. Class (3) included non-gritted wood-block paving and rock asphalt. Road-crusts of class (1) were but a small percentage of the total mileage of roads, as granite setts laid on concrete foundations were very expensive, and the virtues of large granite aggregate in the surface of concrete roads were little known. Crusts of classes (2) and (3) were too often legacies for which the maintenance-engineer was by no means grateful. Such crusts required non-skid carpets imposed upon them, which had to be renewed periodically. So long as road-crusts with slippery surfaces had to be maintained, and consequently had to be covered over with renewable non-slippery carpets, so long would the need exist for such a device as that described and recommended in the Paper.

In Table II a sideways-force coefficient of 0.50 was given for old cement-concrete roads in wet weather. No doubt that value had been obtained on a polished surface containing small aggregate. It would be interesting to have that experiment repeated on the original and untreated surface of a 10-year-old road, surfaced with large aggregate. Such a road could be chosen from 10 miles of unsurfaced non-skid roads in Greenwich, from many such roads in the Docks of the Port of London Authority, from 6-year-old surfaces in the Cardiff streets, or from similarly surfaced streets 60 years old in Edinburgh. A suitable construction for a non-skid concrete road consisted merely of anchoring 6 inches of non-reinforced 6-to-1

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ballast concrete, in 10-foot bays, on to a roughly-graded formation, and topping the unset concrete with a layer 3 inches thick of a 6-to-1 mix of large-aggregate concrete, taking care that all joints were properly interlocked. In many cases such surfaces were sprayed with a mixture of tar and bitumen at intervals of a year or more without giving cause for any complaints of slipperiness. The 1934 report of the experiments made by the Ministry of Transport stated that sections of such roads had been laid in various places. They were not, however, anchored to the ground as were those that had proved themselves so successful during the past 60 years or more. Instead, they were laid as freely-moving slabs on a 3-inch bed of rolled ashes covered with a layer of brown paper. That provision for free movement of the slabs might be thought to be very bad practice. Whilst no useful results were likely to be obtained from such recent experiments until 10 years or so had elapsed, there were in Great Britain many miles of proved roads of any age up to 17 years, and also roads 60 years old or more, which could be examined with regard to their non-skid properties, all-round efficiency, and cheapness of construction.

He would suggest that the proper cure for slippery road-crusts was to replace them as quickly and economically as possible with non-slippery crusts having great compressive strength in all weathers, as was the case with concrete roads when properly constructed so as to give a perfect unwarped running surface. In the meantime, but merely as a temporary measure, all surfaces known to be slippery should be covered up with non-skid carpets, notwithstanding the first and repeated costs of doing so. If the above suggestions were acted upon, the excellent device recommended by the Authors should in time become unnecessary.

Mr. Batson.

Mr. BATSON, in a preliminary oral reply, said that Mr. Turner had mentioned that the reason for the use of a smooth tire on the test vehicle was the change which would have occurred on a tread of normal design due to wear, but there was also another reason, namely, that the type of tread had an important effect on the values obtained. If treaded tires had been used it would therefore always have been necessary to have used exactly the same tread-pattern, and the results would have been peculiar to that tread-pattern, even if wear had not taken place. That might explain some of the results found by Mr. King and referred to in the Paper, where a difference was found between sideways-slipping and straight-on skidding; those differences were due to the type of treads employed. If Mr. King had used treads of a different design he might have obtained a different comparison.

Several speakers had referred to the results given in Table II.

It should be emphasized that those given were only typical values ; Mr. Batson. a technical paper would be published in which the whole of the results would be set forth, and that paper would deal with Mr. Overfield's question with regard to the effect of rainfall on the results obtained.

Professor Clements divided the test results into three zones, and in the last zone put those of the surfaces which gave low sideways-force coefficients whether they were wet or dry. The Authors' experience was that they had been able to obtain low values on dry surfaces only when those surfaces were covered with loose material, the loose material acting as a kind of ball-bearing. Professor Clements also referred to the importance of further work on the lubricating film, in addition to the collection of results by means of the motor-cycle and sidecar. Work on that aspect was being actively pursued at the Road Research Laboratory, and it was hoped in the course of a short time to have some further information on the subject.

The AUTHORS, in completing their reply, stated that they The Authors. appreciated the kind way in which the Paper had been received and the many helpful suggestions which had been made.

They agreed to the suggestion put forward by Mr. T. Peirson Frank that the motor-cycle and sidecar skidding-machine would give a "fair comparative numerical value" and also that the references to deterioration made in the Paper related to deterioration in regard to skidding tendencies. They could not, however, endorse the view that "low coefficients could almost be disregarded so far as present-day practice was concerned." Some types of road-construction which they had tested had shown rapid deterioration after 6 months' use, although the value of 0.7 had been obtained shortly after completion. They would agree, however, that the methods suggested by the British Standards Institution, if carried out under careful supervision, would give a comparatively long skid-free life.

There appeared to be some misunderstanding as to the function of the motor-cycle and sidecar. It had not been designed to take into account vehicle-characteristics other than those of the tire, or to deal with the human element or measure the centrifugal force at curves, but was solely a mechanical device for determining the frictional force resisting skidding between the tire and the road-surface under normal speeds and weather-conditions. It had been found that the camber of the road did not affect the results obtained. The sideways force from the sidecar-wheel was ultimately resisted by the friction between the rear wheel of the motor-cycle and the road, and when a test was carried out the observer rode on the pillion in order to provide the maximum adhesion of the rear wheel. Earlier work on the subject carried out at speeds below 5 miles per

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hour did not show low coefficients even on samples cut from roads which were known, from practical experience, to be dangerous from the point of view of skidding. It was not until tests were carried out with the sidecar apparatus that the large reduction in coefficient with speed on some surfaces was demonstrated, and the results obtained were brought into line with the general experience of road-users. The maximum speed of test with the apparatus depended upon the frictional resistance of the surface, and with the present machine 30-35 miles per hour could usually be obtained. A new machine, having a more powerful engine, was under construction, and higher speeds should be possible when it was brought into use.

Mr. Vallé-Jones suggested that the small lowering of the frictional resistance of the hot-asphalt surface after 4 years' service (given in Table II of the Paper) was evidently due to the road having taken comparatively light traffic. The section of road from which those results were obtained was on the Kingston By-Pass, which carried a large volume of traffic.

It was remarked that no reason had been given in the Paper to account for the fact that the sideways-force coefficient was found to be much less in wet weather in summer than in wet weather in winter. That matter was under investigation at the Road Research Laboratory, but it was believed that one or more of the following factors might be responsible for the effect obtained :—

(a) Higher temperatures in summer caused exudation of the binder and polishing of the surface. In winter, owing to the colder weather, that polished layer would be removed by abrasion.

(b) In summer, rain-water was evaporated quickly, leaving the detritus on the surface, while in winter, owing to lower temperatures and higher humidities, the rain washed the detritus into the gutters and left a comparatively clean surface.

(c) In summer, vehicle-tires were at a higher temperature than in winter and helped the polishing effect on the surface. In summer, also, oil-leakage from vehicles was more pronounced.

In dealing with concrete surfaces, Mr. J. H. Walker stated that many such surfaces were sprayed with a mixture of tar and bitumen at intervals of a year or more without giving cause for any complaints of slipperiness. It was assumed that chippings were afterwards spread and rolled. The measurements that the Authors had made on concrete roads led to the belief that no such treatment was necessary to ensure a non-skid surface.

Several speakers, notably Mr. Hadfield and Mr. Overfield, emphasized the importance of cleanliness of the surface, and with those remarks the Authors were in complete agreement.