Proc. Instn Civ. Engrs, Part 1, 1979, **66**, Nov., 699–713

8144 DISCUSSION

Skid-resistant road surfacings and tyre noise

G. F. SALT

Mr D. J. Russell, Department of Transport

Mr Salt has sharply focused attention on the conflict between increased skidding-resistance and the environmental effect of noise. In reducing noise one unfortunately reduces skidding-resistance and therefore safety. It is not an easy problem to resolve, particularly for those of us who are concerned with the standards of skidding-resistance. Thirty years ago the top speed of most vehicles was 60–70 mile/h, but now this is the average cruising speed easily attained by the kind of vehicle on our motorways. What may have been a satisfactory texture some years ago is not necessarily good enough for the future. I suggest it would be very hard indeed to justify any compromise of safety. After all, the road user has a right to expect every effort to be made to ensure that he can travel in safety, provided that he complies with the speed restrictions. But where does this leave the unfortunate engineer when he is confronted by irate people who find any extra noise intolerable? He must bend an ear to their complaints as well as consider the safety aspects.

34. Micro-texture is not too difficult a problem because adequate materials are readily available in the UK to meet most requirements, but the problem of macro-texture and its noise implications is much more difficult to resolve. High speed roads present the greatest problem in this respect because of the need for greater texture, and also because the noise from the surface–tyre reaction becomes more pronounced in comparison with engine and transmission noise as the speed increases.

35. The Author has demonstrated a unique relationship between skidding-resistance on high speed roads and the noise. Also for the first time to my knowledge a quantitative figure for skidding accidents related to noise has been devised. This enables road engineers to see the problem clearly and, hopefully, to explain it in terms that can be understood by the public.

36. The two most common materials in use for high speed roads both have their advantages and drawbacks. As the Author says, hot rolled asphalt is used to surface about 85% of the high speed roads in the UK. Fig. 12 indicates that a texture of 2 mm is required to maintain the same skidding-resistance whatever the speed—a zero drop-off situation. It seems that a saving of at least £2000–4000 in accidents per kilometre would be possible if the texture could be raised to 2 mm. As an indication of the difficulty, the Department of Transport 1976 requirement for a 1·5 mm texture for its new high speed roads is already creating some difficulty for the asphalt industry, and although this texture is being achieved in some parts of the country, there are several contractors who still find it necessary to qualify their tenders for this work. It is my view that we must resolve this problem somehow or other, even if new techniques are necessary. The cost of accidents is too great for the Department of Transport to revert to previous practice.

Paper published: *Proc. Instn Civ. Engrs*, Part 1, 1979, **66**, Feb., 115–125.

37. The remaining 15% of high speed roads are surfaced with concrete. A texture of 0·8 mm to give a zero drop-off in skidding-resistance is relatively easy to obtain by transverse grooving or by a brushed texture as described in the Paper.

38. The noise from concrete bothers many people, and I find it particularly interesting that, according to measurement with standard equipment, for the same skidding-resistance concrete is no more noisy than asphalt, despite the contrary view being so often expressed.

39. Another problem with concrete is one of retexturing. Although a grooved surface is very durable and retains its skidding-resistance for many years, I do not know of any way that it can be readily renewed once it has worn down below an acceptable level, other than by surface dressing. Surface dressing of high speed roads is quite feasible, and has been done, but not everyone is enthusiastic about it. Perhaps surface planing and subsequent retexturing by flailed groover would be a solution. So far as I know this has not been tried in the UK.

40. These are some of the problems involved when attempts are made to set standards for skidding-resistance for either asphalt or concrete. Structural comparison of the two materials is another matter altogether. In view of the noise relationship with skidding-resistance, perhaps the Author will say if he considers there is any advantage in setting texture standards higher than the optimum levels required for zero drop-off in skidding-resistance (i.e., 2 mm), bearing in mind that motorists in the UK are not supposed to exceed 70 mile/h.

Mr W. E. Murphy, Cement and Concrete Association

In reference 2 to his Paper, Mr Salt proposes that new surfaces, whether bituminous or concrete, should have sufficient texture to give the same skidding-resistance at high speed as at low; Fig. 12 of the present Paper shows that this criterion corresponds to a texture depth of 2·0 mm for bituminous surfacings and 0·8 mm for concrete. The Author also proposes that surfaces shall be treated when the texture depths on bituminous surfaces and concrete surfaces fall to 1·0 mm and 0·5 mm respectively.

42. A concrete pavement, laid between road forms, can be given transverse grooves during construction at little, if any, greater cost than the alternative type of finish, brushing; a length of road has been laid in compliance with the proposal presented in the Paper. At present, a slip-formed road cannot be transversely grooved during construction but suitable equipment could be developed once a decision was made that all concrete roads carrying high speed traffic should be textured in this way.

43. Even under heavy traffic, a grooved concrete pavement with the recommended texture depth of 0·8 mm will have a long life before the texture depth is reduced to 0·5 mm. Although there is no experience of re-treating grooved pavements after wear, roads which never had adequate texture have been grooved satisfactorily.

44. The Author states that the peak noise produced by heavy vehicles is not significantly affected by the road surface. It would be interesting to have his views on the extent to which heavy vehicles blur the relationship between noise and texture depth.

45. Despite its merit, Mr Salt's work can only be of practical benefit if it is the basis for action in the practice of road construction and maintenance. It would, therefore, be of considerable interest if Mr Salt could indicate the response which his proposals have received from those authorities responsible for defining the standards of skidding-resistance required of our roads.

Dr K. R. Peattie, Asphalt and Coated Macadam Association

I should like to comment on the relationship between texture depth and accident rate at 130 km/h, which is a crucial part of this Paper, because it determines whether the cost of achieving a given level of texture depth is justified by the reduction in accidents and associated savings. Although there are certain approximations in the relationship, and reservations regarding the accident data, this relationship is so crucial to the Paper that I think it justifies a more detailed analysis.

47. Figure 10 shows that an increase in texture depth of 1 mm in a bituminous road surfacing produces a 20% increase in the change in BFC between 50 km/h and 130 km/h. The Author states that a similar relationship exists between texture depth and change in SFC. He says that the average value of SFC measured on all roads, presumably at the conventional speed of 50 km/h, is approximately 0·50, and consequently a change in texture depth of 1 mm is equivalent to a change in SFC of 0·10 on high speed roads. It would be somewhat clearer if the last statement were modified to read that it produces a change in SFC at 130 km/h of 0·10. This is an important point because texture depth is related to the change in BFC or SFC between 50 km/h and 130 km/h, and not to the absolute value of SFC measured at the conventional speed of 50 km/h.

48. The Author has introduced a measured increase in SFC and the resulting reduction in accidents to establish a relationship between texture depth and accidents, and hence between texture depth and a saving of approximately £2000/year per kilometre of high speed road. The measurements[2] of SFC were made at 50 km/h. Although some figures for texture depth are given,[2] these are not really adequate to enable any relationship to be derived between the SFC at 50 km/h and the figure that would be obtained at 130 km/h.

49. The site chosen by the Author to develop this relationship is rather unfortunate, since the intention is to extend these results to high speed roads. One would hardly consider a two-lane elevated urban motorway with several quite severe horizontal curves to be typical of UK high speed roads. The section of the M4 motorway referred to in the Paper extends westwards from the Chiswick Flyover: there was initially a speed limit of 40 mile/h for about the first mile, the limit otherwise being 50 mile/h. The first horizontal bend proceeding westwards from the start of the M4 motorway has quite a small horizontal radius, and I think that there were quite a lot of accidents in the early life of this part of the motorway. Subsequently—this may well have been after the surface dressing referred to by Mr Salt—the speed limit at the eastern end of the motorway was raised to 50 mile/h, a value which now exists over the total length of the elevated section. The traffic congestion on that road is such that at certain times of day it is not possible to go even at 50 mile/h.

50. Thus values of SFC have been measured at 50 km/h over a section of elevated urban motorway subject to speed limits of 64 km/h and 80 km/h, together with a change in accident rate observed on this section. It seems quite unjustifiable to claim, as the Author does, that these data can be used to establish the financial effect of requiring particular values of texture depth on roads carrying high speed traffic (at about 130 km/h).

Dr A. R. Williams, Mr J. C. Walker and Mr K. S. MacKellar, Dunlop Ltd

The contribution made by the two main geometric features of the road surface, the microtexture and macrotexture, in the attainment of wet friction are not accurately described in Fig. 2 of Mr Salt's Paper.[7] The microtexture is the dominant factor in both low and high speed wet skid resistance, where the penetration of the water film is essential to the generation of intimate contact between rubber and road aggregate and hence the generation of the frictional force.[8] The function of the macrotexture is solely that of facilitating the removal of bulk surface water from the tyre contact patch, and it has no significant contribution to make in the creation of any energy absorption mechanisms resulting from the bulk deformation of the rubber.[9]

52. The possibility of the friction level rising with test speed as indicated in Fig. 2 of Mr Salt's Paper is incompatible with this view. Although a few test results published by the TRRL using the braking force trailer show friction increasing with speed, the phenomenon is not generally observed in car or truck vehicle testing. The effect appears to be limited to the particular type of trailer–load–tyre combination used by the TRRL.[10] It is suggested that the results are an artefact of the test method. The trailer cannot be considered suitable for predicting the high speed friction performance of wet roads.

53. The percentage drop in BFC between low and high speed is not necessarily related to the grip at high speed.

54. Figure 15 shows that if the change in BFC is plotted against the BFC at high speed for the four basic road surface variants, any correlation will depend on the condition of polish of the road surface.

55. Plotting data published by TRRL, using results from the braking force trailer, in the form of percentage change in BFC against BFC at 130 km/h (Fig. 16), shows clearly that there is little justification for establishing that the former will predict the high speed BFC of a road surface.

56. Using the Stradograph, which operates under more realistic conditions than the braking force trailer, we measured the BFC and texture depth on seven surfaces of very different macrotexture configurations (Fig. 17). None of the results give an increase of BFC up to a maximum speed limit of 110 km/h. Three of the surfaces had a texture depth sufficient to produce at least a zero drop-off of BFC with speed as measured using the braking force trailer. No clear relationship of percentage change in BFC with texture depth measurement could be established.

57. The measurement of texture depth using a sand patch method only evaluates the voids in a surface and not the horizontal permeability. It is therefore not difficult to understand the difference in allowable texture depths for bitumen and concrete surfaces and why in general there is a low correlation coefficient between the BFC at 130 km/h and texture depth under conditions of similar microtexture.

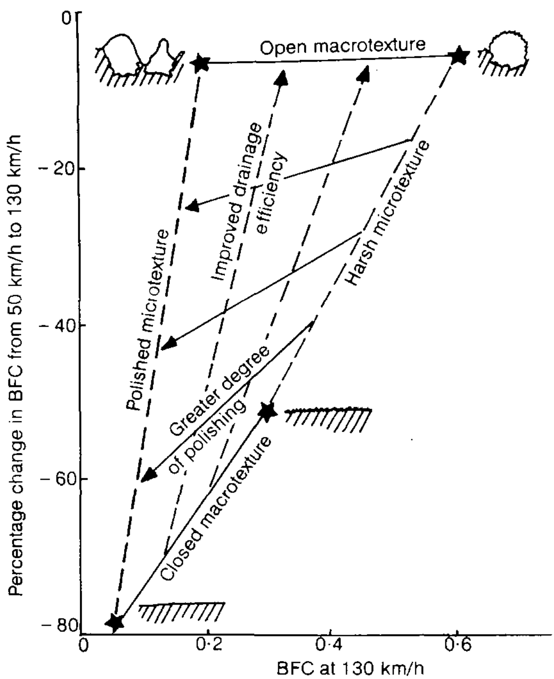

Fig. 15. Effect of macrotexture and microtexture on the relationship between percentage change in coefficient from 50 km/h to 130 km/h and coefficient at 130 km/h : wet locked wheel ; TRRL trailer-tyre 4.00–8, blank tread

58. The evidence for the provision of texture depth at the proposed levels[11] as a means of reducing wet skidding accidents has not been presented either in Mr Salt's Paper or elsewhere. The elevated section of the M4 motorway (the source of Mr Salt's statistics) has a traffic density and effective vehicle speed range similar to those of the Hammersmith Flyover on the A4. Here a surface of more than adequate macrotexture but insufficient microtexture gave an accident pattern which was dramatically changed when the road was resurfaced with a wearing course material of low texture depth, but with an adequate microtexture. The accident statistics are shown in Table 1.

59. There remains the need for some parameter to replace the speed gradient in representing the high speed wet skidding potential of a road surface; for example, the expression

$$\int_{V(\text{minimum speed})}^{V(\text{maximum speed})} \mu \, dV$$

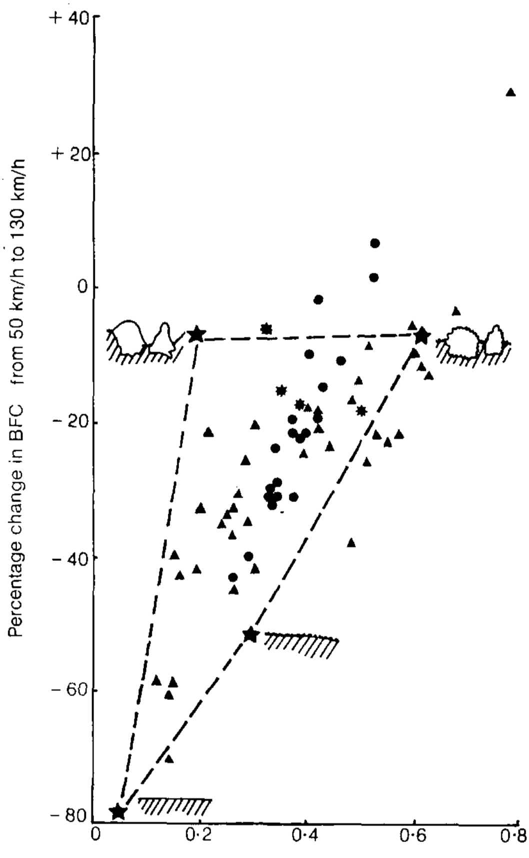

Fig. 16. Correlation between percentage change in coefficient from 50 km/h to 130 km/h and coefficient at 130 km/h : TRRL published road test data ; wet locked wheel ; TRRL trailer-tyre 4.00–8, blank tread

60. The noise data presented in Mr Salt's Paper is not in accordance with the standard practice of measuring tyre/road noise levels, which is based on a coast-by test with the engine off.[12] Walker and Oakes[13] indicate that certain macrotexture configurations minimize tyre-to-road noise generation and have proposed why this should be so.

61. The use of texture depth as the horizontal axis in Figs 12 and 13 in Mr Salt's Paper to construct Fig. 14 is not considered reasonable for the reasons discussed above. Measurement of total traffic noise on the Hammersmith Flyover before and after resurfacing indicated significant advantages in terms of noise reduction from the laying of a road surface designed principally for safer levels of wet friction yet with a macrotexture that will not excite excess and unnecessary levels of tyre-to-road noise.

62. The Paper does not mention the relationship between the macrotexture of the road surface and the wet friction and noise properties of truck tyres. Due to the greater contact pressures and lower maximum speed of operation, wet friction for truck tyres is mainly dependent on the microtexture characteristics of the road surface, and compared with the wet friction for car tyres shows relatively little dependence on macrotexture. Other aspects not considered by Mr Salt include the influence of macrotexture on energy losses in tyres. A reduction in rolling resistance coefficient (Table 2) from 1·65 to 1·43 would represent a fuel saving to the nation of approximately £20 million per year.

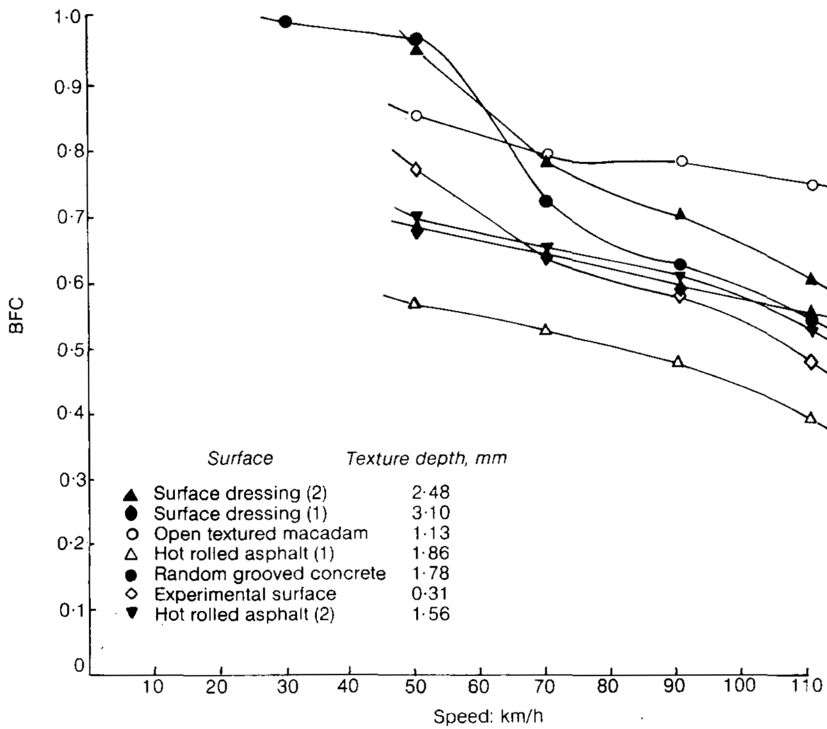

Fig. 17. Measurements of BFC using the Stradograph: locked wheel; water depth 1 mm at all speeds; tyre 165–15 plain-treaded; all measurements in nearside lane; measurements between wheel tracks (unpolished)

63. There is increasing evidence to suggest that higher values of tyre-to-road noise generation need not be a penalty for adequate high speed wet friction. There is an urgent requirement for continuing research into these and all other aspects of tyre-to-road interaction.

64. The points made in this contribution are covered more fully elsewhere.[14] The contributors wish to thank the Greater London Council and the County Surveyors of Warwickshire and Cambridgeshire for their assistance in the collection of data presented and Dunlop Ltd for permission to publish the research findings.

Mr G. H. Potter, Asphalt and Coated Macadam Association

I am as anxious as anyone else to protect the lives of my children and those of my as yet unborn grandchildren; but I think it would be of interest to know what evidence there is that skidding of vehicles actually travelling at speeds in excess of 100 km/h is a significant cause of road accidents. Undoubtedly accidents do occur on high speed roads and it is highly probable that in at least some of these it may well be reported that skidding took place. However, this does not necessarily mean that the skid developed while the car was actually travelling at these high speeds. Skidding may well have developed only after the vehicle had already slowed down substantially to a speed at which SFC at 50 km/h would be a more significant factor than texture depth in relation to accident rate.

66. I wonder if the Author would explain the definition of a skidding accident. I understand that it depends on two opinions: the opinion of the police officer who attends the accident and that of the driver involved in the accident. I think it is an automatic defence mechanism of anyone involved in an accident to say, 'I skidded'. Somehow or other it seems to remove some of the blame. Is the Author satisfied that

Table 1. Accident statistics for Hammersmith Flyover

	Total accidents	Accidents in the wet	Reported skidding accidents
Before resurfacing: 1 Feb., 1971, to 31 Jan., 1975	64	29	16
After resurfacing: 1 Mar., 1975, to 28 Feb., 1979	22	5	1

Table 2. Car tyre rolling resistance coefficients on surfaces of different macrotexture

Surface	Rolling resistance coefficient
Hot rolled asphalt	1·65
Random-grooved concrete	1·42
Brushed concrete	1·65
Surface dressing	1·60
Delugrip road surfacing material	1·43
Smooth metal drum	1·19

basic information on skidding accidents is valid, or would he not agree that the definition of a skidding accident leaves much to be desired.

Mr P. D. Rowden, Cementation Construction Ltd

As a layman, I am convinced of the force of the arguments that increase of texture depth increases safety and that therefore it is a laudable objective. However, I should like to mention one or two points about achieving the extra texture depth.

68. I get the impression that the 1·5 mm texture depth for asphalt roads was rather sprung on the industry. In my company we first met this in specifications of jobs for which we were invited to tender, and we sent it out as part of our inquiry to top subcontractors. Their immediate reaction was to hold up their hands in horror, and to give us a price for doing it the old way: they would not give a price for producing a texture depth of 1·5 mm. As main contractors we were not, of course, allowed to qualify our tenders to the Department of Transport for fear of getting them rejected, so we had to take a risk in submitting the tender that somehow we would get out of the mess. The day of reckoning is now coming, and we are having to put down black top and achieve this texture depth. We have engaged a subcontractor to do this, and it appears that in spite of genuine efforts over a period, he cannot achieve it—whatever supervision he applies—with his normal materials. He is now having to consider using sand from a more expensive source, which is farther away, in order to achieve it. He has been able in a month to get up to 1·4 mm but it appears to be his limit, and I should like to ask whether the Author feels that sufficient investigation into actually achieving this figure in the case of black top was carried out before the Department of Transport started to impose it on contractors.

Dr G. Lees, University of Birmingham

It is not the percentage drop so much as absolute values of skid-resistance that must be considered. In Fig. 14, from which the Author draws the conclusion that one must accept higher noise in order to achieve better skid-resistance, it is not skid-resistance that is plotted against noise; it is the percentage change in BFC. The conclusion is therefore not valid. A further point unconnected with noise, and concerned with skid-resistance only, emerges from Fig. 2. In this figure if one compares the bottom line of the top triangle (a descending line from low speed to higher speed condition) with, say, the horizontal line in the triangle below, it would be assumed, if one accepted the conclusion that it is better to have zero percentage fall than some finite percentage fall, that the horizontal line in the bottom triangle represented a better surface than the bottom line in the top triangle. Clearly this is not so. The one which has a finite percentage fall from low speed to high speed is a better surface at all speeds within the range than the one which has zero percentage fall, because it has better absolute values at all speeds below the maximum.

70. When considering high-speed skid-resistance (say 130 km/h), it must not be forgotten that the skid-resistance at lower speeds is also an important factor in considering stopping distance (or the momentum at moment of impact if a collision occurs). It is not possible for a vehicle to change from travelling at the supposed high speed to being at rest without passing through the intervening lower speeds. Its deceleration is therefore clearly also a function of the frictional coefficients at these lower speeds, and stopping distance would be less for the surface showing the finite drop in skid-resistance with speed (and by implication having a somewhat lower texture depth) than for that which the skid-resistance was independent of speed (by implication possessing a higher texture depth).

71. While it is sound engineering practice to specify minimum values of friction coefficient over the whole speed range (and I accept that this might well be done by specifying a minimum PSV stone to provide a minimum low speed SFC together with an associated minimum texture depth to maintain that value at higher speeds) it is

clearly unsound to exclude materials which would have higher coefficient of friction over the range than these minimum values but have a lower texture depth.

Mr C. Garrett, Kent County Council

As has already been pointed out, a major and critical step in Mr Salt's thesis depends on whether the recorded change in accident rate on the overhead length of the M4 motorway when it was surface-dressed is representative of the average relationship pertaining for all high speed roads. Not unnaturally some have questioned the validity of this step and the conclusions drawn as a result of it, particularly those concerning texture depth requirements. There would appear to be a more appropriate and accurate method of determining the effect of skid-resistance on accident frequency for high speed roads than either the method used in the Paper or the method of Giles *et al.*,[15] which again does not relate to typical high speed roads of today. TRRL carries out yearly skid-resistance monitoring by SCRIM of certain high speed roads throughout the UK; for example, in Kent they have surveyed the A20 Swanley Bypass since 1970. In addition, every year counties such as Kent carry out several thousand kilometres of SCRIM survey, principally on high speed roads. From TRRL in the past Kent County Council has obtained copies of the computerized accident records for Kent and by a regression analysis of this data combined with commercial vehicle traffic data (and if necessary meteorological data) it would appear eminently feasible to produce the required information. Due to the variation in skid-resistance throughout the year, and the variation in roadstones present on the high speed road network in the UK, it would appear possible to determine the incremental change in accident rate with skidding-resistance from, say, a sideways force coefficient of 0·2 to 0·7.

73. Texture depth is talked about as if it has a constant value across a road. My own experience of roads in use is that the texture depth of both concrete and bituminous surfaces varies from lane to lane and also across the width of a lane, particularly the nearside one which generally takes most of the commercial vehicle traffic. Fig. 18 shows the results obtained for a section of the A2 in Kent, the texture depth in the nearside wheel track being reduced from the general level of approximately 1·5 mm to approximately 0·65 mm.

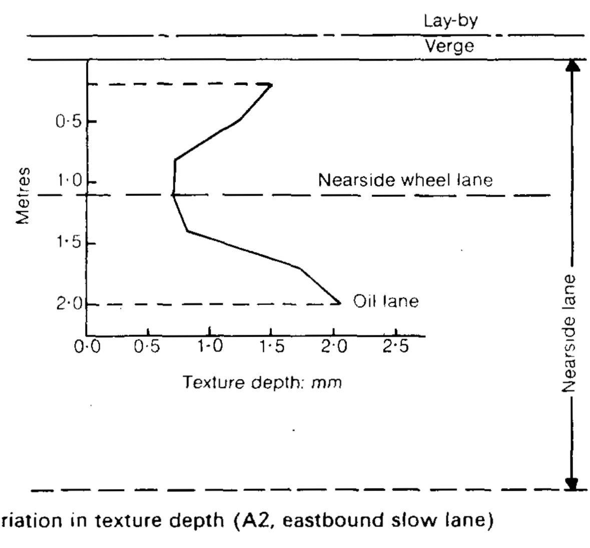

Fig. 18. Variation in texture depth (A2, eastbound slow lane)

74. It has been pointed out that due to the greater contact pressures and lower maximum speed of operation of truck tyres, wet friction is mainly dependent on the microtexture of the road surface, and that compared with car tyres, truck tyres show relatively little dependence on macrotexture. Hence there would appear to be a theoretical dichotomy due to the texture depth being monitored in the nearside wheel track of the nearside lane where it is lowest but least required, and not being monitored in the fast lane where the highest speed traffic travels.

75. The presently available method of monitoring texture depth is the sand-patch test which is slow and labour-intensive. In addition it is difficult and unpopular to carry out on high speed roads, particularly in the fast lane. The high speed texture depth monitoring equipment under development by TRRL will therefore be welcomed, if the role of texture depth and the required levels of it can be adequately substantiated. Other similar test equipment and systems developed by TRRL in the past such as SCRIM and bump integrator have, I think, been inadequately developed and it is suggested that counties such as Kent should assist in the final development and trials of this equipment.

The Chairman, Dr S. F. Brown, University of Nottingham

I should like to ask the Author whether the data in his Paper referring to open-texture macadam include friction courses, and, indeed, to question whether the concept of texture depth is relevant to this type of surfacing, which is essentially provided for drainage of surface water over an underlying impermeable surface. In view of the difficulties contractors are having in producing the specified texture depths, I should like to ask whether there is not some way in which an end-product specification could be introduced by a measurement of the resultant skid-resistance, instead of the specification of a particular texture depth.

Mr J. Tiplady, Eastern Road Construction Unit

In § 31, the Author derives the cost in accident terms of a 1 dB(A) reduction in noise. In the Department of Transport's recent standard calculations of accident costs, there is an element for grief, pain and suffering amounting to one third of the total cost of each accident. I do not know whether in the Author's calculation of £8 million a year he includes such an element. I suggest he ought not to do because the noise itself also involves suffering—the somewhat lesser suffering of people living alongside the road.

78. My second point concerns the worth of road research to reduce noise from high speed road surfaces. If we are to get a worthwhile reduction in the L_{10} (18 h), this must be not less than 3 dB(A). If the Author's conclusions are accepted and his figures are used, this means that a change in BFC from low to high speed of 45% will be inevitable. This sort of reduction in high-speed skidding resistance is unlikely to be acceptable. One wonders therefore what is the future of further research into quiet surfaces for high speed roads.

Mr J. Sargent, Kent County Council

It is a pity that Mr Salt seems to have confined his argument to the effect of noise from light vehicles and not attempted to evaluate the effects of varying carriageway textures on the total noise from a mixture of vehicles. Generally the noisiest vehicles on the roads are lorries: the TRRL showed that, at 80 km/h, total noise from heavy vehicles was some 8 dB(A) higher than for light vehicles at the same distance.[16] In general these heavy vehicles travel more slowly and so the peak noise not only will be higher but will last longer. Therefore, even though these heavy vehicles generally represent only a small proportion of traffic on the road they do contribute significantly to the L_{10} level. My own work in the vicinity of the M20 Ditton Bypass, which has a particularly rough brushed concrete surface, confirms this.

80. Because, as reported, transmission and engine noise tends to mask tyre noise

from heavy vehicles, the effect of changing the carriageway surface texture would be considerably less significant for these vehicles than for cars etc. Therefore in the 'real' situation of a mixture of traffic, both light and heavy, it would require a reduction in texture depth considerably more than indicated in Fig. 14 in order to reduce L_{10} (18 h) noise levels by 1 dB(A). Consequently, I feel that the Paper tends to underestimate the cost in terms of accidents of achieving what is probably an imperceptible decrease in noise.

81. I would be interested in Mr Salt's comments on the above and to know whether he has developed his appraisal to include the effects of heavy vehicles.

Mr K. S. MacKellar, Dunlop Ltd

It is surely time that the specification for the requirements of a bituminous surface were looked at in order to produce requirements that would both satisfy the need for high-speed skidding resistance and enable contractors to meet these requirements.

83. Figure 2 of Mr Salt's Paper indicates that there are three ways of reaching any given level of skidding-resistance at high speed. These are

(*a*) a higher level than required at low speed which drops as the speed increases;
(*b*) the required level which is maintained at all speeds;
(*c*) a lower level than required at low speed which increases as the speed increases.

While methods (*a*) and (*b*) are, I think, accepted, the possibility of significant increases in skid-resistance with speed must be doubtful on the evidence to date.

84. However, there is now surely sufficient data available to enable the required level of high-speed skidding resistance to be reached by specifying various levels of SFC value, each value having its own minimum texture depth requirement. This would permit the use of materials that reached the required level by either (*a*) or (*b*) mentioned above. It would both satisfy the need to have a routine method for establishing the high-speed skidding resistance of a surface (the same method as at present used) and more importantly enable contractors to provide the level of safety which everybody agrees is necessary.

Dr A. G. Davis, Centre Expérimental de Recherches et d'Etudes du Bâtiment et des Travaux Publics

The percentage changes in BFC from 50 km/h to 130 km/h given in Figs 10 and 11 are measured by the Miles trailer with a small diameter wheel. Watering conditions during testing are not given, other than that the surfaces were 'wet'.

86. At CEBTP, it is our experience that many problems exist in testing surfaces with high macrotexture if the contact area and normal load between tyre and surface are not reasonably constant, and if a minimum free water film thickness cannot be maintained at different speeds. Small wheel trailer units without autonomous watering systems are particularly prone to these problems. The scatter in percentage change in BFC in Fig. 10 (from -20% to $+15\%$, for example, at a texture depth of 1·5 mm) cannot possibly be due to differences in microtexture over this speed range, but is more probably a result of the problems mentioned above.

87. The diagrammatic relationship given in Fig. 2 would lead the reader to believe that the small-wheeled trailer showed a regular increase in BFC between 50 km/h and 130 km/h for those surfaces with a positive percentage change in BFC shown in Figs 10 and 11. The NASA of the USA have presented typical results obtained with the Miles trailer in a comparative study.[17] The characteristic curves of BFC with speed on wet surfaces show an initial fall in BFC on all surfaces, sometimes followed by a rise in BFC values at higher speeds. If similar curves of BFC with speed were obtained for the tests reported by the Author in this Paper, then the choice of speed interval for the percentage change in BFC becomes critical, and one must question the logic in selecting the absolute values of 50 km/h and 130 km/h for this correlation. The

arbitrary choice of these two speeds is not justifiable in a correlation study of this nature unless a reasonably linear progression in BFC is registered over this speed range, as is obtained with more sophisticated equipment such as the CEBTP Stradograph,[18] where vertical wheel load and watering conditions can be tightly controlled at all speeds.

88. Even then, one must question the use of the change in BFC over a given speed range to isolate the effect of macrotexture, since for two surfaces containing aggregates with different microtextures, the same change in BFC for both surfaces usually indicates that the surface with a rougher microtexture has a poorer macrotexture, and hence would be expected to produce less road noise at high speeds. To isolate the macrotexture effect, it would be preferable to divide the change in BFC from 50 km/h to 130 km/h by an absolute low speed value of the latter, say at 50 km/h, thereby eliminating the microtexture variable.

Mr Salt

Mr Russell asks whether there are any advantages in using textures above those corresponding in Figs 10 and 11 to zero change in skidding-resistance from low to high speed (i.e., 2 mm and 0·8 mm respectively). The justification for using deeper textures would hinge on there being a continuing gain in skidding-resistance as texture is increased, and while there is no doubt in my mind that such a gain does result from braking force measurements, I do not think that this would justify the extra noise that would result. I would recommend, therefore, that 2 mm and 0·8 mm are the maximum values that we should be seeking.

90. **Mr Murphy** raises two points. The first concerns the question of total noise from heavy vehicles and the extent to which this blurs the relationship between tyre noise and texture depth. We have established this relationship at TRRL and it is similar in form to that for light vehicles, although less significant. I am confident, however, that if very quiet heavy vehicles are developed then tyre/road noise will come into its own and the relationship will be about the same as that for light vehicles.

91. The second point raised by Mr Murphy concerns the response from the specifying authorities to the proposals discussed in the Paper. Although I cannot speak for my colleagues at DTp Headquarters, I think that it would be fair to say that the ultimate aim is to achieve textures as near to 2·0 mm and 0·8 mm as are practicable.

92. **Dr Peattie** disputes the basis which I have adopted for obtaining a measure of the monetary values involved in this problem and he has pinpointed the stage in the argument at which an equivalence has to be established between texture depth and absolute skidding-resistance. This is a complex relationship and one in which it is impossible to be precise. I have made the assumption that a straight line links skidding-resistances at low and high speed at any given texture depth, but I am aware that there is evidence that in some cases this line is curved, dropping to a minimum point and then rising to the high speed value.

93. Nevertheless, the ultimate result which I have used (1 mm of texture equating to 0·10 of SFC on a high speed road) agrees well with the only other attempt, of which I know, to establish the relationship. This is by Miss Sabey,[19] in which she states that '. . . up to 50 km/h . . . an increase of 1 mm of texture depth equates with ·05 in skidding coefficient . . . and for higher speeds, up to 100 km/h, 1 mm is equated to 0·15 coefficient'. These values span the figure of 0·10 which I have used and I consider that the agreement is well within the general accuracy of the calculation.

94. The question that Dr Peattie raises about the speed limit on the elevated section of motorway M4 is not relevant because I have only used data from that site to relate the change of low-speed skidding resistance with change of accident frequency, not high speed values. I have also made a 50% allowance for its not being a typical motorway. The reason for using the data is that it is one of the very few schemes that have been well monitored both before and after treatment, and that have a consistent surfacing over a sufficient length for the accident statistics to be significant. It is not perfect information but it is the best that we have.

95. In the contribution by **Dr Williams, Mr Walker** and **Mr MacKellar**, there is one major point to which I should like to respond and I think that this affects the whole basis of the contribution. It concerns the function of macro-texture in the basic mechanism of skidding.

96. The contributors quote Dr Williams[8] in claiming that micro-texture is the dominant factor in both low and high speed wet skid-resistance, and say that since the function of macro-texture is solely that of facilitating the removal of surface water from the contact patch, there can be no possibility of friction level rising with speed. They claim that the observed phenomenon reported by TRRL is limited to the test method adopted and does not apply in other braking circumstances.

97. I should like to refer Dr Williams and his colleagues to successive reports of the PIARC Technical Committee on Slipperiness, of which I am a member. In the report to the Prague congress in 1971, the reporter on the effect of the thickness of the water film on skid-resistance[20] concluded that the surface texture of the surfacing was of great importance in the measurement of longitudinal friction, both with a braked wheel at 13% slippage and a locked wheel; surfacings with a macro-texture of 2·5–4·0 mm gave coefficients of longitudinal friction very much better than finer surfaces even for reduced thicknesses of water.

98. In the 1975 report to the Mexico congress, the reporter (the late Dr Schulze) covering the relation between skid-resistance and accidents[21] quoted some well documented German experience from a 7 km length of motorway where the provision of a new surfacing with good micro-texture but poor macro-texture led to an increase in the number of accidents in wet conditions. Only when macro-texture was subsequently created was the accident level reduced.

99. Thus it can be seen that the fundamental concepts behind the work described in this Paper are not merely the views of the Author or of TRRL alone, but are held by the experts represented on that PIARC committee.

100. The point raised (§ 62) on the relationship between macro-texture and rolling resistance is one which perhaps has not received the attention it deserves. In the present world energy situation the effect should certainly be evaluated, but I doubt if it could influence the overall situation in an appreciable manner.

101. I think that the first of **Mr Potter**'s points is answered by the PIARC experience which I have quoted. The second point concerns the attribution of the cause of an accident to skidding and whether we are satisfied with the present accident statistics. All I can say is that, whether we are completely satisfied or not, the police records are the only data available, and if we wish to do anything numerate in this field we have to make use of them. One safeguard is that when we are considering changes in accident rate such as those I quote for M4, both 'before' and 'after' figures would suffer from any bias in the statistics, and so the difference can be taken to be a valid one.

102. **Mr Rowden** raises the contractor's viewpoint of the problems of meeting the specification requirement of 1·5 mm and I can only say that there were indeed many trials carried out before the specification was implemented. Most of these were on normal commercial contracts and I am satisfied that if the correct control is applied, especially to the rate of spread of chippings and to the rolling temperature, textures of over 1·5 mm can fairly readily be achieved.

103. **Dr Lees** claims that Fig. 14 does not enable any conclusions to be drawn relating noise and accidents because the plot is of percentage change of BFC and not absolute BFC. The use of percentage change was deliberately chosen to eliminate the effect of micro-texture, and as minimum values of PSV are included in specification proposals (which Dr Lees goes on to accept) I do not think that there is much difference in our basic thinking. I believe that Dr Schulze's evidence at PIARC[21] justifies the exclusion of high micro-texture, low macro-texture materials from high speed roads.

104. **Mr Garrett** wonders whether there is not sufficient evidence now available from data banks of skidding measurements and accident statistics for correlations to be established which are better than those of Giles and his colleagues from the 1950s. I

agree that the new statistics should be analysed but we should not assume that any correlation will be a straightforward one. Many factors other than skidding-resistance are concerned, including the road layout, the profile, adverse cambers and drainage. These all tend to make the relationships much more difficult to establish than might at first appear. However, it is our intention to tackle the problem at TRRL after the development of the high speed texture meter has been completed.

105. The **Chairman**, Dr Brown, asks whether an end-product specification based on skid-resistance could be used instead of a minimum texture depth requirement, especially with the aim of using pervious macadam surfacings wherever possible. While I agree that there are many advantages to be gained from using these surfacings, a complete end-product specification would lead to almost insuperable contractual problems, both at the tendering stage and also in the eventuality of non-compliance. If pervious wearing courses do prove to be genuinely cost-effective over the full maintenance cycle, then I think that they will have to be nominated in their own right rather than within a general end-product scheme.

106. **Mr Tiplady** may well be correct in suggesting that the element of suffering is included in both sides of the cost equation which I have proposed. My intention has been to put forward a decision-making process rather than a completely precise solution. I cannot, however, agree with the suggestion that the work is barely worthwhile because only a few decibels difference can be achieved. The results on Fig. 14 are from roads in use and they show a difference of 8 dB(A) from one extreme to the other. Within this range of possible surfacings, there are very real differences both in the noise to local residents on the one hand and in levels of safety to road users on the other.

107. **Mr Sargent** wonders whether the appraisal has been extended to include heavy vehicles and I can only repeat my reply to Mr Murphy. TRRL is involved, in another area of its work, in the development of quiet heavy vehicles, and the work discussed in the Paper assumes that commercial vehicles of the future will be much quieter than those at present in use. In that case the relationships discussed here will be much more applicable to heavy vehicles than at present.

108. **Mr MacKellar** also raises the possibility of using lower texture depths if the low speed SFC is good enough, and I think that that point is answered by the PIARC experience.

109. **Dr Davis** has, I think, based his comments on a mistaken assumption concerning the ordinate units in Figs 10 and 11. These are, in fact, precisely what he advocates (i.e., the change in BFC from 50 km/h to 130 km/h divided by the value at 50 km/h), and are expressed in percentage terms. They do, therefore, eliminate the micro-texture variable as he advocates. I agree with him that the relationship in Fig. 2 is only diagrammatic and it is not intended to indicate that a locked-wheel braking force trailer produces results exactly in that form. The actual results obtained at TRRL are of a form similar to those quoted by Dr Davis from NASA[17] and nearly always show a drop at intermediate speed (80 km/h) before any increase becomes apparent at 130 km/h. However, my answer to Dr Peattie indicates that only a small degree of approximation results from a straight line assumption.

110. I should like to express my gratitude to the contributors for the very salient points which they have raised in this difficult area. I must express slight disappointment at the lack of response from the local authorities, many of whose staff must be involved in noise problems from road surfacings, but I hope that the publication of this Paper will be of some assistance to them in attempting to quantify the issues involved.

References

7. Lees G. (Pell P. S. (ed.)). Skid resistance of bituminous materials and concrete surfacings. In *Developments in highway pavement engineering*—1. Applied Science Publishers, Barking, 1978, chapter 6.
8. Williams A. R. *et al.* The tyre/road interface—its effect on braking. *Conference*

on braking of road vehicles. Institution of Mechanical Engineers, London, 1976, paper C25/76.

9. BOND R. and LEES G. Advances in the physical understanding of tyre/pavement friction. Presented at the American Chemical Society, Rubber Division, May 1977.
10. NATIONAL AERONAUTIC AND SPACE ADMINISTRATION. Pavement grooving and traction studies. Conference held in 1968 by NASA, Hampton, Virginia, USA.
11. DEPARTMENT OF TRANSPORT. *Specification requirements for aggregate properties and texture depth for bituminous surfacings to new roads.* Her Majesty's Stationery Office, London, 1976, Technical Memorandum H16/76.
12. UNDERWOOD M. C. P. *A preliminary investigation into lorry tyre noise.* Transport and Road Research Laboratory, Crowthorne, 1973, report LR 601.
13. WALKER J. C. and OAKES R. D. The reduction of tyre road interaction noise. Paper presented at Aviation, Surface Transportation and Plant Noise Symposium, Dallas, 1979. Symposium sponsored by Environmental Protection Agency *et al.*, US Government.
14. WILLIAMS A. R. *et al.* Submission to the discussion on the paper by G. F. Salt, 'Skid-resistant road surfacings and tyre noise' (full version). Dunlop Ltd, Tyre Technical Division, Fort Dunlop, 1979, TD 1100.
15. GILES C. G. *et al. Development and performance of the portable skid-resistance tester.* Her Majesty's Stationery Office, London, 1964. DSIR, RRL, road research technical paper 66.
16. TRANSPORT AND ROAD RESEARCH LABORATORY. *Transport and road research 1974.* Her Majesty's Stationery Office, London, 1975.
17. Pavement grooving and traction studies. Conference at Langley Research Centre, Hampton, Virginia, USA, 1968. NASA.
18. MAJCHERCZYK R. Effect of the geometrical roughness of a pavement on water removal at the tyre–road interface and on vehicle skidding. *Annales de l'Institut Technique du Bâtiment et des Travaux Publics*, 1978, July–Aug., No. 363.
19. SABEY B. E. (CEMENT AND CONCRETE ASSOCIATION, ed.). Accidents: their cost and relation to surface characteristics. *Safety and the concrete road surface—design, specification and construction.* Cement and Concrete Asociation, Wexham Springs, 1973, 8–9.
20. PERMANENT INTERNATIONAL ASSOCIATION OF ROAD CONGRESSES. *XIVth congress, Prague, 1971: report by the Technical Committee on Slipperiness.* PIARC, Paris, 1971, 22–53.
21. PERMANENT INTERNATIONAL ASSOCIATION OF ROAD CONGRESSES. *XVth congress, Mexico City, 1975: report by the Technical Committee on Slipperiness and Evenness.* PIARC, Paris, 1975, 8–25.