RESEARCH ON SKID-RESISTANCE AT THE TRANSPORT AND ROAD RESEARCH LABORATORY (1927-1977)

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Research on skid-resistance of roads started in Britain in 1927 at the National Physical Laboratory at Teddington but the work was transferred to the newly formed Road Research Laboratory at Harmondsworth in the early 1930's. It has continued there (now the Transport and Road Research Laboratory, Crowthorne) to the present time and a considerable fund of knowledge now exists on the subject. The paper reviews this work, starting with the development of apparatus to measure skid-resistance reliably. An early machine was an adapted motorcycle and sidecar, the sidecar wheel being mounted at an angle to generate a sideway-force. This was later superseded by in-board systems in front-wheel drive cars and has led to the present-day commercial production of a sideway-force routine investigation machine (SCRIM) which is available for general use and which produces an automated output suitable for computer processing. The paper goes on to discuss the evolution of standards of skidding resistance which are necessary to minimise numbers of skidding accidents and describes work which has enabled materials to be specified to give levels of micro-texture necessary for the nominated low-speed skidding values to be maintained. High-speed skid-resistance and its dependence on macro-texture is then discussed together with side-effect problems (eg noise and spray) connected with the creation of surface texture; the paper concludes with 25 references to major publications in the field. An indication is given of the probable form of a comprehensive specification scheme which may be adopted soon in Britain.

1. Early Research at the National Physical Laboratory

By the middle 1920's the dominance of motor transport was becoming very apparent in Britain with the total numbers of both commercial and private vehicles showing spectacular rates of increase. But with the increased number of vehicles came an increased number of accidents, many of which were directly attributable to lack of adhesion between tyre and road, especially in the wet. It became clear that here was a potentially important field of research because the problem would become more severe as the years went by.

In 1927, Batson started work at the National Physical Laboratory at Teddington, with the aim of understanding the phenomena involved in the process of a vehicle skidding, his first experiments consisting of drawing rubber sliders over the surfaces and measuring the tractive effort required. This work soon indicated that there was a speed effect involved and that an apparatus was needed to carry out tests over a range of road speeds.

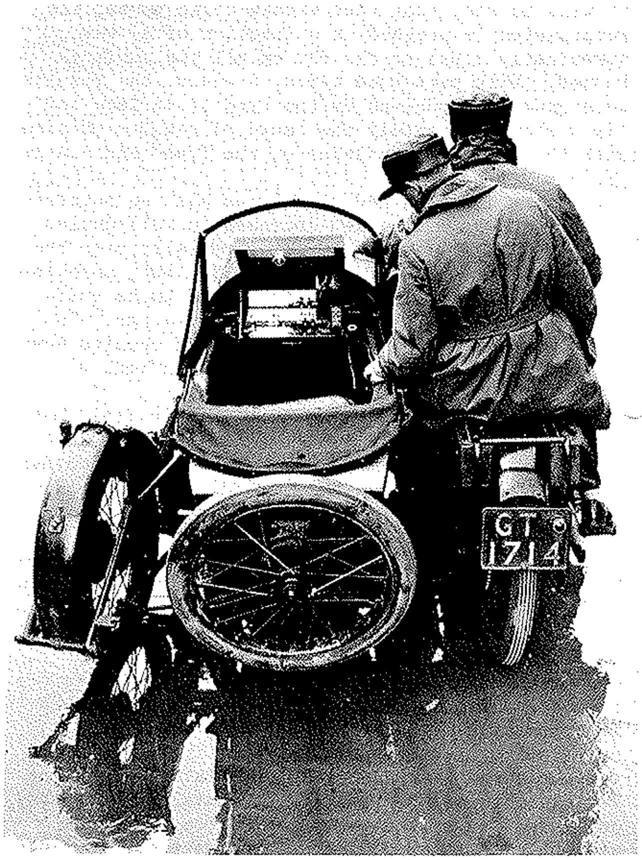
1.1 Skid-resistance Measurements - 1929

The apparatus took the form of a specially designed motor cycle and sidecar with the sidecar wheel mounted at an angle to the direction of travel (Plate 1). The side thrust on this wheel and the vertical reaction between the tyre and the road were measured and transmitted by a link-mechanism to a pen which gave a single track on a moving paper chart. The ordinate of the record was proportional to the ratio of sideway-force to load and was, therefore, proportional to a form of the coefficient of friction which was called Sideway-Force Coefficient (SFC). The tread of the tyre employed had to be of a standard form and it was decided to use smooth tyres for the work to eliminate problems which would arise as a patterned tyre wore during use. The modern apparatus is a development of this early machine but the principles involved are identical and the SFC is the same as that measured in the work of nearly fifty years ago.

1.2 Road Experiment - 1930

An early road experiment on the skidding resistance of a range of bituminous materials (using this method of measurement) was laid in 1930 on the Kingston By-Pass, about 16 km to the south-west of Central London. Eleven materials were laid in sections, eight of which were treated with chippings to provide resistance to skidding. In the remaining three sections the claim was put forward that the porosity of the materials was such as to give adequate wheel-grip. Skidding measurements were

Plate 1. Early motorcycle and sidecar for measurement of SFC.



carried out using the motorcycle and sidecar at speeds up to 50 km/h and the results showed that the eight sections that were treated with chippings showed good resistance to skidding throughout the speed range. The other three materials, however, exhibited a marked falling off in the value of the coefficient at speeds above 25 km/h.

The value of texture and the influence of speed on skidding resistance were thus starting to be recognised by the year 1931, but it was to take many years for these interactions between tyre and stone to be fully quantified and put into contractually implementable form.

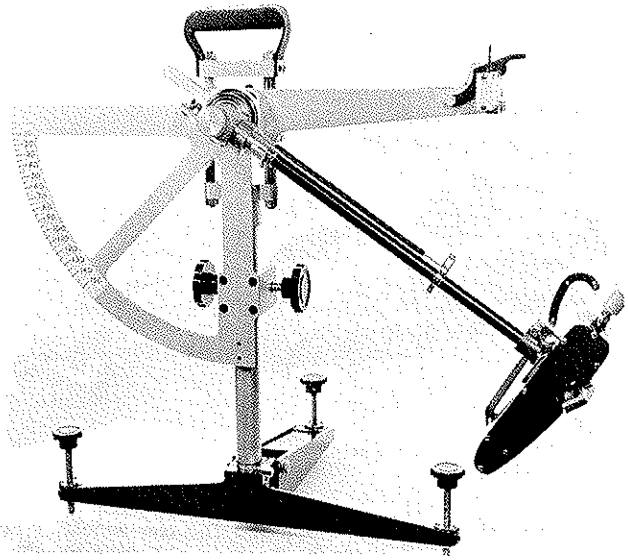
2. Development of Test Methods

Further changes in the techniques and apparatus of skid-resistance measurements between that period and the 1950's[1,2,3] were more of detail than of fundamental concept but the work of the next few years led to rapid advances in the field.

Three forms of apparatus had come into use in Britain, the portable skid-resistance tester, braking force machines (in the form of either trailer or vehicle decelerometer) and a more advanced version of the sideway-force machine. Each of these still has a role to play although it will be seen that SFC has now been adopted in Britain as the basic measure of skid-resistance.

2.1 Portable Tester

Plate 2. Portable skid-resistance tester.



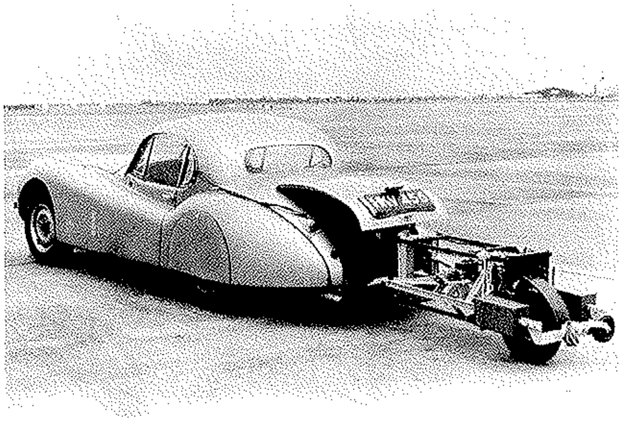
This apparatus, shown in Plate 2, is now well known in many parts of the world. It was designed to provide a simple and rapid method for checking skid-resistance in local areas and entails measuring the frictional resistance between a rubber slider (mounted on the end of a pendulum arm) and the wetted road surface. There is some link here with Batson's early work, but in this case the loss in energy of the pendulum arm, after the slider has traversed the surface, is equated to the work done during the sliding process, and it has thus been possible to calibrate the instrument directly in terms of a form of the coefficient of friction termed the Skid-Resistance Value (SRV). Full details of the apparatus and of its method of operation are given elsewhere[4]; it is sufficient to say here that useful as the apparatus sometimes is to give a quick local guide to skidding resistance, it suffers from two major disadvantages. One is that on coarse textured surfacings (ie with chippings larger than 12 mm) results can be misleading, even in skilled hands, and the other is that it provides only partial and slow coverage if routine monitoring of road networks is planned. Other forms of measurement are clearly needed for this purpose.

2.2 Braking-Force Machines

2.2.1 Braking-Force Trailer. A small trailer apparatus, built by the Laboratory, has been used for some years for studying braking-force coefficients (BFCs) at high speeds on roads and runways (Plate 3). The skidding resistance of the surface is determined by measuring the torque acting on the trailer brake when the wheel is locked for about 2 seconds on a wet surface. This apparatus has been particularly valuable in investigating the skid-resistance of airfield runway surfaces on which tests are carried out at speeds of up to 130 km/h and also in studies of the effect of texture depth on the high-speed skid-resistance of roads (see Chapter 4).

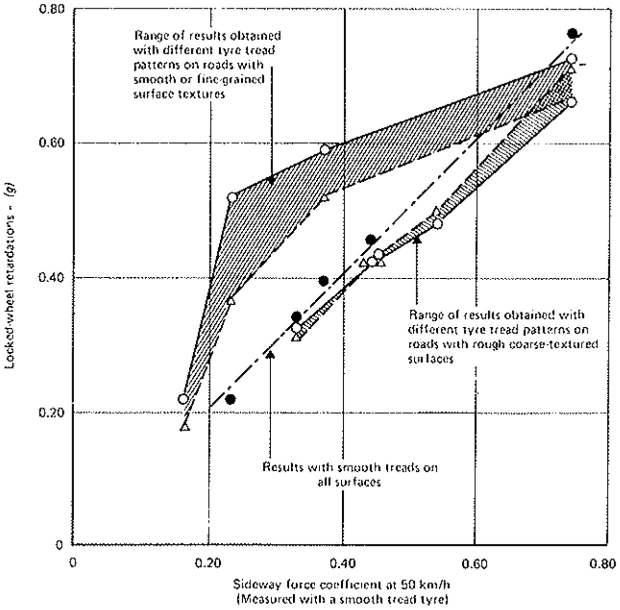
2.2.2 Road Vehicle with Decelerometer. A simple locked-wheel braking method was found to be of particular value in making rapid comparisons of the non-skid properties of tyre tread patterns. A brake-testing meter is used to record the decelera-

Plate 3. Trailer for measurement of BFC.



tion when the brakes are applied for one second from an intial speed of 50 km/h, locking all four wheels and making them skid. The method showed good correlation with the sideway-force method when the vehicle used was equipped with smooth-tread tyres (see Fig.1) but is not easy to standardise if different tyres are used on the different vehicles employed. It cannot, of course, be used for tests on bends or curves and care has to be taken that all four wheels are fully locked.

Figure 1. Vehicle retardations from 50 km/h obtained with a variety of tyre tread patterns and road surface textures under wet conditions.



2.2.3 Effect of Tyre Tread Patterns on Skidding. The decelerometer method was used by the Laboratory in the early 1960s to investigate the effect of tread patterns on tyres by fitting the different sets of tyres to be compared, in turn, to the same vehicle. The deceleration from 50 km/h was obtained both on fine-grained surfacings with SFCs ranging from 0.17 to 0.75 and on coarse-textured surfacings with SFCs from 0.33 to 0.75. The main features of the results obtained are given in Fig.1, from which it will be seen that with smooth-tread tyres, the retardation (expressed as a fraction of g) was numerically equal to the SFC on all the surfaces tested. With patterned tyres, however, the results were greatly dependent on the type of surface and Fig.1 shows separately the range of results obtained with the different patterns on the fine- and coarse-grained surfacings.

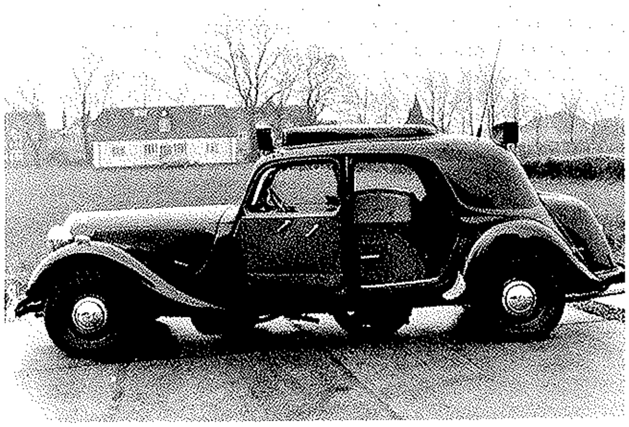
On the fine-grained surfacings all the patterned tyre treads gave a marked increase in retardation over that of the smooth tyres, especially over the important range of SFCs (0.3 to 0.5), but, perhaps surprisingly, the situation was found to be quite different on the coarse-textured surfacings. In this case the smooth tyres gave better results than the patterned ones when braking from 50 km/h with locked wheels in the wet.

A great deal of further work in this field has since been carried out be the major tyre manufacturers and modern tread patterns have become increasingly effective in improving skidding resistance, especially when braking from high speeds.

2.3 Sideway-Force Coefficient Routine Investigation Machine (SCRIM).

The development of machines to measure SFC passed through several phases following the use of the early motorcycles. The first of these was the incorporation of a fifth wheel in a front-wheel drive car. A Citroen car was the first production vehicle found to be suitable and Plate 4 shows the vehicle with the test equipment installed. In the early 1960s a suitable British saloon car became available (Austin 1800) and three of these were converted in a similar way to the Citroen.

Plate 4. Citroen car for measurement of SFC.

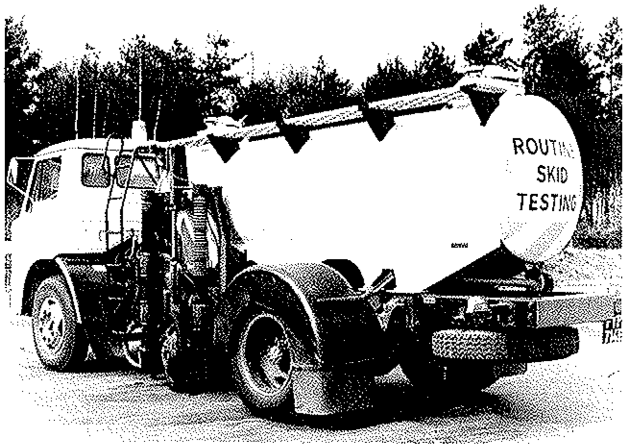


In each of these cases, the test cars were designed specifically for research work and not for routine use by highway authorities. They required separate water tankers to wet the road in front of them (although they did carry small water tanks for local use) and the processing of the pen-recorded paper charts was time consuming and suitable only for comparatively short stretches of road. A machine suitable for routine use was clearly necessary with the following basic requirements:-

(a) To be robust enough for field use.
(b) To be operable within the normal traffic stream.
(c) To be capable of testing an average of 100 km/day.
(d) To produce test results meaningful over the range of normal traffic speeds.
(e) To produce the results in a form readily processable by computer.

The first prototype of the Sideway-force coefficient routine investigation machine (SCRIM - Plate 5) manufactured to Transport and Road Research Laboratory specifications was delivered in 1968, and 15 are now in use throughout the world. Commercial production is in the hands of a manufacturing company in Bristol and the machine is available for sale, complete with electronic recording apparatus.

Plate 5. Sideway-force coefficient routine investigation machine (SCRIM).



The sideway-force is generated by a test-wheel running at an angle of 20° to the direction of travel of the vehicle and carrying a smooth tyre similar to that used on the original sidecar. The vehicle is mounted on a production commercial vehicle chassis and its essential feature is a 2,700 litre water tank to wet the road in front of the test wheel. This quantity is sufficient for some 50 km of testing (ie half of one day's work).

The test wheel has its own deadweight, spring and shock absorber, to give a known static reaction between tyre and road, and in the hub there is an electrical load cell to provide the sideway-force input to the recording system. A speed input is provided from the vehicle transmission system.

Output, on magnetic or punched paper tape, consists of a record at 5 m, 10 m or 20 m intervals of SFC, speed and data to indicate location of the test. The recorder is fitted with facilities for calibration of the system, and the unit is mounted in the vehicle cab for operation by a technician accompanying the driver.

It is intended that in the near future a number of SCRIMS should be available to provide a standardised monitoring system for the national network under the control either of Central Government or of Local Government. In either case the operation of the machines may be direct (ie the vehicle purchased outright and manned by the authority's own staff) or on an indirect hire basis, an auxiliary service already being provided on an introductory basis by the manufacturing company.

2.4 Tests for Roadstone Quality

During the era covered by development of these skid-resistance test methods, parallel work was going on in another sector of the Road Research Laboratory on the polishing and wear properties of roadstones. It was by then being appreciated that stones from different geological sources varied greatly in their resistance to polish by the tyres of vehicles, limestones being notoriously bad in this respect while quartzites and gritstones were good. The gritstone group, however, suffered in some cases from rapid abrasion under traffic, and so, although the stones did not polish, the road lost macrotexture by wear. Two standardised tests were, therefore, developed, the Polished Stone Value test and the Aggregate Abrasion Value test, both of which are now fully documented in a British Standard[5].

The first of these tests gives Polished Stone Values (PSVs) ranging from about 30 for some limestones to up to 75 for some gritstones, and the second gives Aggregate Abrasion Values (AAVs) ranging from 1 or 2 for very hard flints to values above 20 for soft aggregates. Modern specifications nominate each of these properties for given levels of traffic flow and skidding accident potential.

2.5 Summary of Terms Used

The terms used in the remainder of this paper are as follows:-

(a) SRV - Skid-resistance value, measured by portable tester (pendulum) on the road surface.
(b) BFC - Braking-force coefficient, measured by locked-wheel trailer on trafficked roads and airfields.
(c) SFC - Sideway-force coefficient, measured (now) by SCRIM on trafficked roads.
(d) PSV - Polished stone value, measured on a laboratory-polished sample using an adapted portable tester (different scale from SRV).
(e) AAV - Aggregate abrasion value, measured in the laboratory by loss of weight of a sample under accelerated wear.

3. Correlation of Skid-Resistance with Accidents, Materials and Traffic Flow

By the late 1930's the restoration of a rough texture to a smooth road surface was widely achieved by means of surface dressings and macadam carpets, but there was no recognised quantitative method of establishing when such treatment had become necessary.

The first proposal for a method of doing this was to study accident reports in detail and to plot on large-scale plans the locations of those accidents in which wet-road skidding was a predominant factor. From this work at the (then) Road Research Laboratory, it gradually became clear that in many areas these accidents occurred in clusters and that a common factor between many of them was that a high degree of polish existed on the roadstones in the surfacings. Following from this it was also shown that if these areas were then given maintenance treatment, accidents could be reduced in numbers significantly.

This procedure has an appealing simplicity about it for use as a maintenance indication as it encompasses all the factors which combine to cause skidding accidents ie alignment, topography, surfacing regularity and surfacing smoothness. Unfortunately, it also suffers from the overwhelming disadvantage that it is necessary to wait until accidents have occurred before any information is obtained. Obviously a method was required of spotting danger areas before any harm had been done.

3.1 SFC and Accidents

The next major requirement, therefore, was to establish values of SFC which were required in order to minimise the number of skidding accidents at given categories of site so that routine monitoring could detect potential danger areas in advance. This was a very large task indeed and entailed the collection of data, both on SFC and on numbers of skidding accidents that had occurred, from a wide ranging variety of sites.

The work culminated in 1957 in a paper to the Institution of Civil Engineers[6] by Giles in which he related SFC at 50 km/h to the relative liability of a site to become the scene of repeated skidding accidents in wet weather. He concluded that, whilst a surface with a coefficient of 0.60 and above may by chance sometimes be a scene of an accident in which a vehicle skids in wet weather, the risk that it will be the scene of repeated skidding accidents is extremely small. This risk first becomes measurable with a coefficient of 0.55 to 0.60 and increases sharply by more than 20 times as the coefficient falls to values of 0.40 to 0.45 and by about 300 times when the coefficient is 0.30 to 0.35. These data clearly provided the basis of a set of skidding standards (see Chapter 5) but knowledge of the type of stone needed to give a nominated SFC was also necessary before a full national roads policy could be implemented.

3.2 SFC, Materials and Traffic Flow

3.2.1 Bituminous Surfacings. During the years up to 1970, a large number of measurements of skidding resistance had been made on road experiments in which a range of different road aggregates had been used in the surfacing. In order to study the relationship between the PSV of the stone and the low-speed SFC of the surfacing, regression analyses were made of the data from 13 of these experimental sites, 20 analyses being possible because of division into different traffic lanes or types of surfacing at some sites. Details of the results of this work have been published[7] and a synopsis of the findings is that a change of 1 unit of PSV corresponds to a change of 0.01 units of SFC at 50 km/h (SFC_{50}).

The effect of traffic was not so simple to establish but a close study of the measurements taken on one site over a period of years showed that despite variation in skidding resistance during a given year, if a 'mean summer SFC' was taken, the high value of SFC obtained on a newly laid bituminous surfacing rapidly decreased, and within about one year settled to a constant value. It remained at that value provided that no significant change in traffic volume occurred in that time. Examples of results from a few sites are shown in Figs.2 and 3.

If identical surfacing materials were compared on different sites, the level of SFC was found to be inversely related to the volume of traffic.

One conclusion which was apparent from these observations concerns the manner in which SFC and traffic are inter-related. The effect of traffic on SFC is not cumulative from year to year and, therefore, the concepts used, for example, in fatigue studies do not apply to skidding resistance. Instead SFC is simply related to traffic volume for any aggregate of given PSV.

Figure 2. Effect of traffic on skidding resistance of a typical motorway standard surfacing (rolled asphalt with precoated chippings of PSV 58-60)

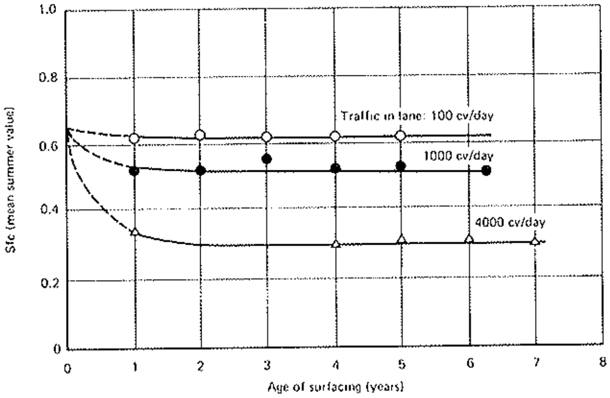
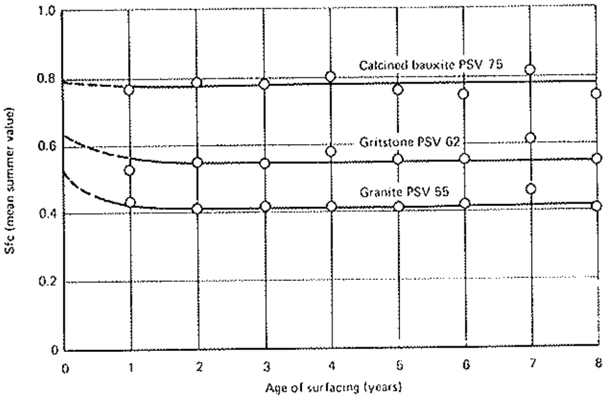


Figure 3. Levels of skidding resistance recorded on different sections of road (surface dressing using 13 mm chippings. Traffic in lane: 2100 commercial vehicles per day)



A possible explanation of these observations and one that is generally accepted, is that at the same time as traffic is tending to polish the surface, other factors, usually identified as complex physico-chemical phenomena described as 'weathering', are acting in the opposite way, restoring micro-texture of the exposed aggregate. Thus the resultant resistance to skidding represents an equilibrium between the effects of certain naturally occurring conditions on the one hand and those of traffic on the other.

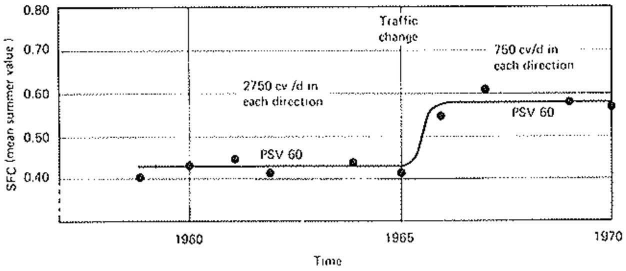
If, on any particular site, traffic flow changed (as a result, for instance, of road development in the area), a corresponding change in SFC would result. Fig.4 shows this phenomenon (as an increase in SFC) as measured on Trunk Road A4 at Colnbrook, Middlesex, when traffic decreased after a nearby section of Motorway M4 had been opened.

When it had been established that the three variables SFC, PSV and traffic were inter-related, a regression analysis was carried out to correlate the three simultaneously. One hundred and thirty nine different sections of road with traffic densities up to 4000 commercial vehicles per day were examined to provide data and the following highly significant correlation (correlation coefficient 0.91) was obtained:-

$$SFC_{50} = 0.024 - 0.663 \times 10^{-4} \cdot q_{cv} + 1 \times 10^{-2} \cdot PSV$$

where q_{cv} = flow of commercial vehicles per lane per day (in one direction). The relationship applies to straight roads only.

Figure 4. An increase in the level of skidding resistance recorded on trunk road A4, Colnbrook by-pass when traffic decreased due to the opening of a motorway.



The publication of this work[7] is regarded as a major advancement in the field of skid-resistance as it provides a method of nominating at the design stage the properties of the stone required to provide a given ultimate skidding resistance provided that the commercial traffic flow can be estimated.

3.2.2 Concrete Surfacings. Research to quantify the materials effect on low-speed skidding resistance in a concrete pavement is complicated by the greater number of variables involved. Here the polishing and wear characteristics of both the fine and coarse aggregates have an influence on the result, as does the strength of the concrete.

This field has been researched in Britain as a joint venture between the (Transport and) Road Research Laboratory and the Cement and Concrete Association, work starting in 1964 and still being active in 1977. The first major report[8] from this work appeared in 1970 and it concluded that the most important constituent in the mix was the fine aggregate. The use of high-silica-content natural sands always yielded higher skid-resistance values than did relatively soft sands or crushed fine materials.

The polishing characteristics of the coarse aggregate had only a very slight effect on the skid-resistance of concrete, an increase in PSV from 35 to 72 producing an increase in SRV of less than 5 units. Normally not more than 12 per cent of the surface of a concrete road consists of exposed coarse aggregate.

As a result of this and other work, the Department of the Environment Specification[9] introduced two aggregate restrictions for concrete surfacings on Trunk Roads and Motorways. Firstly the fine aggregate used in the top 2 inches of the carriageway was limited to a 25 per cent calcium carbonate content (that being the polishable constituent of the sand) and if the coarse aggregate was limestone it was required to satisfy an accelerated wear test. This latter test is carried out on concrete samples incorporating the aggregate in question and thus occupies a period of several weeks because of curing time. It would be more practicable to be able to forecast the ultimate low-speed skid-resistance of the finished concrete from laboratory tests on the constituents, so that delays could be avoided at the tendering stage of a contract.

To this end, a first study[10,11] has been made of a limited amount of data with the object of correlating the skidding resistance with the properties of the constituents. The aggregate properties and the strength characteristics have been subjected to multiple regression analysis and the equation derived from Motorway M4 (3400 commercial vehicles/day) was:-

$$SRV = 47.1 + 0.210 \times PSV_f - 1.11\ AAV_f + 0.335\ AAV_c - 0.204\ (\text{strength}) + 0.189\ (\text{fines content})$$

(Suffices 'f' and 'c' refer to fine and coarse aggregate respectively, 'strength' is compressive strength of concrete at 28 days (MPa) and 'fines content' is per cent by weight passing a 4.76 mm BS test sieve. The correlation coefficient was 0.84.)

This work is still in progress and it is hoped that it will soon be possible to specify materials to give a nominated SFC_{50} as accurately for concrete surfacings as for bituminous.

3.2.3 Factors other than Resistance to Polishing. Although resistance to polishing is the most important single characteristic of an aggregate in determining the resistance to skidding of a bituminous surfacing, a study[12] has been made of other characteristics of aggregates that have been thought to influence resistance to skidding. The most important of these were:-

(a) Geological group
(b) Particle size
(c) Differential wear of mixtures of two or more roadstones.

Briefly the findings of the work were:-

(a) Some aggregates, notably quartzites and blast-furnace slags, gave a resistance to skidding equivalent to that given by other roadstones which are 3 units higher in PSV. All the other types of roadstones tested performed as would be expected from their PSVs.

(b) Provided that adequate road surface texture is maintained, reducing the nominal size of an aggregate raises the low-speed resistance to skidding of a surfacing made with it. In the case of macadams this increase can be up to 0.10 units of SFC for a 3 mm maximum size material when compared with one containing 19 mm particles. This relative effect is even greater in the case of chipped surfacings, but it is difficult to prevent embedment of small chippings.

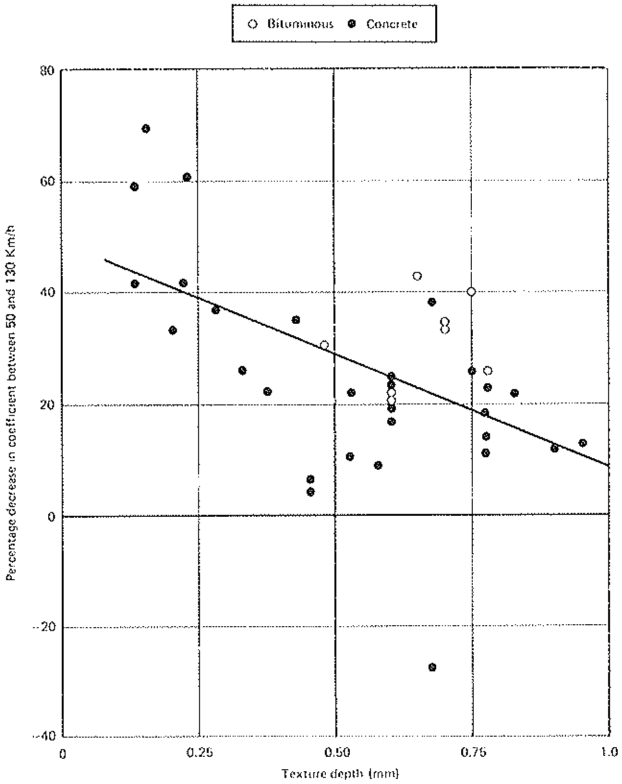
(c) The use of mixtures of two or more aggregates of normal surfacing quality yields a resistance to skidding and a depth of surface texture that is approximately equal to the means of those given by the constituents on their own.

4. Effect of Texture on High-Speed Skid-Resistance

The work discussed in Chapter 3.2 has made it clear that low-speed (50 km/h) SFC is provided by the micro-texture of the surfacing and is quantified in terms of the resistance to polishing of the aggregates used. The next question is that of the macro-texture and what its contribution is to the skidding resistance of the road.

It has been mentioned previously in Chapter 1 that various researchers had reported a 'speed effect' on the measured skid-resistance and that the small braking-force trailer (2.2.1) had been used to investigate change in skidding resistance from low to high speeds. The first attempt to quantify this effect and to correlate it with road surface texture came in 1966[13]. The texture used was that measured by a sand-patch method[4] and one measure of change in skidding resistance that was tested for correlation against texture was the percentage decrease in BFC between 50 km/h and 130 km/h. The relationship is plotted in Fig.5 and is seen to be linear, with a correlation coefficient of -0.52. A first attempt at nominating a mandatory texture requirement was made on this evidence and this was that a texture depth of 0.025 in. (0.64 mm) should be provided in order to restrict the decrease in skid-resistance to 25 per cent. This figure of 0.025 in. was subsequently included in the specification[9] for concrete roads but it has been used only as a guide in bituminous specifications. Consideration is now being given to new texture requirements based on the latest work in the field.

Figure 5. Effect of texture depth on percentage decrease in coefficient between 50 and 130 km/h.



Further evaluation of BFC measurements on a wider range of surfacings has shown that the random texture of bituminous surfacings has a different effect from that of the predominantly transverse texture applied to most concrete surfacings in the UK. Figs.6 and 7 show the effects of texture depth on change in BFC from low to high speed on bituminous and concrete surfacings respectively. These are plotted in a slightly different way from that chosen for Fig.5 because the later survey included a number of deep-textured surfacings which have the effect of actually increasing the skidding resistance at high-speed compared with that at low speed; as will be discussed later, this advantage brings with it a penalty of noise.

Figure 6. Bituminous surfacings: effect of texture depth on the change in BFC from 50 to 130 km/h.

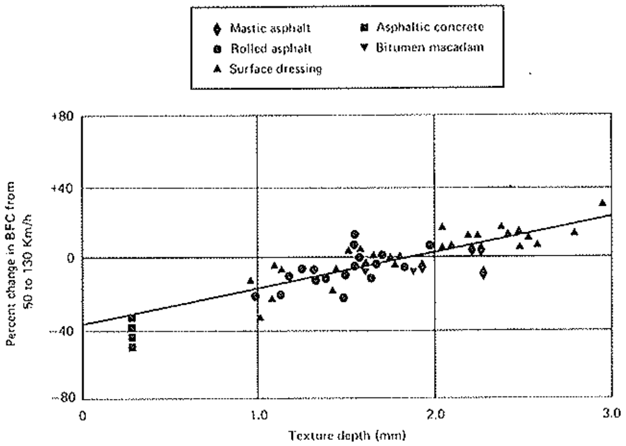
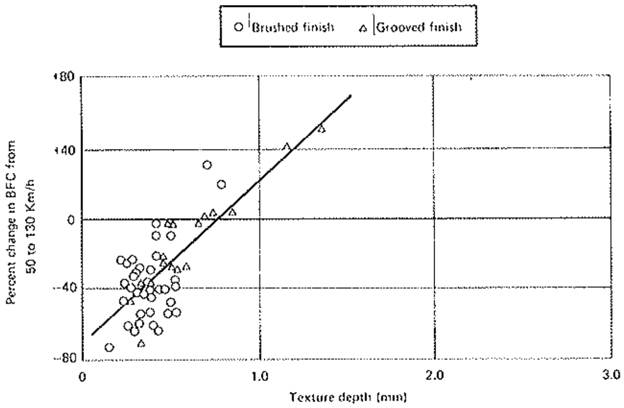


Figure 7. Concrete surfacings: effect of texture depth on the change in BFC from 50 to 130 km/h.



A comparison of Figs.6 and 7 shows that, for equivalent performance, the transverse texture of a concrete surfacing can have a lower average value than the random texture of a bituminous one. For example, for zero drop-off in BFC (ie the maintenance of the same skidding resistance at high speed as at low) a randomly textured surfacing requires 2.0 mm of texture whilst with a transverse texture only 0.8 mm is needed. This important finding is discussed again in Chapters 5 and 7 in connection with standards of texture required on roads and the noise that such textures will generate.

5. Standards of Skid-Resistance

5.1 First Standards Proposed (1957)

Mention has been made in Chapter 3.1 of Giles' work in the 1950's and of the relationship he obtained between SFC and numbers of wet skidding accidents. In the same paper[6] he suggested levels of SFC for different categories of site, which were intended as a very tentative guide and as a basis for further study. These figures are given in Table 1.

Table 1. Giles' suggested sideway-force coefficients (1957).

Category	Type of site	SFC at 30 mile/h on wet surface
A	'Most difficult sites' such as: 1. roundabouts 2. bends with radius less than 500 ft on fast derestricted roads 3. gradients 1 in 20 or steeper of length greater than 100 yds 4. approaches to traffic lights on derestricted roads	above 0.6
B	'General requirements' ie: roads and conditions not covered by categories A and C	above 0.5
C	'Easy sites' eg: mainly straight roads with easy gradients and curves and without junctions and free from any features such as mixed traffic especially liable to create conditions of emergency	above 0.4
D	'Proved sites' eg: roads with coefficients below 0.4 which because of factors such as very slow or infrequent traffic cannot be shown by accident studies to be above normal danger	-

With minor amendments (eg the substitution of 0.55 for 0.60 for Category A), these proposals were included in the suggested target values of SFC adopted by the Marshall Committee[14] on Highway Maintenance, whose report was submitted to the Minister of Transport in 1970. These values have never achieved a status higher than of proposals in Britain, aimed at providing guidance for the maintenance engineer but, in order to have maximum effect in improving road surfaces, it is essential that any standards should eventually have mandatory backing. One major deterrent to the adoption of such mandatory standards is common throughout the world, and that is the legal consequences of such action. In 1970 the Transport and Road Research Laboratory set out to try to produce a scheme which would be acceptable from all points of view.

5.2 1972 TRRL Proposals

5.2.1 SFC. The starting point of this study was a consideration of the limitations of the existing proposals. The recommendations of minimum values of SFC for three or four broadly defined categories of site has the advantage of simplicity but it does not fully reflect the fact that a slippery surface is just one of many factors contributing to the incidence of skidding. Two sites fitting into the same category may show widely different skidding accident records, because their liabilities to become a scene of such accidents will be influenced by factors such as traffic speed, road geometry, superelevation on bends, visibility and others.

Another problem with the old proposals was that since their introduction a considerable increase in traffic had occurred (59 per cent increase in commercial vehicles between 1956 and 1969) and the polishing effect of this traffic had reached such proportions that it had become impracticable to maintain the target values on many heavily trafficked lanes of motorways using any available natural aggregate.

The new proposals which were prepared[15] were based on a site classification system broadly similar to the existing one but including a new super class of high risk site. The main feature of the scheme was that in place of a rigid system, the minimum value of SFC required on any site should be additionally dependent on a 'Risk Rating' which would be determined locally by the accident potential of that site. If the mean summer SFC falls below the minimum value the maintenance authority should initiate remedial action by including the length of road in question in the programme for future maintenance work provided the accident record gives no grounds for re-coding with a lower risk number. The proposals are given in Table 2.

The ultimate aim to be achived after the scheme has been in operation for some time, is that every site should be rated at the correct risk level. This condition would be indicated by the disappearance of sites having a skidding accident record substantially different from an average value.

5.2.2 PSV Required. The materials requirements to achieve the nominated SFCs have been discussed in Chapter 3.2 and a summarised version of the PSV requirements for use in bituminous surfacings has been produced for a range of traffic conditions. These are given in Table 3.

5.2.3 Surface Texture. The effect of macrotexture on the change in skidding resistance with speed has been discussed in Chapter 4. The TRRL proposals for an all-embracing policy on surfacings include texture requirements and a summary of the effects mentioned previously is given in Table 4.

It is proposed that new surfacings, bituminous or concrete, should have sufficient texture to give the same skidding resistance at high speed as at low (ie zero drop in Table 4) and that maintenance intervention should take place when texture is reduced to the point where a 20 per cent drop occurs. These conditions require 2.0 mm for new bituminous

Table 2. Minimum values of skidding resistance for different sites.

SITE	DEFINITION	SFC (at 50 km/h) Risk Rating 1	2	3	4	5	6	7	8	9	10
A1 (very difficult)	(i) Approaches to traffic signals on roads with a speed limit greater than 40 mile/h (64 km/h) (ii) Approach to traffic signals, pedestrian crossings and similar hazards on main urban roads						0.55	0.60	0.65	0.70	0.75
A2 (difficult)	(i) Approaches to major junctions on roads carrying more than 250 commercial vehicles per lane per day (ii) Roundabouts and their approaches (iii) Bends with radius less than 150 m on roads with a speed limit greater than 40 mile/h (64 km/h) (iv) Gradients of 5% or steeper, longer than 100 m				0.45	0.50	0.55	0.60	0.65		
B (average)	Generally straight sections of and large radius curves on: (i) Motorways (ii) Trunk and principal roads (iii) Other roads carrying more than 250 commercial vehicles per lane per day	0.30	0.35	0.40	0.45	0.50	0.55				
C (easy)	(i) Generally straight sections of lightly trafficked roads (ii) Other roads where wet accidents are unlikely to be a problem	0.30	0.35	0.40	0.45						

Table 3. PSV of aggregate necessary to achieve the required skidding resistance in bituminous surfacings under different traffic conditions.

Required mean summer SFC at 50 km/h	PSV of aggregate necessary Traffic (in commercial vehicle per lane per day) 250 or under	1000	1750	2500	3250	4000
0.30	30	35	40	45	50	55
0.35	35	40	45	50	55	60
0.40	40	45	50	55	60	65
0.45	45	50	55	60	65	70
0.50	50	55	60	65	70	75
0.55	55	60	65	70	75	
0.60	60	65	70	75		
0.65	65	70	75			
0.70	70	75				
0.75	75					
AAV Chipped surfacings	not greater than 14	not greater than 12		not greater than 10		
Macadams	not greater than 16		not greater than 14		not greater than 12	

surfacings, and 0.8 for new concrete surfacings with maintenance coming into play at 1.0 mm and 0.5 mm respectively.

Table 4. The effect of macrotexture on the change in skidding resistance with speed.

Drop in skidding resistance with speed change from 50 to 130 km/h %	Texture Depth (mm)	
	Flexible	Concrete*
0	2.0	0.8
10	1.5	0.7
20	1.0	0.5
30	0.5	0.4

* when textured predominantly transversely

6. Surfacings with High Resistance to Skidding

It is, of course, pointless to nominate surfacings with given properties unless the materials required for them are economically available in the required quantities, and much research effort has been expended at the Laboratory in identifying or developing materials with resistances to skidding to suit all categories of road. It is convenient to consider these in reverse order of the categories listed in Table 2.

6.1 Category C Sites

Roughly 80 per cent of the roads of the country are covered by Category C, and as the geology of Britain covers the complete range of rock types, there is no shortage of roadstone suitable for these roads.

6.2 Category B Sites

When we move up the scale to Category B, which includes about 15 per cent of the road network, difficulties start to emerge. It can be seen from Table 3 that with traffic of 4,000 commercial vehicles/day/lane, the maintenance of an SFC of 0.45 requires the use of a stone with PSV of 70. Very few sources of such stone exist in Britain and those which are available are all in the gritstone group and may not be suitably resistant to abrasion (eg soft sandstones). In 1972, a survey of the arenaceous rocks existing in Britain was conducted in conjunction with the Institute of Geological Sciences, and the findings published[16]. Rocks were classified as to their suitability for making skid-resistant surfacings, the range being from those with a PSV greater than 70 and AAV better than 10 (Class 1) to the poorest materials (Class 6). Five sources were identified in Class 1 and eighteen in Class 2 (PSV 65-69, AAV 10). A number of the sources listed were from disused quarries or were unworked, and the intention was that, as demand grew, some of these exposures would be commercially exploited. Considerable interest has already been shown in a number of these.

A commercial development of the use of high-PSV aggregates is based on work at Birmingham University[18] in the late 1960s concerning the packing properties of graded aggregates. The development concerned the use of two aggregates with different wear properties and with good PSVs, and has led to a Patent being filed[19] in 1971 to cover the production of a proprietary surfacing material. The material is under observation by the Laboratory on a number of sites.

6.3 Category A2 and A1 Sites

When roads in Categories A2 and A1 (Table 2) are brought into the problem, the use of artificial aggregates has to be considered, together with the development of improved binders to attach them to the road. Calcined bauxite was first proposed for such use by the Laboratory in the late 1950s and trials which included this material were carried out on Trunk Road A4 (Colnbrook By-Pass). An epoxy-resin binder was used and although the treatment appeared prohibitively expensive to the traditionalists, it was soon taken up by the Greater London Council for use in high-risk situations (Plate 6) and has proved to be highly cost-effective at certain sites[17]. The treatment is now marketed commercially in Britain and the producing companies are in active collaboration with the Laboratory, with a view to future improvements and widening the scope by producing cheaper binders for use on Category A2 sites.

Plate 6. The use of calcined bauxite/epoxy resin treatment in London

Work is also in progress at the Laboratory to identify other improved binders for up-graded surface dressing work, and good results have been obtained with thermoplastic polymer additives to bitumen and tar.

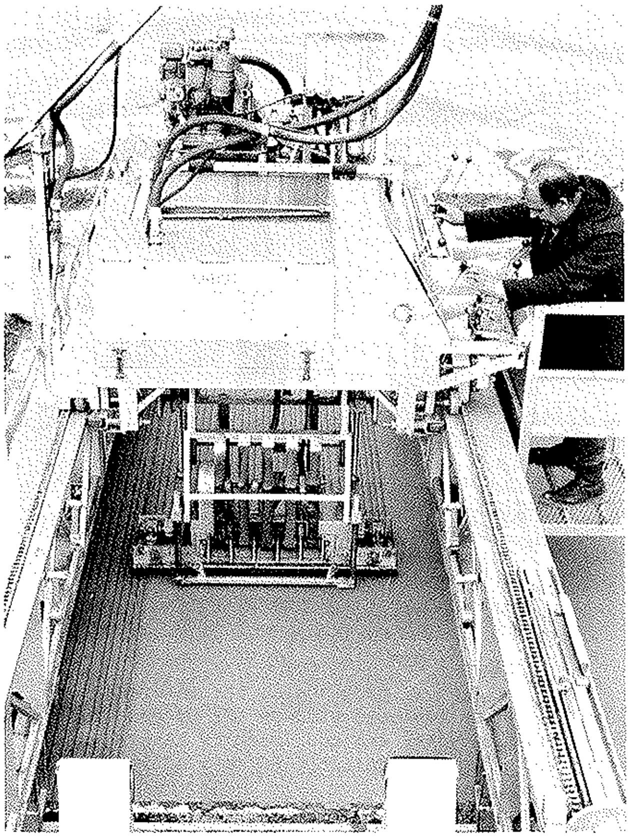
A summary of the work on high-PSV aggregates at the Laboratory and elsewhere was published in 1976[20]. It covers both natural rock aggregates and those manufactured from synthetic materials and contains a list of references on the subject. It concludes that few other artificial materials are as good as calcined bauxite, but a number exist which would fill the demand for an aggregate which is better than the natural rocks (either in polishing or abrasion resistance) and is less expensive than calcined bauxite.

7. Problems Associated with Texture

7.1 Noise

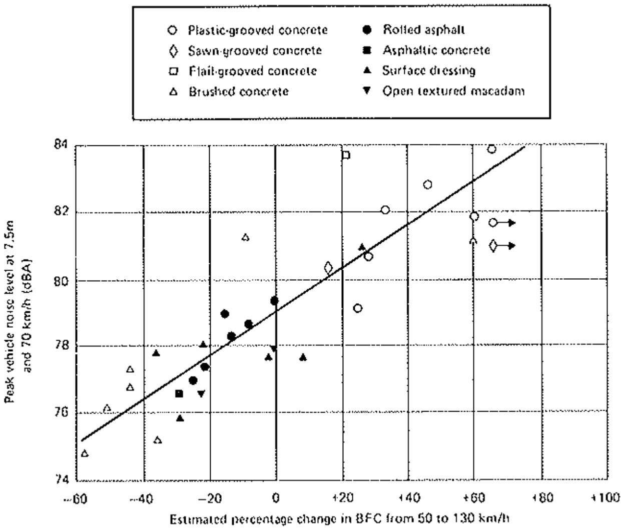
The problem of tyre noise generated on deep-textured surfacings was mentioned in Chapter 4 and this has been one of the subjects of recent close study at the Transport and Road Research Laboratory. The problem came to the fore because of the suitability of a concrete surfacing for accepting (and retaining) a deep texture while it is in the plastic state during construction. This advantage has, of course, been appreciated for many years throughout the world and in Britain a specialist machine was developed[21] for constructing 6 mm x 6 mm grooves rapidly and precisely (Plate 7). These are arranged at random centres to avoid the single-tone whistling noise which results from spacing the grooves uniformly, but when a major road scheme was built using the system, adverse criticism was received from local residents due to the total traffic noise generated. It was claimed that this was greater than that from a typical bituminous surfacing.

Plate 7. Plastic grooving machine for concrete.



A detailed study of the problem led to the conclusion that although the deep-grooved concrete did indeed create more noise than a typical bituminous surfacing, it was also providing greater benefit in terms of high-speed skidding resistance. Measurements from a large number of roads were then analysed and a summary of the results is plotted in Fig.8; this shows that the tyre/road noise emitted from a surfacing is linearly related to the effectiveness of that surfacing from the point of view of high-speed skidding resistance. For example, a bituminous surfacing with 2.0 mm of texture emits the same noise as transversely textured concrete surfacing with 0.8 mm of texture (see Chapter 5.2.3).

Figure 8. Relationship between estimated BFC of various surfaces and noise from light vehicles.



This finding dispels the previously widely held belief that concrete surfacings are noisier than bituminous ones and is important in the formulation of a specification policy which can cover all forms of construction in a general and equitable manner.

7.2 Spray

The problem of spray thrown up from the wheels of fast moving vehicles especially heavy commercial ones, has grown in importance as traffic intensities have increased. It is difficult to be precise about the numbers of accidents caused by poor visibility in periods of heavy rain but an estimate has been made[22] that 10 per cent of wet-road injury accidents may be in this category.

Research was undertaken at the Laboratory[23] in the 1960s to measure the depth of water on rolled asphalt and brushed concrete surfaces, using a 11 m x 5.5 m tilting platform and a 30 m rainfall simulator. The primary conclusions were that the distributions of water on the surface of rolled asphalt and brushed concrete during rainfall are very similar, indicating that, as far as the hydraulics of rain water flow is concerned, the surfaces can be considered to have similar roughnesses. Increasing the crossfall of the road pavement from 1 in 60 to 1 in 30 had a relatively small effect on the depth of water flowing across the road. Clearly any major improvements in this field are to come from surface texture improvements, but as these will in most cases involve increased noise, a compromise will have to be evolved.

In order that this compromise can be properly quantified, an apparatus is being developed which will measure the severity of spray thrown up from a surfacing. This operates on a reflected light technique, measuring the intensity of light scattered back from the spray particles. This work is currently in progress and will be reported when completed.

Considerable interest is being shown in many parts of the world in pervious surfacings of various forms and Great Britain is no exception. After early experience on airfields in the early 1960s, experimental surfacings were laid on roads in 1967 by TRRL and, independently, by Warwickshire County Council. In 1970 further experimental sections were laid by the Laboratory on Trunk Road A45 in Warwickshire[24], which at that time carried 4,500 commercial vehicles per day (in one direction) in the nearside lane. After 6 years, 4 of the 6 materials used are considerably reduced in perviousness but the 2 best formulations are still reasonably effective. One of these materials has been laid in a trial on Motorway M1 under the most severe traffic conditions (7,000 commercial vehicles/lane/day) and Plates 8,9 show the effect in heavy rain. Other trials are also taking place on some 10 sites in various parts of the country, and noise measurements are being made at some of these in addition to spray assessment.

Plate 8. Spray from standard surfacing on Motorway M1.

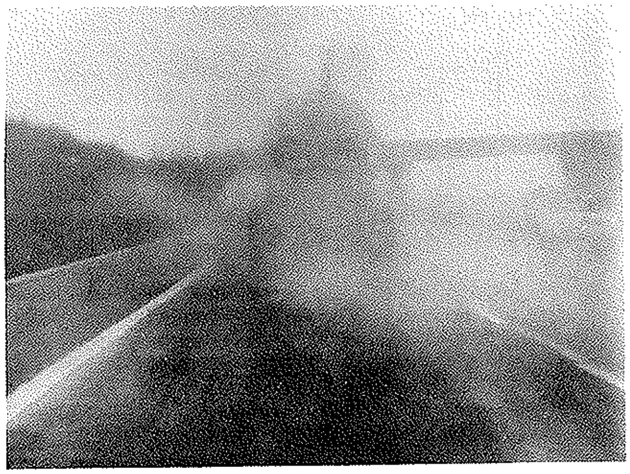
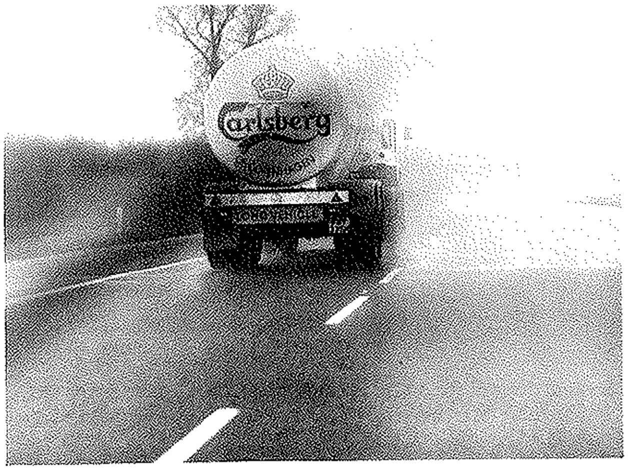


Plate 9. Spray from pervious surfacing on Motorway M1.



8. Specification of Materials and Texture in Practice

Most of the physical factors that have to be considered in writing specifications for skid-resistant roads have been discussed in the preceding chapters. The final problem is that of implementation in practice.

In Britain, the specifying authority for Trunk Roads and Motorways, ie those which receive their financing solely from Central Government, is the Directorate General of Highways of the Department of Transport. They receive recommendations from the TRRL, consider them in the context of the current economic, commercial and political situations, and issue specifications to suit. The subject of skid-resistance is a particularly delicate one, because the final decisions require a balance between cost and safety, with legal issues influencing matters.

The policy to be adopted is under consideration by the Directorate General of Highways but a decision has not been reached at the time of writing on the precise use of the proposals outlined in this paper.

A summary of these proposals is as follows:-

New construction:

1. The PSV of stone to be used would be nominated for the design traffic flow to maintain a given SFC. (Table 3 Chapter 5.)
2. The initial texture would be specified with the aim of giving zero drop-off in skid-resistance from low to high-speed (Table 4 Chapter 5). This would be backed up by a maximum AAV requirement (Table 3 Chapter 5).

Maintenance:

The inclusion of a road in a maintenance programme would depend on its mean summer SFC as measured by SCRIM, and on its texture depth as measured with a laser-based system at present under development[25]. The intervention level for texture would be aimed at 20 per cent 'drop-off' (Table 4 Chapter 5) but a national survey of existing road textures will be carried out to confirm the feasibility of this figure.

When this stage is reached, there will exist a complete package to enable British highway engineers to construct and maintain their roads to an optimum standard with the aim of keeping wet-skidding accidents to the minimum practicable level.

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