

## The assessment of maintenance needs for road pavements

R. S. MILLARD & N. W. LISTER

**Mr F. J. S. Best**, Deputy Chief Engineer, Department of the Environment

Highway engineers know only too little about the state of their roads, and the apparatus and methods described in the Paper for the routine assessment of their condition should be of the utmost value and have come at a very timely moment when closer attention than ever before is being directed to highway maintenance programmes.

64. The Marshall Committee referred to the need for greater precision in forecasting maintenance requirements, and these can be obtained by the methods described by the Authors. My Department was no exception and we realized that the information in our possession about the strength and surface qualities of our trunk roads left something to be desired. This was quite evident from the adjustments which have to be made during the year to our annual maintenance programmes to deal with unexpected occurrences and occasional failures. For some years past we have employed the Benkelman beam to test for strength of pavements and the pendulum tester to measure skidding resistance. The Benkelman beam has proved a most useful tool and has enabled major maintenance works to be carried out in a most economical manner.

65. Examples which come to mind: on the M1 it told us with reasonable accuracy the areas where Foundations needed to be replaced. On the Stamford by-pass it told us of the thicknesses of overlay required to provide the necessary strength of pavement. Without the beam I think it very probable that in both these cases we would have overdesigned with considerable loss of economy. There is obviously a clear need for more apparatus of this kind.

66. The pendulum tester has, however, not been nearly so useful and, as the Authors point out, it needs considerable skill to interpret the results. The result of this has been that it has tended to be carefully locked away in various offices of the Department.

67. Both machines suffer severe limitations in use. They are slow in operation and are difficult to use on high speed roads, as personnel obviously have to be protected adequately from traffic. Neither can be used without a great deal of advance preparation. Sufficient lessons have, however, been learned from these machines to make it clear that substantial improvements in the economy and efficiency of our maintenance programme might well be practicable if better apparatus can be made available. The development of the SCRIM and deflectograph machines which might do just that is, therefore, particularly welcome. We are, therefore, in process of setting up a unit called the Road Surface and Strength Testing Unit which will have the job of assessing the effectiveness of operation of these machines in normal operational usage and of establishing whether they will lead to improved standards of skidding resistance and pavement maintenance thereby permitting the more effective use of available funds. Initially, at any rate, the unit will be operating in our South-Eastern Division, and a provisional plan has been drawn up for its work during the coming summer. This unit will work in very close conjunction with our agent authorities and the Divisional Road Engineer.

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68. The SCRIM machine will be used to establish the present level of skidding resistance on the 500 miles of trunk road in the division, and when the results are known sites with low readings of sideways force coefficient will be examined in relation to other known facts such as the accident record and alignment, and detailed investigations will follow.

69. We shall also have to consider the frequency of testing required, in order adequately to monitor the condition of the road surface, and many factors come into this. We know that stones tend to polish in the summer and roughen in winter, so that there is a relationship between climate and sideways force coefficient, and, as the Authors have pointed out in Fig. 11, age is probably not significant after the first year or so, but certainly dramatic changes in traffic volumes are. The deflectograph is a much slower machine, and we think that it is unlikely in practice that it will be able to cover more than about five miles a day.

70. Another limiting factor is that it cannot operate in extremes of temperature. For these reasons we shall be giving priority to testing roads scheduled to be re-surfaced during the current year and the deflexions obtained should indicate variations in strength so that assessments can be made of the depth of overlay required for each section of road. We also propose to carry out surveys of roads for which there are major maintenance proposals, and these will be used to assist in the assessment of the priorities to be given to particular schemes. We think that a sound procedure has already been established for deflectograph surveys and the results obtainable will form a most valuable addition to the information which can be used for the assessment of the condition of roads. Existing experience in pavement design and the availability of improved materials is such that remedial measures can be specified with some confidence once the weak areas of roads have been established.

71. However, we feel doubtful whether the total concept of SCRIM is quite so far advanced. Certainly the machine is a most useful device for the rapid determination of sideways force coefficient, but much remains to be done to find out all the factors which give rise to skid resistance and to set realistic standards in terms of materials and costs; and only when this has been done will the full potential of the SCRIM machine be capable of assessment.

72. The work undertaken by our unit should give us for the first time properly based data on the present state of all the trunk roads in the South-Eastern Division, and this information should be invaluable, enabling us to adjust standards, both as to skidding and strengthening, so that a practical balance can be obtained between costs and benefits.

**Mr J. A. Gaffney**, County Surveyor, West Riding

I should like to comment first on the way in which the Authors have drawn attention to the point made in the Marshall Committee Report about the timing of strengthening works. In laying down the criteria for pavement maintenance, structural deterioration, riding quality, slipperiness and other surface deterioration, Marshall put the last one first, and suggested that is the time when you start constructional maintenance. The Authors themselves have been tempted to say 'There is not much we can do to change the situation of investigation of the surface, and realization that something has gone wrong'. But there is no doubt that the importance of this Paper is that it points the way to elimination of this situation. This is really the nub of it, I would hope. I know it is perhaps optimistic, but I look forward to the day when I do not have to look at a road in company with various members of my staff and say 'We should have done something about this four years ago'. If we are successful in adapting the proposals here, we shall have gone a long way to eliminating that particular aspect.

74. I am tempted too, at this stage to say that, in a sense, the title of the Laboratory does not reflect the enormous importance of the work that the Laboratory and people like Dr Millard and Mr Lister do in effecting development work. It is not just a

question of research. It is a very difficult stage between research into the problems that need to be solved and the development of the machine which can help in solving them, and the RRL for many years has played a critical part in developing machines. There is no doubt that merely to refer to it as a research laboratory does not convey the impression of the work done in developing machines of the sort referred to in the Paper.

75. Turning to the details of the Paper, I was delighted to read the statement in § 12 that reconstruction of base and surfacing 'will normally prove to be a more expensive means of extending the life of the road than that of a well timed overlay'. One can only concur and wish that this statement was made more frequently into the ears of people who are influential in contributing to finances in the highway field: accountants and politicians rather than engineers. In general, engineers would agree with the Authors.

76. However, I am not sure that I am with the Authors in the last sentence of that paragraph where it suggests that dual carriageways with three or more lanes present a special case, because I would not have thought that in practical terms the reconstruction of the one lane could be cheaper than doing an overlay over the whole width if carried out at the right time. I accept that there might be an argument that it is wasted on the outer lane, but I have a feeling that digging out the slow lane is such an expensive process and the effect on the centre lane, the adjacent lane, would be such that I would have thought the overlay was bound to be the better bet in most cases.

77. As to the next part of the Paper which deals with deflexion methods, in the West Riding we have been using the Benkelman beam as a method of assessing performance. We do a series of tests with specific coring and positive investigations, but they are nearly always too late. Perhaps 100 km a year is achieved by this process, but it is nearly always for the purpose of major work. We hope—and perhaps this can be confirmed—that instead of doing 100 km a year, we would perhaps be investigating 1000 km, and to this end we are contemplating the purchase of a deflectograph in the West Riding in the coming year. This really ties in with the sort of figure that Mr Best was talking about in time scale and, as we have 7500 km, by eliminating a third of them on which we probably would not use the deflectograph anyway, it means once every five years which happens to be the figure quoted in the Paper. Running costs are anticipated to be about £6500 a year. We consider, therefore, that it will cost something like £6 per km surveyed which, if one thinks of it in terms of total money spent on maintenance, is probably not an enormous amount. I wonder whether that is the sort of figure for which we ought to be prepared.

78. The Authors may know that in the West Riding we have been trying the use of the Benkelman beam to investigate trench reinstatement, on the theory that if the trench exhibits the same qualities as the road, it is all right. If the trench is too hard or too soft, then we have got the wrong reinstatement. It is a struggle to get this principle established and accepted. The aim is to get uniform strength, assessing the strength of the road and of the trench by deflexion methods. The Post Office are so interested that they have bought a Benkelman beam and I think they are checking up on the principle. The Gas Board and the District Councils are interested and we are now testing compaction plant. The question posed is: Are we going to be able to use the deflectograph on the same sort of principle? We are not too concerned with the detailed sort of deflexions which were shown in Fig. 7; it will be comparative testing between the trench and the adjacent road. We think that possibly it can be used additionally at a time of the year when it would not be in use for other deflexion methods.

79. In § 32 it is stated that we have roads in this country of better riding quality than elsewhere. If so, I am tempted to lower our riding quality if only to impress upon the politicians that we need more money for roads, because if our roads have a good riding quality they assume that everything is all right! I should like some

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assurance on this; perhaps we are aiming our sights too high. The Paper says in § 35 that there are shortcomings in present methods of recording riding quality, and this is absolutely critical. One of the factors with which we are very concerned in the West Riding is the standard of riding quality following the effect of mining subsidence. This is extremely difficult to assess. In fact, on M1 we have got quite a length that has gone down about 30 in., and although the riding quality as far as a car is concerned is not too bad, visually it looks awful. We are now, with the Department of Environment, in the process of discussing with the National Coal Board whether to go for partial reinstatement or full reinstatement. It is really very difficult to assess what is acceptable and is it practical to think in terms of the development of a machine which might be used for this purpose?

80. As to skidding resistance and the use of SCRIM, I do not mind a great machine haring down the motorways measuring resistance at 100 km/h, but I am not very happy at the thought of it on all the other roads. It seems to me that we have got to try to strike a happy medium. I do not think the pendulum test is completely out of date in this context. If there is the right sort of expertise in using it I think it still has a tremendous scope, but when one sees the effect of wear of traffic, one wonders whether SCRIM is the answer in any case. I think it might just prove that we have a lot of slippery roads and does not necessarily give the answer of how to deal with the problem. Slightly off the subject of the Paper, I wonder whether the results on hot rolled asphalt are due to polishing or due to the precoated chipping going into the asphalt. Dr Millard rather destroyed my hope that if a high stone content asphalt is surface dressed with a very good chipping, we might have something better than the situation whereby stone was being pushed down into low stone content asphalts; but Dr Millard remarked that the effects of traffic on surface dressing were similar to asphalts with precoated chippings.

81. Finally, I should like to raise one point about this business of other surface deterioration. One of the main causes of deterioration in strength of a road is undoubtedly poor drainage. It is a bit of a hobby horse of mine that one should get rid of water, but a lot of problems are due to imperfect drainage conditions. I wondered whether there was any prospect of the deflectograph—I am trying to think of it as a multi-purpose machine—giving the information, not that we want a bit of strength but a bit of drainage. Over a length of road there might be a structural thickness similar to that on an adjacent length but it may show different deflexion characteristics due to different drainage properties on that length. It is just a possibility, it seems to me, that the deflectograph could be useful in this case and these investigations also may not be critical as to the time of the year.

**Mr L. W. Hatherly**, Greater London Council

First of all I would like to congratulate the Authors on a Paper that is most appropriately timed to follow the publication of the Marshall Report. There has for many years been a need to measure road performance and road engineers will welcome the availability of the deflectograph and the SCRIM machine: my Authority has both of these machines on order. We have made a detailed study of the back-up organization required to operate them and some of our thoughts may be of interest to the meeting.

83. It is first necessary to indicate the route to the driver of the test vehicle and secondly to record the results in such a form that they can be conveniently retrieved. Both of these needs can present major problems to authorities with substantial road mileages or with complex route networks; but we are fortunate in having commenced recording accident data on the computer, using a system of numbered nodes and links. The nodes are major road junctions and links are defined as the roads between nodes. We are now producing a set of strip maps to a scale of 1 in 1250 on which are shown the numbered nodes and also events such as pedestrian crossings or traffic signals which occur on the links between the nodes. The computer is being

programmed to accept a punched tape output from SCRIM and to extract the mean of the last four test values preceding an event together with the mean, maximum, minimum and standard deviation of the remainder. Emphasis is being placed upon the skid resistance at events since these are likely to be the accident areas. Arrangements have been made to re-centre the output tape at each event to compensate for the difference between the true road distance and the vehicle mileage. It has been found that these two values do not coincide because the test vehicle in a city is frequently required to make diversions around parked vehicles or other temporary obstructions to the carriageway. The production of a strip map is in itself a major operation since the rapid introduction of one-way systems, traffic management schemes and major road reconstructions makes it necessary to up-date manually the Ordnance Survey sheets from which the strip maps are produced.

84. One of the measurements required by the proposed Marshall method of rating is the deformation in the wheel tracks. In § 38 it is stated that the national skidding rates are 17% on dry surfaces, 32% on wet surfaces and 76% on icy surfaces. In the Metropolitan Police District, however, the skidding rates are 6% on dry surfaces, 15% on wet surfaces and 45% on icy surfaces. Thus the skidding rates in London appear to be very much lower than nationally, probably because in many cases drivers and witnesses are not aware of a skid occurring. This might suggest that skidding is not a problem in urban traffic, but this has been demonstrated to be false by the various accident studies that we have carried out following road surface improvements. We have shown that very large reductions in certain types of accidents can be achieved by road surface improvement—notably in rear end collisions—and it is felt that this is a much more reliable indicator to the need for skid resistance improvement than the skidding rate in urban conditions. This is a most important matter since 76% of all accidents occur in urban locations.

85. I should like now to refer to Fig. 11 which shows that the degree of polish of roadstones used as chippings in hot-rolled asphalt is dependent upon traffic intensity. I would like to make two suggestions to the Authors. The first is that the traffic effect on the degree of polish of roadstones is not exclusively a function of total vehicles, commercial or private, but it is also very strongly dependent upon the manoeuvres being carried out by these vehicles. For example, in London we find that the degree of polish imparted to roadstones in the immediate vicinity of a pedestrian crossing or a set of traffic signals is very much higher than elsewhere on the road, and this we believe to be due to the polishing effect of vehicles braking and turning; thus one can achieve a very high degree of polish on some areas of road which in fact carry a relatively modest number of vehicles. The second suggestion is that not all roadstones polish to the same degree with increasing traffic. I believe that the pattern of behaviour indicated in Fig. 11 may well be true of the majority of igneous rocks but I also believe that some classes of rock—notably gritstones and some quartzitic rocks—polish to a much lesser extent and their behaviour from the skid resistance point of view under very heavy traffic is often superior to an igneous rock with a similar polished stone value. The polished stone value therefore does not appear to be a satisfactory guide to the performance of roadstones under heavy traffic and there appear to be two alternative courses of action which can be adopted by road engineers. The first is to modify the polished stone value test in such a way that it imparts a greater degree of polish to the test specimens than the present test; and the second, and possibly interim, method is for road engineers to specify by name those chippings which they have found to be satisfactory in practice. This latter method is presently being adopted by my Authority. For the reasons outlined above I do not necessarily agree with the conclusions stated in § 59 since I believe that it is possible to achieve an SFC of at least 50 at 50 km/h using conventional roadstones as chippings, provided that the best polish resistant natural stones are used in the surfacing. Regrettably, however, the PSV test will not indicate the stones which should be used for this purpose.

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86. Finally, I have doubts about the suggested target values for skidding resistance proposed by the Marshall Committee and given in Table 2. In general terms I think these represent a reasonable compromise between what is regarded as practically feasible on the one hand and what is economically justifiable on the other. In particular I doubt very much whether the maximum suggested target figure of SFC of 0.55 is adequately high for the known high accident risk locations in urban areas. It may well be that an extension of category A given in the table is required for these locations which are numerically great, but in terms of total area of road surface are comparatively small. I refer of course to areas such as the immediate approaches to road junctions and pedestrian crossings which we are now treating with a form of surface dressing consisting of an epoxy resin with calcined bauxite grit on an increasing scale. Clearly, the introduction of SCRIM will enable more positive information to be obtained on this matter.

**Mr A. V. Wild**, Surrey County Council

Many counties find that the polish on roadstones is a major maintenance problem. The approach used by Surrey County Council has been on two lines: first, to select the most suitable of the roadstones offered commercially in the county, and to find and encourage the use of some high-quality roadstones not previously available to us and to use these roadstones to their best advantage in dressings and carpets appropriate to the sites; and secondly, to locate sites where polishing is becoming a problem, by using experience to assess the life of the surfacing under various site, traffic and weather conditions; by inspection and the use of the pendulum skid tester, and reports of damage to road furniture, vehicle debris and accident reports.

88. The selection of materials can be carried out with reasonable efficiency by means of sample and full-scale trials, using test methods which have been available for some years. The location of sites where polishing is becoming a problem is, however, very difficult. Visual assessment is a very poor method, and the pendulum skid tester has a very low output. During the summer of 1970 the Road Research Laboratory tested 360 miles of county and other local authorities' roads in Surrey in five working days using SCRIM. The county council wanted to determine the general state of the roads, and so a single pass at 50 km/h was made in one direction on all trunk, many principal and some non-principal and unclassified roads in order to get the maximum coverage. The sample included urban and rural roads of varying traffic density and speed. SCRIM's output was rapid and large. The 50 000 or so SFC results were punched on tape, analysed by computer and presented in a digestible form.

89. The actual quantity of work, though, is a great problem and we are still working and trying to analyse the results. The individual accuracy appeared to be good. Frequent zero checks during the runs were made, and checks using the pendulum on some of the worst sites gave the same order or result if some allowance was made for the texture depth. The main difficulty found during the trial was one of accurate siting of results. The method that we adopted was to have a lead vehicle guiding the SCRIM machine round the roads and a radio link between the two. Various sections of road were then indicated to the operator and he was asked to punch in junctions at roughly 400 m intervals if possible, to try to establish points along the tape. In fact, it was very difficult at times to get the junctions accurately located, and, as Mr Hatherly found, we had quite a lot of tape, or too little tape, at times for the length of road that was in fact tested. One ideal way is to tie up the road inventory with the location of points. The test run carried out for Surrey County Council should, I consider, be used as an initial run to determine the location of poor SFC lengths. These lengths should then be re-tested to locate accurately the bad areas. The vehicle speed was not too critical, and in general only a small increase in SFC was noted, when the vehicle speed dropped from 50 to 30 km/h. We did all our testing at 50 km/h—nothing at 80—when 20 m test lengths were printed out. The 10 m

test lengths we found were excellent. What was surprising was the number of 10 m and 20 m lengths that were slippery. We got a large number of these within a run.

90. The vehicle interfered little with other traffic, the test wheel being on the wheel track, but the vehicle itself was balked occasionally by slower vehicles. Stopping for lights and pedestrians caused most trouble, in the urban areas, and baulking at junctions, especially roundabouts, elsewhere. Offpeak testing and traffic control were thought necessary for some sites. Refilling of the water tank, which was done probably two or three times a day, caused very little trouble. We used a gully emptier and a centrifugal pump to transfer the water. Other people, I think, have used the mains. With about 10 water authorities in Surrey, we could not get enough co-operation to use this method. The vehicle was found to be under-powered at times. I believe this is particularly so if one is trying to test at 80 km/h. SFC fell fairly rapidly when the surface texture depth dropped below 0.65 mm. This is due to the smooth test wheel, and should be considered when interpreting the results.

91. The initial examination of the results allowed some unsuspected sites to be treated last summer, and the results have been of value in planning this coming year's surfacing and surface dressing work. Analysis of the results is not yet complete, but reasonable relationships are being established between SFC, texture depth, material, age and site category. These relationships again emphasize the difficulty of making compatible the recommended standards for SFC in the Marshall Report with the use of natural roadstones. The maintenance money is readily available. SCRIM impressed us during its short programme as a good maintenance tool which will be of great value to the highways engineer.

92. We also looked with interest on the Road Research Laboratory's use of the deflectograph and its value for maintenance assessment. Surrey have for some time used a deflexion beam to assist in the determination of the pavement strength of roads. The method has been of value where (a) the road has a history of heavy patching, and (b) traffic density has been increasing, especially vehicle weight. In this case the test has been of great value in assessing the strength of haul routes for motorways. Improvements where a new road line is to be partly superimposed on an old road is a third use.

93. The main problems of the deflexion beam have been the great slowness of operation and lack of working standards for other heavily constructed pavements. For lightly constructed roads, Surrey are finding that deflexions less than 20/1000 are acceptable for moderate traffic and only over 40/1000 in. is the road very weak. These standards are, however, very tentative, and deflexion beam results are used comparatively between sites and to supplement the results of other tests. The main trouble is that we have not enough experience to be able to use proper standards.

94. I have touched on two aspects of maintenance assessment methods which received much support from the Materials Section of the Highways Laboratory. Surrey County Council spend some £¼ million on surfacing and surface dressing. That is about £1250 per mile on principal and £550 on non-principal roads.

95. To assist in the determination of allocations to the 20-odd highway authorities in Surrey, the Materials Engineer carries out with each local authority's engineer an inspection of the roads proposed for surfacing and surface dressing in the estimates, and reports to the Assistant County Engineer for maintenance. If necessary, this inspection is followed by site testing. In this way it has been possible to determine the relative priority of the work throughout the county, obtain a consistency of standard of road, and be more consistent with the use of materials and methods.

96. Finally, a maintenance rating pilot scheme is to be tried, in keeping with the proposals of the Marshall Report.

**Mr Stapleton, Worcester County Council**

I enjoyed the Paper, having had some experience of resurfacing a motorway working to a specification based on the results of the Benkelman beam survey.

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98. In my experience, the use of the Benkelman beam has proved to be an invaluable guide to the engineer in the field. I think we could say that on the M5 in Worcestershire it gave us about a 70% correct prediction of what we could expect to find in the base. I think that figure is very good.

99. In fairness to the Authors and to the beam, it must be remembered that the Benkelman beam survey was carried out probably 18 months to two years before the actual work was carried out, and this is a very important point from the estimator's point of view. Would the Authors like to comment on that and whether one should up-date the information from the time when the survey is carried out to when the work is actually done?

100. The Authors have also stressed the importance of visual inspection. Again it is appropriate to sound a note of caution to those preparing designs and estimates for resurfacing or reconstructing major carriageways. Because of the difficulty of maintaining desirable headroom at over-bridges and the necessity to maintain the existing level at under-bridges, it may not be possible to strengthen the existing carriageway with an additional layer of asphalt as suggested purely by the results of the Benkelman beam survey. In many cases the entire carriageway has to be broken out and reconstructed to a greater strength at an existing level. On a length of motorway where there are many bridges per mile, this can result in far higher reconstruction costs than those indicated by the initial Benkelman beam survey. The alternative of obtaining additional head room by raising the bridge deck is not always possible or economical. I should like to ask the Authors whether this is one of the other considerations referred to in § 26 of the Paper.

101. I understand that the techniques developed so far do not readily enable the engineer to say at what depth a weakness in the pavement structure is to be found, and it may be necessary to undertake further survey work with the Benkelman beam on an exposed base. The exploratory nature of this work makes it extremely difficult to write a realistic bill of quantities, particularly for the preparatory breaking-out works, which is fair to both contractor and employers. My previous experience suggests that in some cases the preparatory and exploratory survey work is best carried out by the highway authority so that the contractors can be presented with a more accurate contract document for resurfacing. This applied more so in view of the latest instructions for preparing contract documents.

102. The proportion of exploratory and preparatory break-out work on the M5 has been of the order of one-fifth of the total cost of the job. Indeed, experience gained during the last three years in Worcestershire suggests that greater use can be made of the Benkelman beam and deflectograph when the preparatory work is undertaken directly by the highway authority.

103. I think the point made by Mr Gaffney about it being cheaper to anticipate putting a new wearing course on, rather than breaking out base, is a very good one. We found that if the percentage of break-out on the base does not go over about 1%, the breaking-out costs are about 20% of the total cost. We also found that we could reduce the breaking-out cost to a very economical rate, but the operation that cannot be done cheaper is to provide the bituminous material for the new base. That is a high price anyway, and however economical the breaking-out costs are, it is very difficult to reduce the cost of replacing the base. If the base is allowed to break up, reconstruction costs rapidly increase.

104. Reference is also made to improving riding quality to an acceptable standard of comfort. But surely riding quality is just as important from a structural point of view. A new carriageway which may be structurally sound but which has been constructed to a poor profile will be more likely to suffer from the impact loading of heavy commercial vehicles producing further deformation. Could the Authors say whether there is any correlation between the poor riding quality of a road surface and the rate of its deterioration?

**Dr S. F. Brown**, University of Nottingham

In discussing the use of surface deflexion measurements, the Authors state that at the time of measurement the condition of the road is noted, presumably qualitatively. Has any thought been given to the possibility of describing the condition of the road by some method such as the present serviceability index? While the PSI as devised for the AASHO road test is somewhat limited, it does take into account several factors and gives a numeric value to the road state. Would it not be possible to devise a similar rating system incorporating deflexion measurements, permanent deformation, traffic to date and the state of the road in terms of riding quality and cracking?

106. Vibration testing of road structures by use of the surface wave method is a technique which the RRL played a large part in pioneering. Has this non-destructive method of assessing pavement condition been considered for wider use than at present?

107. With reference to Fig. 5, perhaps the Authors could explain how early an 'early life deflexion' is and whether there is a reason for the coincidence of the lines for all the non-cement bound bases. Is there also an explanation for the discontinuity of the line for lean concrete at a life of  $10 \times 10^6$  axles?

108. The lines on Fig. 11 would seem to indicate that there is no deterioration in skid resistance after the first year. If the value reached by then is acceptable, the implication is that new skid resistant surfaces will not be required. Surely there is some general decrease in skid resistance with time and use other than in the early life of the road.

**Mr J. H. Scarlett**, County Surveyor, Buckinghamshire

My county, like Surrey, had the use of the SCRIM machine for five days in 1970. Mr Best has said that we need realistic standards, and this I find is a big problem. The SCRIM machine told us that of 317 miles which were tested in Buckinghamshire—again a mixture of roads—29.8% of the mileage tested had an SFC of less than 0.5. It did, I admit, enable us to take advance remedial action at two or three sites, so we welcomed its use for that reason. But if I may take a particular case, of the M1 in Buckinghamshire, it tells me that 44.9% of the length has an SFC of less than 0.5 which is the required standard. My computer accident record tells me that in the last four years—and I would remind you that M1 in Buckinghamshire was reconstructed about four years ago—from 1 January, 1967 to 31 December, 1970, there were 228 injury accidents on that length of road and 41% of those accidents involved skidding. To date, we have not been able with our computer program to relate the print-out from the SCRIM machine to our accident record, and it would obviously simplify matters to relate the sites of accidents to the lengths with low SFCs.

110. I should like to ask the Authors two questions. First of all, we found on one day in particular we were getting some rather high SFC values of 0.7–0.9. I wonder whether the Authors have checked the variability of the reproduction of results with the SCRIM machine. Secondly, one gets a lot of isolated low SFC readings—that is, single low figures at the 10 m intervals. Do the Authors feel that, having regard to accident prevention, there is any value in considering isolated low SFC readings; or should one only take note of cases where two or three consecutive low SFC readings occur?

111. One final point. From tests which we have done in Bucks, with the pendulum tester, we know that there is very considerable variability in the SFC on a length of road in a period of dry weather. Therefore, I would suggest that the SCRIM machine would be needed on the same length of road possibly two or three times in the period May to September to get an accurate average value of the SFC.

**Mr J. R. Duffell**, Hatfield Polytechnic

I should like further clarification of Fig. 11, on the point raised by Dr Brown. One of the problems, I think, is always to try to isolate the discrete projects for research students. Looking at Fig. 11, this suggests to me that the pre-coated chip, by the time that one year has elapsed, has been firmly embedded into the main matrix of the material forming the wearing course. Do the Authors have any comments on this general point? Do they feel that this graph in particular shows any further ideas for further research on the proportion of coarse aggregate within the rolled asphalt? Can one optimize the coarse aggregate to the exclusion of chippings?

**Sir William Glanville**, Past President

The developments described by the Authors are of considerable practical importance, and I am particularly interested in this attempt to rationalize road maintenance in terms of a specific set of tests. We have, of course, for years been thinking of particular tests, but, as far as I know, this is the first time that these tests have been set out in this way.

114. There are one or two questions that I should like to ask. I am particularly interested in these percentages—skidding rates. I refer to §§ 38–39 of the Paper. We had a comment from Mr Hatherly of the GLC about the percentages of the GLC as compared with these percentages. I wonder whether the Authors could give any information about these percentages and what they are based on. Are they based on recent experience or does it go back over a number of years? The figures are not, as I read them, in agreement with the figures in the documents or any published by the Laboratory which gave, I think, much lower percentages than those, and, I would have thought, much more in line with the figures which the GLC has given.<sup>9</sup> To me, these figures seem to be abnormally high. I should like more information about what they are based on.

115. I always feel that I must look more closely into results when they are presented as neatly as those in Fig. 11. Are the results related to the kinds of chippings used? Were they all obtained in one part of the country? How far do they depend upon location, upon the traffic, or is there anything else relevant which is known about them?

116. The SCRIM machine is an interesting development. It is a bit of a juggernaut compared with what they were trying to develop in the Laboratory, and I am not sure that I would like to meet it on a country lane travelling at high speed. But it seems to have value. One always wants to get figures for the length of the road so as to be able to assess it not on one particular result or a few results, but to get a good average. This itself, of course, presents a difficulty, as one or two speakers have mentioned, because even though you obtain more results, a great volume of results, you have got to know what to do with them.

117. How do you analyse them? You want also a standard method of analysing them. You have also got to decide what you do about choosing a particular line on which the tests are done. How many lines are needed to obtain sufficiently representative results? There are a great many points of this kind which arise once an attempt is made to introduce tests into practical use.

118. The difficulties with any form of skid test are, of course, numerous. They were numerous, goodness knows, when the first sidecar machine was used, and the skid resistance test or the pendulum test presented a whole series of difficulties many of which were not wholly overcome. One of the difficulties may be overcome by this testing method; I refer to the difficulty of obtaining useful figures at high speed.

119. The skid resistance tester did not get over that difficulty, but I should like to know whether the skid resistance tester is now lost in the past, so to speak. Does the RRL now regard it as something which they have given up? Is it buried? What is the position? Are skid resistance testers still being used? Is there any possibility of them being replaced by SCRIM within a reasonable period?

**Mr Nelson, West Riding**

Mr Gaffney has touched on many of the points which are of common interest to himself and myself. The final part of § 32 says: 'Vehicle design and travelling speed have a considerable influence on riding comfort and changes in design are likely to influence the requirements for road profile to achieve a given standard of riding comfort.' Do I understand from that, that the Authors really think that vehicle design and travelling speed will improve and increase to such an extent that we shall have to do something about the standards—the very high standards—which we are set in designing our high speed roads? I think it extremely unlikely.

**Mr D. W. Rolfe, Gloucestershire**

I suggest that the statement in § 41 that 'it is necessary to be clear that the simpler, much cheaper scaled down portable machines type (c) are not suitable for normal routine testing' may discourage the use of one of the most valuable tools at present in the hands of the engineer.

122. About 500 RRL portable skid testers are in use at the present time and as recently as 1969 the RRL reissued RN 27.<sup>10</sup> In Gloucestershire for the period 1963 to 1969 pendulum tests and texture depth measurements were made at all sites on trunk and principal routes (and most sites on other roads) where the police had reported skidding of any vehicle in an accident. In a typical year, 1968, there were 260 such accident sites where a total 107 injuries and one death occurred (about 3.5% of total road casualties in Gloucestershire). The skid resistance and texture depth at each site were measured by the methods described in RN 27. The cost of testing 260 sites was only £800.

123. Remedial treatment was limited by the amount of money available so that 'borderline' sites were not treated. Table 3 shows the reduction in the proportion of accidents in which skidding was reported for the five years 1965-69.

Table 3. Skidding accidents as a percentage of total accidents

Year	Dry road						Wet road					
	R			UR			R			UR		
	1	2	3	1	2	3	1	2	3	1	2	3
1965	8.4	11.1	9.8	19.5	18.8	18.8	18.5	19.1	18.7	26.3	26.3	29.4
1966	10.0	10.8	10.2	20.7	19.9	19.3	19.5	19.4	18.3	29.3	27.2	29.1
1967	8.1	12.8	10.3	16.8	23.7	19.6	22.7	21.0	19.2	33.6	30.2	30.0
1968	7.8	11.6	9.9	16.4	21.5	19.6	12.5	19.9	17.8	25.6	29.7	29.2
1969	4.5	9.3	7.0	13.1	20.7	17.5	7.4	16.0	14.2	20.6	27.9	26.0

1—Gloucestershire, excluding Bristol city. 2—surrounding counties. 3—whole of Great Britain. R—roads with 30 or 40 mile/h speed limits. UR—other roads.

124. Many factors such as the opening of the M4 to Tormarton in 1966 should have contributed to the reduction in total accidents and possibly to the proportion of skidding accidents in Gloucestershire (and in the surrounding counties). The results do suggest that the small cost of pendulum tests at skidding accident sites and the subsequent treatment of these sites is worthwhile and that the pendulum should not be discarded.

125. Although the Marshall Report does not make precise recommendations it may be presumed that eventually the use of SCRIM will enable the engineer to locate

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sub-standard roads before accidents take place. This will only be of value where there is sufficient money to treat all known accident sites before going on to those where accidents do not yet occur. It may be some time before SCRIM has got over its teething troubles and the empirical values obtained on a particular type of smooth tyre can be related to accident information from vehicles with treaded tyres. The RRL pendulum has a 10 year lead in this.

126. In § 56 it is stated that 'only seven quarries in Britain produce stone of the best quality for skid resistance'. Three such sources are used in Gloucestershire and there has never been difficulty in obtaining supplies. Prices in the quarry are comparable with those of lower PSV stone, e.g. igneous rocks. At the present time gritstone is being used for base courses because of the lack of demand for this stone. Two gritstone quarries have closed within the last 10-15 years because the only demand for their aggregate (used successfully on trunk roads) was for use in precast concrete products. Recent proposals to quarry a gritstone with PSV 73 were turned down after local quarries had submitted evidence that they could supply all demands.

127. It would be useful to know if the data given in Fig. 11 are for igneous rock or for gritstone, what was texture depth, and what was flakiness index of the chippings. It has been common experience that, using stones having the same PSV, a lower skid value can be obtained on a road surfaced with igneous rock than on one surfaced with a gritstone.

128. Joint small scale road tests done by RRL and Gloucestershire County Council suggest that stones laid with their flat faces exposed to traffic polish to give a lower value of skid resistance than that obtained with random chipping with edges exposed. This effect had been noticed in the past on Gloucestershire roads and in consequence for several years the GCC specification has required the flakiness index of coated chippings to be less than 25. Gritstone chippings with flakiness index of 12 or less and PSV 69-74 are obtainable at an quarry price of £0.40 per ton more than prices for normal production from the same quarry.

**Mr R. L. Mitchell**, Ministry of Roads and Road Traffic, Rhodesia

The technological development of overlay design is proceeding on parallel lines in Britain and Rhodesia. Retirement is of major interest to many countries which commenced their major infrastructure development immediately after World War II. Herein lies a major difference with Britain where presumably overlays are normally necessary primarily to restore ride, whilst in Rhodesia retirement is not only to restore ride but to raise the design condition in view of the increased traffic loads—increased from some 10 vehicles/day per lane to 1000 vehicles/day per lane and doubled in axle loading.

130. I fully agree with the axiom that asphaltic overlays should be given before structural deformation takes place, but it is difficult to obtain retirement funds before existing pavements distort or craze as the public is unaware of the fatigue problem. However, some American writers differ and recommend stage construction of black base and asphaltic overlays—surely a dangerous practice.

131. I have not seen the Marshall Committee recommendations for the timing of strengthening; in Rhodesia priorities are assessed from Benkelman beam deflexion results—some 2000 km of pavements were tested biannually—combined with present serviceability index ratings determined from the Portland Cement Association roadmeter, which give quick, convenient readings. The Bureau of Public Roads roughmeters (bump integrators) which the Authors were using had been discarded after the development of the roadmeter.

132. In the absence of the expensive La Croix deflectographs, we use Benkelman beams at an output rate of 30 km per day, the spacing between the dual readings being some 100 m as opposed to the 19 m of the Authors, which had restricted their output to some 1.5 km per day. Whilst Rhodesian output is higher it is possible that

its spacing should be reduced for statistical reasons, and I should welcome the Authors' comments. What distribution had the Authors experienced?

133. The spring thaw does not occur in Rhodesia which, in the absence of frost, suffers from a wet and dry season climate. Dr Millard and myself established test sites in Rhodesia in the early sixties and van der Merwe<sup>11</sup> had analysed results. He had shown that deflexions of well-drained pavement on average increase 13% above the mean after the rains, and drop 8% below after the dry season. Van der Merwe had also shown that outer wheel track deflexions were marginally higher and had also shown that before and after overlay reductions in deflexion approximated to theory.

134. This leads to consideration of Fig. 7. Could the Authors explain the data on which this was based? It must surely have been based on equivalent axle load calculations, on limiting design deflexions of the existing pavement and of the overlay material, and on deflexion test results either in inner or outer wheel tracks, taken in either the spring or the autumn.

135. On the subject of the 80 kN single axle equivalencies determined at the AASHO test road, I have certain reservations. This test had shown that equivalences had been based on various terminal present serviceability indices (rural main roads in Rhodesia are ideally retired at 2.5), but were established for only one climatic and geological condition, and presumably normally reflected subgrade failure.

136. Taking the 80 kN single axle as unity and considering for example a 100 kN single axle load we get AASHO equivalency factors of 2.57 and 2.35 for terminal PSIs of 2.0 and 2.5 respectively,<sup>12</sup> 2.30 using the Heukelan and Valkering formula for static loadings,<sup>13</sup> and 21.5 using the formula<sup>14</sup> developed from the analysis of innumerable plate loading tests. The divergence of the latter figure is serious; it may reflect different theory concepts, static loading or geological and climatic conditions though, in my opinion, the divergence is due to test failure in the borderline materials (gravels and thin bituminous surfacings) used in Rhodesia, as opposed to heavy crushed stone and asphaltic bases and surfacings used in the AASHO test road. Whatever the reason doubt is cast on the universal applicability of equivalency factors which affects the use of Fig. 7.

137. Again, Fig. 7 assumes the use of asphaltic overlays. It is my practice to calculate overlays in terms of granular material as many roads had to be thickened in granular material alternatively to, or additionally with, premix. Premix, when used, is counted as double its thickness in terms of granular base. However, premix and granular materials have differing limiting deflexions; in fact I wonder whether curvature measurements, as developed by Dr Dehlen of the South African National Institute for Road Research, might not be a better criterion for premix overlays. In any event surely the overlay material used would necessitate a considerable modification to Fig. 7.

138. I would also appreciate the Authors' views on the measurement of deflexion, firstly as to seasonal, and outer-wheel-lane allowance, and secondly as to its statistical determination. I use the mean plus two standard deviation concept—a 98 percentile design, assuming normal distribution. One difficulty experienced is that of determining the end points of any stretch of road for retirement. As the length under consideration increased the 'mean' deflexion (and hence overlay requirement) naturally reduced and it seemed that a 'running' computer program was necessary for selecting critical retirement lengths.

139. A further point in selecting a design deflexion results from the Rhodesian use of some 2% cement in base gravels. Whilst the *unconfined compression strength* is only some 1 MPa, the deflexion in these bases is markedly less than on natural gravel bases, but I doubt whether the overlay thickness could be reduced.

140. I conclude from the above arguments that Fig. 7 had to be extended for differing conditions of desired PSI, for differing materials in the existing pavement and for differing overlay materials and that the traffic axis in Fig. 7 had to be entered

with caution according to the dubious universal applicability of AASHO axle load factors.

141. Finally, the Authors tend to condemn the RRL pendulum tester, firstly due to its low output rate—this is not a problem in Africa where costs restrict special treatments to ‘black spots’—and secondly due to its unreliability where surface stone is larger than 12 mm, which is often the case. Accepting this limitation, could the Authors suggest a means whereby the sideways force coefficient could be adequately extrapolated?

**Mr R. J. Livesey**, Glasgow

It is noted that roads are more slippery in the summer period and subject to wide variations in slipperiness. Is there any indication that this could be due to the presence of biological slimes, bacteria or other similar material, not necessarily growing on the road surface but being deposited thereon to form a greasy surface when wetted? The incidence of biological activity is seasonal in effect.

**Mr Lister**

We at the Laboratory are very pleased at the enthusiasm shown by the Department of the Environment for the deflexion approach, and I am sure we shall learn much from the operation of their pilot study with the deflectograph. We have had three years of experience in testing roads with the deflectograph, and prior to that, seven years using the deflexion beam. The results have been most promising, and real money has been saved. The deflexion survey carried out on the Stamford bypass mentioned by **Mr Best** resulted in savings of about £8000 per mile of carriageway in the cost of strengthening the road by overlaying. On the Northamptonshire length of M1 the survey enabled the areas which only required the removal of the surface asphalt and its replacement to be distinguished from areas where the upper layer of cement bound base was damaged and needed replacement, and also from the areas where the entire depth of base needed replacement. It was gratifying that when the road was reconstructed, our predictions as to base condition were substantially correct. The saving was of the order of £6000 per carriageway mile. In both cases the savings are derived from a knowledge of the programme of strengthening which would have been implemented in the absence of a deflexion survey.

144. **Mr Gaffney** is correct in implying that at present our surveys are not normally anticipating pavement deterioration but are prompted by it. This is a pity. Our recommendations are in any case less accurate for a road which is already badly damaged. While there is a limited amount of maintenance money available, we cannot avoid this situation. At present the deflectograph will probably best be employed in optimizing the use of maintenance money that we have by defining the most urgent jobs and the most economic solution for them.

145. While the cost of materials in overlaying a three lane motorway will be similar to that of completely reconstructing its slow lane, I agree with **Mr Gaffney** and **Mr Stapleton** that the costs of digging out the existing materials would make the overlay the cheaper alternative particularly as the effectiveness of the reconstruction solution can be reduced if bad weather is encountered. We would much prefer to overlay wherever possible but have encountered opposition to this solution from authorities who have only recently added new fast lanes to two lane motorways.

146. It was hoped to survey 1000 km per year with the deflectograph. The working season is about 20 weeks, 12 in the spring which is the preferred operating period and eight weeks in the autumn when temperature conditions for measurement are also reasonably suitable. It is, however, possible to get misleading results in the latter period after an abnormally hot summer. It is as yet difficult to estimate the running costs of the deflectograph in detail. They will however depend on the way the equipment is utilized. We operate the vehicle with a driver and a technician.

If the vehicle is intensively used during the testing season and results are required quickly a larger team is needed for the immediate analysis of the records. The French authorities require four people to service each deflectograph, this figure probably reflecting the large amount of manual analysis of results which they carry out.

147. I am sure that the deflectograph could be used to check the adequacy of trench reinstatement if the trench is accessible to the machine. Most trenches run along the length of a road and the deflectograph is certainly manoeuvrable enough to operate with one wheel on the line of the trench and the other on the pavement to give comparative values. When used to give purely comparative results, it can be used at any time of the year.

148. Deflexion is more sensitive to sub-grade strength than to that of any other layer of the road and sub-surface drainage differences are therefore definitely distinguished by deflexion measurements. On the Northwich bypass drainage improvements were undertaken on a badly drained length as a result of deflexion survey.

149. **Mr Hatherly** raised a serious question, common to the operation of both SCRIM and the deflectograph; that of defining the position of the test vehicle on the road so that a particular result can be associated with that position. While great accuracy is not vital in siting overlays it is necessary to locate local areas requiring reconstruction to within 4 or 5 metres. He referred to the particular problems posed by passing parked vehicles in the town. We have had problems when operating the deflectograph on rural roads lacking local features which could be used for the purposes of location and are therefore planning to attach an automatic distance measuring device to the deflectograph.

150. **Mr Wild's** experience with the deflexion beam does not appear to be inconsistent with our own but without more information as to the traffic intensity on his roads I cannot comment in more detail. He mentioned the difficulty in developing standards from his own experience. We are publishing information more detailed than is given in the Paper later this year which should be of use in this respect. This will give recommendations applicable to the main forms of pavement construction for roads carrying medium and heavy traffic. There is very little danger in extrapolating results down to the lighter categories of traffic, although on the narrow lighter-trafficked road frost action and changes in the moisture content of the sub-grade between winter and summer play a bigger part in determining the performance of the road and the actual traffic perhaps less, than on the roads on which we have gained the majority of our experience.

151. **Mr Stapleton's** estimate of 70% success with the beam in locating sub-surface damage in a lean concrete base on M5 was encouraging. In these circumstances the measured deflexion is to a certain extent a function of where the tip of the beam rests in relation to the developing crack pattern in the base and individual measurements are therefore of reduced significance. The deflectograph, making measurements at 3.3 m intervals, should thus eliminate the uncertainties associated with a deflexion survey based on measurements every 17 m.

152. The timing of the application of overlays is important. Critical conditions generally develop when the road has carried about 75% of the traffic required to bring about complete failure. In a design life of 20 years this represents about 16 years' traffic when allowance is made for traffic growth. If failure takes place after only 10 years the margin between critical and failure conditions is reduced to about 2 years. While our recommendations are framed to allow for a delay of up to a year in implementing strengthening measures, longer delays can lead to substantial further deterioration of the pavement requiring more extensive repairs than originally recommended. In these circumstances we would therefore have to recommend a further deflexion survey to update the strengthening measures required.

153. There does not appear to be any completely satisfactory solution to the limitations imposed on overlay thickness by the presence of overbridges with limited

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clearance. Reconstruction on the immediate area of the bridge leaves the problem of ensuring a smooth transition on to the adjacent overlaid lengths. One solution would be to anticipate the difficulty by increasing pavement thickness in the area at the time of construction. Underbridges cannot always sustain the weight of an overlay required to strengthen its approaches. A compromise solution is required in these circumstances.

154. It is true that a deflexion survey does not indicate the source of weakness in a pavement. It is not however normally necessary to know this when designing an overlay and recommendations to be published will identify the circumstances where it is important. In making strengthening recommendations we do however take into account all available information as to pavement condition.

155. Where recommendations include reconstruction of the base and surfacing it may well be more economical for the work to be done by direct labour. There is then flexibility to remove the minimum material necessary. If the work is to be done by contract this flexibility should, if possible, be incorporated in the contract.

156. We have a limited amount of evidence as to a link between loss of riding quality in a pavement and its structural deterioration. On an early motorway bump-integrator results increased slowly with time before structural deterioration became evident and this suggests the possible use of a machine capable of measuring riding quality at high speed to select lengths of road for more detailed investigation by the much slower moving deflectograph.

157. The first of **Dr Brown's** queries referred to the concept of the present serviceability index (PSI) developed in America to describe the present ability of roads to carry traffic and whether we were likely to extend this concept, presumably bringing in deflexion as another parameter. The PSI is related to three physical factors: (a) the degree of rutting, (b) the degree of cracking on the road, and (c) the ride, expressed in terms of the longitudinal slope variance. The model is heavily dependent on ride, and gives little weighting to cracking of the pavement. An extensively cracked road, which from the point of view of the maintenance engineer would require considerable expenditure of money today, may still have a reasonable serviceability index.

158. When the concept was applied to experimental pavements at Alconbury Hill considered to be in sound condition we were surprised to find that nearly all were described as being failed. The subsequent survival of many of these pavements for a number of years suggests that as an absolute rating the concept is of little value. It may be possible to link deflexion and other factors in an overall performance rating, but it is unlikely that it will be derived from an extension of the AASHO approach. The non-destructive wave propagation test is a very powerful tool if used in conjunction with deflexion measurement. Deflexion will define overall stiffness, and with a certain amount of experience give some indication of where the weakness lies in the road. The wave propagation measurement will often identify this weakness and in our own experiments we have used the two techniques in conjunction to explain the way in which pavements fail. The main difficulty is again one of speed. If the deflexion beam is considered slow in the context of this Paper, wave propagation techniques are perhaps 10 times slower still. Given money and time, one would like to see a wave propagation team running in conjunction with several deflexion teams. Because of the time factor I am not sure that it is a practical possibility. When the French road authorities set up their organization for the planning of maintenance they intended to use wave propagation teams to examine roads with bound bases thought to be too stiff for the deflectograph to test. They have had to revise their ideas and are making the deflectograph more sensitive to carry out the work originally envisaged being done by wave propagation.

159. Dr Brown asked whether it was a coincidence that tarmacadam, asphalt and slag 'wet-mix' gave the same relations between deflexion and performance. Unbound bases are less stiff than the bound ones but greater thicknesses are required to

give any given life. The two factors tend to compensate to give similar deflexion/performance relations.

160. The discontinuity in the curve for lean concrete bases reflects the fact that under a moderate thickness of asphalt, whatever the strength of the pavement, a maintenance problem develops by lateral cracks in the base rupturing the surfacing and ultimately requiring major remedial measures to be taken. The thickest pavements we have under observation will require maintenance expenditure after about 10 million or 15 million standard axles. In the current edition of Road Note No. 29 the recommendation is to use a composite base with 150–200 mm of bituminous material which will effectively preclude these cracks coming through the surfacing. It will not, however, affect materially the relationship between deflexion and road performance that was obtained with the lighter traffic, and therefore for composite construction we extend this line as shown in Fig. 5.

161. In the first few months of its life the granular materials on the road will compact and the deflexion will consequently decrease. The sub-grade nearly always suffers a disturbance in the construction phase, also affecting deflexion values. We think measurements after six months are probably representative of an early life deflexion. If further deflexion measurements can be taken over several years, preferably in the spring, an even more reliable result will be obtained.

162. In reply to the first major comment in the lengthy written contribution from **Mr Mitchell I** would not agree that overlays are applied to British roads primarily to restore their riding quality. They are needed to avoid structural failure on both old roads and on the large amount of construction completed since the end of the Second World War. The commercial traffic on many of these roads is as intense as anywhere in the world; traffic which is growing both in numbers and in the damaging power of individual vehicles.

163. The spacing of deflectograph readings represents complete coverage of the road as the area stressed by one measurement overlaps that stressed by the succeeding one. This is therefore the ideal method of survey. Such a close spacing is not however always necessary and represents an expensive luxury if implemented on road systems having a high mileage and low traffic intensity. A practical choice of spacing is governed by many factors, including the type of construction being tested, the rapidity with which changes of subgrade and drainage conditions occur along the line of the road, the extent and distribution of visible deterioration and not least, the available test resources in relation to the length of road requiring to be surveyed. Where a road of uniform construction and surface condition is built over relatively unchanging subgrade conditions testing every 200 metres may be sufficient to characterize the road. Where conditions are more variable and particularly if a stiff cemented base is involved we consider the spacing of 17 m normally employed with the deflexion beam as barely adequate, particularly if local areas requiring reconstruction are to be located.

164. The Road Research Laboratory is planning to use a statistical approach to the optimal design of both the thickness and location of overlays. For such a system to respond sensitively to the rapidly changing conditions often encountered in Britain the close spacing provided by the deflectograph is most suitable.

165. In presenting his reservations as to the general applicability of the recommendations given in Fig. 7 of the Paper the correspondent expressed a widely voiced doubt as to the validity of the wheel load equivalences derived from the results of the AASHO road test in other environments. The performance of the thicker pavements at the test site was relatively unaffected by the severe conditions of the spring thaw which was the main cause of damage to the thinner pavements. The wheel load equivalences derived from their behaviour are however substantially independent of pavement thickness for the range of practical thicknesses used in Great Britain (Structural Numbers 2 to 6). These equivalence factors are therefore not particularly sensitive to changes in environmental conditions and their use in other

climates can be justified. It should be stressed that the Road Research Laboratory, while using these equivalence factors in both the design of new roads and overlays, does not accept the conclusions of the AASHO test regarding pavement thickness which will undoubtedly be influenced by changes in the road environment. Fig. 7 was derived from relationships between deflexion and performance obtained on overlays applied both to full scale road experiments and as normal maintenance practice. Knowledge of the reduction in deflexion brought about by overlays of different thickness was also obtained from this research programme. The recommendations are designed to be implemented before major structural deterioration has occurred, a condition not strictly definable in terms of present serviceability index. Details are given in LR 375 referred to in the Paper. The use of overlay materials other than rolled asphalt, which is standard in Great Britain for roads in the medium and heavy traffic categories, would of course modify the form of Fig. 7.

166. It is therefore concluded that the use of the AASHO wheel load equivalences is justified in our approach and that our recommendations are satisfactory for British conditions.

### Dr Millard

Mr Lister has replied to comments on the deflectograph; in continuing to take up issues raised on skidding and riding quality the first point to be made is that the three testing methods described in the Paper complement each other, the aim being to provide a routine method of measuring the condition of road pavements and thus to derive maintenance needs in numerate terms.

168. This restatement of aims helps in reply to Messrs Hatherly and Rolfe, and Sir William Glanville, all three of whom were concerned about the place of the portable skid resistance tester. SCRIM has been developed for a task that cannot possibly be undertaken by the portable tester, the routine examination of many miles of road at regular intervals. The portable tester will still have a use, particularly in expert hands, for special tests at sites of particular interest.

169. Many of the comments were on the mechanism by which road surfaces became slippery. Bituminous surfacings must rely on the nature of the exposed aggregate to maintain a high resistance to skidding. If the chippings become submerged in the bituminous substrate on which they are laid then there will inevitably be a loss in resistance to skidding. The aim, whether in surface dressing or with pre-coated chippings, is to provide a complete and persistent surface of exposed aggregate. Thus there are distinct possibilities of the process proposed by Mr Gaffney of surface dressing on a hard asphalt substrate. The skidding data in Fig. 11 of the Paper were all derived from asphalt surfacings on which care had been taken to make sure that a continuous surface of aggregate is always presented to traffic. Some of the results were from RRL experiments, some from normal work. All the sites were in the southern half of the country. But it does not seem likely that the results will be affected by the variations in climate in the British Isles.

170. There were several comments on Fig. 11 ranging from Dr Brown, who asked for how long resistance to skidding remains constant, to the apparent incredulity of Sir William Glanville on the consistency of the results displayed.

171. Sir William also asked about the provenance of the 'skidding rates' quoted in the Paper. The information on which these rates are based is of course derived from the accident records maintained by the Police. The figures quoted in the Paper are consistent with the picture over the past ten years, the rate on wet roads having stayed consistently in the range 32-35% whilst the rate on dry roads has steadily increased from 14 to the current 17%.<sup>15</sup> This could be taken to suggest that our measures to improve the skid resistance of wet roads have been having some effect in the face of increasing traffic speeds. But I would reiterate the comment in the Paper that changes in skidding rate can undervalue by quite a lot the effects of anti-skid treatment in reducing accidents.

172. We too were at first surprised at the consistency of the relation between traffic intensity and resistance to skidding illustrated in Fig. 11. It continues to be displayed in further results both on rolled asphalt and surface dressing and has been supported on one site in an unexpected way; when traffic decreased on the Colnbrook Bypass consequent on the opening of the M4, the resistance to skidding improved in proportion to the reduction in traffic.

173. There can be no doubt of the general conclusion illustrated in this figure, that with aggregate of given polishing characteristics as defined by their Polished Stone Value, the skidding characteristics of a bituminous surfacing vary inversely to the traffic intensity, and whilst traffic intensity remains constant so does the resistance to skidding. In answer to Dr Brown, we do not know for how long the effect persists. But it is reasonable to expect it to continue as long as the surface texture persists, i.e. until either the chippings are worn away by abrasion or until the surfacing becomes inadequate for other reasons.

174. These results were obtained on the open straight road. Mr Hatherly is of course quite right in his qualification that the polishing effect of traffic must be dependent on traffic manoeuvres and that where there is heavy braking and accelerating, more polishing must be expected. One of the most intractable facets of the skidding problem is that it is just in these situations of greatest danger where the highest resistance to skidding is needed, that the greatest polishing effect occurs.

175. He and Mr Rolfe are right too in noting that the correlation between the PSV and observed skidding characteristics on the road is not perfect. It would be remarkable to find a laboratory test that does simulate to perfection a full scale condition. But the disparities are not large and I think Mr Hatherly does the test less than justice in suggesting that PSV is not a useful guide in selecting aggregate for surfacings on heavily trafficked roads.

176. The pursuit of better correlation between test and road behaviour may well further complicate a test that is already far from simple and I believe that the right course now is to concentrate on establishing the test as giving reliably reproducible results and to use the experience we are gathering to interpret the results in selecting suitable aggregates for particular uses.

177. Several speakers gave useful information based on their early experience in assessing SCRIM for routine testing purposes. One of the first aims must be to test the validity of the skidding standards proposed by the Marshall Committee; I am sure that the work now in progress will show that these figures merit some revision. Mr Scarlett asked about the reproducibility of SCRIM measurements. Sufficient tests have been done to make sure that the machine gives consistent results provided it is correctly calibrated and checked at regular intervals. But it is important to remember that the skid resistance of a road surface is far from constant. It varies with temperature and it is materially affected by the weather in the preceding few weeks. This is why the mean summer SFC is employed to define skidding characteristics, summer because resistance to skidding is lowest in summer months, and mean because a representative figure must be based on measurements done on several occasions during the summer.

178. Isolated low figures of SFC and a single low figure over a 10 ft length are probably of little significance. It may well be worth locating the length to check by visual inspection whether it has unusual characteristics. But normally one would expect to apply treatment only when lengths of 40 ft or more are found to be slippery.

179. Mr Gaffney's comment that 30 in. of settlement from colliery subsidence under the M1 had not reduced riding quality below an acceptable level, reinforces our contention in the Paper that we may in Great Britain be valuing riding quality too highly. This will I hope correct the impression left with Mr Nelson; we do not believe that changes in vehicle design and increasing speeds will call for higher standards of road profile in new works. Certainly poor riding quality increases impact stresses and there is a potential for increased damage to the road structure—

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and incidentally for ground-borne vibrations which may affect buildings near the road. This correlation exists as Mr Stapleton supposes, and as we are able to quantify it more precisely we shall have better guidance on one aspect of minimum standards of riding quality.

180. Mr Livesey's suggestion that variations in resistance to skidding might be explained by biological activity is one of many hypotheses put forward to explain the effect. We have not been able to identify any biological activity on the surface of heavily trafficked roads, and the explanation of the effect, we believe, lies elsewhere most probably in mechanical and chemical effects on the surface of the road stones presented to the vehicle tyre.

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