THE LOCATION AND TREATMENT OF URBAN SKIDDING HAZARD SITES

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The first part of the paper reviews the research that has been carried out in recent years by the Transport and Road Research Laboratory and others in Great Britain and shows that for asphalt surfaced roads the sideway force coefficient can be predicted from a knowledge of the stone in the surfacing, the traffic intensity and the amount by which vehicles are manoeuvring. The difficulty of establishing minimum standards for skid resistance is discussed and it is suggested that the selection of a minimum standard depends upon economic considerations. Many roads which can be shown to be slippery when judged against existing standards are not necessarily hazardous and their treatment may not be economically justifiable. The majority of personal injury accidents occur in urban areas and the majority of these occur at road intersections. In London for example there are approximately 55,000 personal injury accidents each year and over 70% of these occur at road junctions. For this reason, action in London has been aimed at the junction problem and more than 800 junction and other similar hazard areas such as the approaches to pedestrian crossings have now been treated with an epoxy resin/calcined bauxite form of surfacing dressing. 'Before and After' accident studies on groups of the treated sites are presented and the economics of this form of treatment are examined. Two methods of locating sites where the accident rate can be reduced by surface treatment are described, based upon the use of a machine for monitoring skid resistance and the use of computerised accident data. It is suggested that the philosophy and the methods described in the paper could be applicable to many other urban areas.

The Wet Road Problem

The drivers' greatest hazards in wet weather are slipperyness of the road surface and impaired visibility, the latter presenting different problems by day and by night. In 1971 in Great Britain, there were 258,535 personal injury accidents of which 73,374 occurred on wet roads. Codling (1) has shown that the increase in accidents on wet roads (whether raining or not) is about 50% over the expected number on dry roads when all other conditions are the same. This means that in 1971 there was an excess of about 25,000 injury accidents on wet roads which would not have occurred had the road been dry.

Sabey (2) suggests that a measure of the increase in accidents involving skidding due to road wetness can be obtained by comparing dry and wet road skidding accident rates (i.e., the percentage of accidents in each condition which involve skidding). The accident records for 1971 show that the dry road skidding rate was 11.8% and the wet road skidding rate was 27.8%. Since the same roads exist whether it is dry or wet and they carry largely the same vehicles with the same tyres and driven by the same people, Sabey concluded that it was reasonable to assume that the difference in skidding rates between dry and wet conditions is primarily due to the change in skidding resistance brought about by the wetness of the road. The increase in the wet road skidding rate over the dry road rate represents and increase of 13,000 injury accidents in 1971. Sabey further noted that the reporting of skidding on wet roads tended to be under-estimated so that the figure of 13,000 injury accidents may well be a conservative estimate.

Nationally, therefore, it would appear that there is a potential saving in accidents of at least 13,000 annually which could be brought about by an improvement in road surface skid resistance. Experience in London particularly, as described later in this paper, suggests that the accident saving potential may be considerably higher than these figures, at least in so far as accidents in an urban situation are concerned.

The annual cost to the community of these 13,000 accidents attributed to low skid resistance is conservatively estimated to be £35,000,000 (1974 values). (3).

The Factors Which Affect Skid Resistance Of Roads

These are, for vehicle speeds up to about 40 mph and for asphalt roads:-

1. The character of the stone exposed on the surface of the road,
2. The traffic intensity and
3. The extent to which vehicles are manoeuvring.

For many years, the significance of the type of stone predominantly exposed in the surface of the asphalt road wearing course has been understood and it is widely accepted in the United Kingdom that the resistance to polishing of road stone can be measured by the polished stone value (psv) test of British Standard 812 (4). In general terms, the higher the psv of the aggregate then the higher will be the skid resistance of the road surface.

The most significant new knowledge in this field concerns the effect of traffic wear on skid resistance of road surfaces. When new, most surfacings have a high resistance to skidding but it falls during the first year under the polishing action of traffic. The extent to which it falls depends upon the nature of the stone exposed in the road surface and also on the traffic intensity, particularly, it seems, on the intensity of heavy vehicles with high tyre contact pressures. Thereafter, provided the traffic is constant, the mean skid resistance will decrease and if for any reason traffic is reduced then the skid resistance will increase to a higher value. In other words the action of traffic in polishing the road surfacings is balanced by the natural weathering which makes the surface rougher. The heavier the traffic, the lower will be the skid resistance at which this balance is struck.

Salt and Szatkowski (5) have illustrated the combined effects of traffic intensity and stone type by Table I which shows the polished stone value of aggregates necessary to achieve a given skid resistance in a bituminous surfacing where coarse aggregate forms the majority of the exposed surface, under differing traffic conditions. The Table refers to a straight road condition in which traffic is rolling without braking, turning or accelerating. Hosking and Tubey (6) have shown that there is a further reduction in skid resistance caused by the effect of turning and braking and conclude that aggregates to be used in surfacings at most sites where traffic is turning or braking should have a psv at least 5 units higher than that which is indicated for similarly trafficked event-free sites in order to maintain the same level of resistance of skidding.

In general terms, it has been found in London that the predicted values agree reasonably well with measured values although it is not always easy in practice to establish the various factors with precision.

The implications of this work are indeed unfortunate. It is immediately apparent that it is virtually impossible to obtain a sideway force coefficient (sfc) in excess of about 0.45 using natural aggregates on any road carrying more than 4,000 commercial vehicles per lane per day since in Great Britain there are no natural aggregates available with a psv above 75. There are only 2 or 3 quarries producing hard and durable aggregates with psv's between 70 and 75. Higher sfc's can be obtained only by using expensive artificial aggregates having a high resistance to abrasion and to polishing such as the R.A.S.C. (Refractory Grade A, Super-Calcined) grade calcined bauxite from Guyana (7).

However, the highway engineer is now in a position to specify and use an aggregate to give any required sfc within the limitation given above, based upon a knowledge of the probable traffic intensity.

The above comments apply to roads surfaced with bituminous materials where traffic speeds are relatively low. Where traffic speeds are high, skid resistance is affected by coarse or macro-texture which is required to provide a path for water to drain from the road surface and to be dispelled rapidly away from the contact area between tyre and road (2). It is the macro-texture which influences the rate at which skid resistance falls off as speed increases. Fortunately the lack of macro-texture does not present a problem in a city with a predominantly slow speed traffic pattern. Since all of the heavily trafficked roads in London are surfaced with bituminous materials the particular problem associated with concrete roads will not be discussed in this paper.

The Urban Accident Pattern

This can best be illustrated by the situation in Greater London which includes an area of some 1,600 sq.km. containing about 10,000 km. of roads of all types. Some 50-60,000 road accidents involving injury or death occur in Greater London each year of which no less than 35,000 or 70% occur at road junctions. Further, about 80% of these road accidents occur on the 10% or so of the roads which carry the heaviest traffic loads. A situation thus exists in which there is a large concentration of accidents at clearly defined locations on a small proportion of the total road network. Nationally, about 50% of all of the road accidents involving injury or death occur at urban road junctions. It is at such locations that the skid-resistance of the road surface will be lower than elsewhere on the road network because of the concentration of vehicles in clearly defined lanes, with a high proportion of them executing manoeuvres such as braking, turning or accelerating and thus imparting extra polish to the road surfacing.

There has been little positive information on the relationship between the skid-resistance of the road surface and accident levels at these high risk areas in urban situations but nationally skidding is considered to be a contributory factor in about 28% of accidents occuring on wet roads. In London the wet road skidding rate is rather less than 15% so that it could perhaps be considered that lack of skid resistance is not a major factor in causing accidents. Because of the lack of positive information and also because of a suspicion that the wet road skidding rate was not a good index of the risk rating in a city, the Greater London Council embarked upon a programme of localised skid resistance improvement at accident-prone junction sites in 1968 after a series of preliminary trials to establish the feasibility of using a system of surface dressing with an epoxy resin binder and calcined bauxite aggregate (8). The results from the first series of trials were so encouraging in terms of accident reduction that it was concluded that the incidence of skidding on wet roads in a city was very largely under-estimated. This may well have arisen because of the slow traffic speed in urban situations and the difficulty of establishing whether a vehicle is in a locked wheel condition before the accident impact occurs.

Standards Of Skid Resistance

There have been several published tentative minimum standards for skid resistance (9), (10), most of which suggest minimum values for selected types of sites. In general, the most dangerous sites require the highest skid resistance but it has now been shown that the higher values proposed are very often not obtainable with natural aggregates because the most dangerous sites generally carry the most traffic with the greatest amount of

Table 1. PSV of aggregate necessary to achieve the required skidding resistance in bituminous surfacings under different traffic conditions.

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

* SFC values in these traffic conditions are sometimes achievable with aggregates of extreme hardness and very high resistance to abrasion, such as certain grades of calcined bauxite.

polishing action.

The most recently published set of tentative standards, by Salt and Szatkowski (5) introduces, for the first time, the concept of risk rating. From his knowledge of accident history and local knowledge, the highway engineer is required to assess the relative accident risk of a given site and it is suggested that lower minimum standards can be assigned to low risk areas in each particular category. In theory this is a sound concept, but it pre-supposes a good accident recording system and also implies the acceptance of a given level of accident risk which few engineers would be prepared to quantify. On the other hand, it provides a method of apportioning priorities when expenditure is limited, and as such it is a valuable document.

for several years the authors have been attempting to derive basic relationships connecting road surface skid resistance with accident levels at various standard types of junction or hazard areas in a city. The establishment of such relationships is clearly desirable to permit the development of an overall strategy for road maintenance management based upon a sound economic assessment of accident costs. It must be recognised that because numerous factors other than skid resistance are involved, some of which are impossible to quantify, the relationships cannot precisely predict the performance at individual sites. The work to date has demonstrated that there is a statistically significant correlation between accident rate and skid resistance. There is evidence to suggest that the statistical relationships defined by the regression equations are also functional relationships and that an increase in skid resistance results in a reduction in accident rate.

These studies also supported the important finding reported by Schulze et al (11) and Schlosser (12) that, within normal ranges of skid resistance, there is no threshold level of skid resistance beyond which a further reduction in accident levels cannot be achieved. It would appear that the concept of a general minimum acceptable level of skid resistance is illusory and that the selection of an appropriate minimum value must be based upon an economic assessment of the cost of attaining it in relation to the possible accident savings.

In London sites where accident reductions can be achieved by a road surface skid resistance improvement have been selected by the operation of one or both of the two simple measurements. These are:

1. The number of accidents reported to have occurred when the road was wet is substantially in excess of 26% which is the annual average for London as a whole or
2. The road surface skid resistance has been found to be significantly lower than on the rest of the road being examined.

The selection process has been greatly simplified by the existence of computer-stored details of all personal injury accidents in London from 1969. Details are now readily available for about 350,000 accidents and since the recording system is based upon a nodal concept, where the nodes are normally major road intersections, it is relatively easy to obtain details such as the percentage of accidents which occur on a wet road surface for the major road junctions in London. The introduction of SCRIM (13) (Sideway Force Coefficient Routine Investigation Machine) has enabled a regular annual monitor to be made of the skid resistance of the 1300 km of main road controlled by the Greater London Council. This machine was developed by the Transport and Road Research Laboratory and automatically measures the sideway force coefficient every few metres and records the results on punched tape.

The data is analysed by computer and produced in the form of a multi-coloured transparent overlay to 6" maps so that the existence of relatively short lengths of slippery road are evidenced by a colour change. For the specific problem of junction and similar areas, digital output is also used.

Having located sites for treatment by either or both of the above methods it is then necessary to apportion priorities and this is normally done on the basis of total numbers of accidents. It is clearly a more economic use of resources to treat those sites first which have the greatest accident saving potential.

Methods Of Improving Skid Resistance At Urban Junctions Or Similar Hazard Areas

In a developed city such as London the need to improve the road surface skid resistance in small areas such as road junctions and the approaches to pedestrian crossings presents a difficult problem both in the choice of material and in the application method. All of the heavily trafficked roads in London are surfaced with Hot Rolled Asphalt with a variety of road bases but mainly Portland cement concrete. Any addition to the road construction thickness by overlaying with premixed bituminous materials is generally not possible because of the restraints imposed by surface drainage, the presence of road furniture and the presence of hard surfaced footways. It would be possible to heat and plane the existing asphalt surface and replace it with another of higher polish resistance but this operation would be both costly and difficult because of the presence of road furniture, man-holes and in many cases traffic signal apparatus. A thin surface overlay was therefore sought which could be applied without auxiliary work and which would satisfy the following requirements:

1. It should be of small thickness to avoid the need for lifting kerbs etc.
2. It should be capable of being applied overnight between about 2100 hours and 0600 hours because of the need to avoid traffic congestion.
3. The binder should adhere to asphaltic wearing courses and be sufficiently strong to resist embedment of the aggregate under heavy traffic loading.
4. The surfacing should have a high resistance to skidding and should have a life in excess of five years.

The early experiments carried out in 1967 confirmed that a particular type of extended epoxy resin in association with calcined bauxite aggregate was capable of satisfying all of these requirements and to date about 800 sites have been treated.

The process and the materials employed have been described elsewhere (14) and for the purpose of this paper it is probably sufficient to comment that experience of its use has shown that it has a life in service of at least 7 years and probably substantially in excess of 10 years and it has been found to be the only practical method by which relatively small areas of road surface can be treated in the context of heavily trafficked city roads.

It is normal practice to treat a length of about 50m. of road on the approaches to a junction or hazard area, together with the centre of large

Table 2. 'Before and after' accident studies on 23 junction sites treated with resin/bauxite and 14 untreated but otherwise similar sites in London.

Accident Type			12 months Before	12 months After	Nett change as a result of treatment %
All		treated	269	152	*
		control	179	147	-31.2
Wet Road		treated	109	33	*
		control	73	42	-47.3
Skidding		treated	15	2	
(wet and dry)		control	15	6	-66.7
2 or more					
moving	Wet	treated	10	2	
vehicles		control	6	4	-70.0
same	Dry	treated	20	16	
direction.		control	17	10	-36.1
2 or more					
moving	Wet	treated	40	11	*
vehicles		control	23	13	-51.3
different	Dry	treated	45	41	
directions.		control	24	23	-4.9
1 moving	Wet	treated	29	8	*
vehicle		control	12	10	-66.9
- no	Dry	treated	32	20	*
pedestrians.		control	10	19	-67.1
1 moving	Wet	treated	21	9	
vehicle		control	23	12	-17.8
- pedestrian	Dry	treated	36	21	
injured.		control	37	44	-51.0
bus	Wet	treated	9	4	
passenger		control	9	3	+33.3
and other	Dry	treated	27	19	
accidents		control	18	10	+26.6

* Statistically significant at 95% confidence level.

Table 3. Possible 10-Year Programmes
Forecasted accident and cost reductions
on Metropolitan road junctions using
resin/bauxite treatment (1970 values).

Initial assumptions:-

cost per site = £2,000
accident reduction = 30%
cost of P.I. accident = £1,090
mean life of treatment = 5 years
total number of accidents on all roads
in London Area = 56,000 p.a.

Annual Expenditure	£100,000	£200,000	£300,000	£400,000	£500,000	£600,000
No. of sites treated per annum (inclduing maintenance).	50	100	150	200	250	300
Total No. of sites treated after 10 years.	375	750	1,125	1,500	1,875	2,250
Total accident reduction in 10 year period.	10,800	17,300	22,300	26,300	29,600	32,700
Total cost of accidents saved in 10 year period.	£.1.8m	£18.8m	£24.3m	£28.7m	£32.2m	£35.6m
Total cost of anti-skid treatment.	£1m	£2m	£3m	£4m	£5m	£6m
Cost of preventing one accident in 10th and subsequent years.	£61	£78	£92	£107	£119	£131

Note: The annual expenditure after 10 years would continue at about the same rate but without increasing benefit. The continuing expenditure would be required to maintain the treated areas.

junctions, but increased lengths (up to 100m) are treated where traffic approach speeds are high.

The sfc of the junctions before treatment was of the order of 0.4 and after treatment of the order of 0.8 Although the macro-texture is relatively unimportant in a city because of the slow traffic speeds, it is relevant to note that the texture depth provided by this form of treatment has been found to be of the order of 1mm (14). This would be considered to be adequate for high speed roads.

The Results Obtained By The Use of Localised Skid Resistance Improvements

Many 'before and after' accident studies have been done on junctions and other similar areas treated with the epoxy resin/calcined bauxite material since its widespread use was commenced in 1968. All of these have shown a very substantial reduction in accidents and the results of one such study is given in Table 2. A series of sites was selected and 23 were treated with the epoxy resin/calcined bauxite material and 14 selected upon the same basis were left untreated as controls. All of the 37 sites were selected on the basis of their accident records and before and after studies were made on all of them. The results are summarised in Table 2 from which it will be seen that the average net change in accident numbers was a reduction of 31%. Before treatment the average number of accidents per site used in the study was 12 per annum so that the treatment has reduced accidents on each of the treated areas by an average of about 3½ per annum.

The Table gives details of the effect of the process on most common categories of road accident and it is interesting to note that there was an increase in the number of injury accidents involving bus passengers. Whilst there was only a small number of accidents in this category, all of the other accident studies that have been made in this project have shown the same trend. Possibly this has resulted from the increased ability of public service vehicles to brake and stop more rapidly, thus possibly causing injury to standing passengers.

The Economics Of This Form Of Treatment

In 1970 the economics of using this form of treatment at typical junction sites in London were examined (8) The conclusions from this study are given in Table 3 which shows the various costs involved at differing rates of annual expenditure. This Table was drawn up on the basis of the stated assumptions and on this evidence, it was decided to commence a 10 year laying programme at an annual rate of expenditure of £300,000. It was appreciated at the time the decision was made that the probable excess of the accident cost saving over the cost of the anti-skid treatment was so large that the economic analysis was relatively insensitive to the initial assumptions, but it is nevertheless interesting to examine the accuracy of this forecast in the light of further experience.

The more recent accident studies, the results of which are in Table 2, show that the average accident reduction due to anti-skid surfacing was 31% compared with the 30% assumed in Table 3, and the mean life of the treatment has now been established as being at least 7 years and probably in excess of 10 years. The overall economic picture is thus even more favourable than the early study suggested. The annual rate of expenditure since 1970 has been increased to keep pace with inflation and is at present at approximately £420,000. Thus it may be said that the initial economic assessment of the viability of this form of treatment has been amply substantiated in practice.

It should perhaps be emphasised that the quoted figures apply strictly to the situation in London where treatment is given to the most accident-prone sites in order of priority. Whilst a similar economic forecast could readily be made for other major cities, somewhat different figures might result depending on the average numbers of accidents per site, the traffic pattern and intensity and the number of days in the year in which the roads were wet. Table 3, however, shows that the excess of accident cost savings over expenditure is so high that it would seem probable that the economics of this form of treatment could well be favourable if applied to road junctions on heavily trafficked roads in many major cities.

The annual reduction in personal injury accidents in London at the beginning of 1976 is estimated to be 2,500 or 5% of the total accident numbers. This reduction has resulted from the treatment of some 800 sites and will increase further as more sites are treated.

General Conclusions

1. In Great Britain about 70 per cent of all road accidents occur in urban areas.
2. In London, about 70 per cent of all accidents occur on road junctions on about 10 per cent of the total road network. Nationally about half of all road accidents occur on urban junctions.
3. The skid resistance of asphalt roads can be predicted from a knowledge of the stone used in the surfacing, the traffic intensity, and whether or not the traffic is manoeuvering (braking, turning or accelerating).
4. Although the existing tentative minimum standards of skid resistance for city junctions are suspect, routine measurements of skid resistance and accident data may be used to indicate junctions where a skid resistance improvement can be expected to reduce accidents.
5. Over 800 junctions and other hazard areas such as the approaches to pedestrian crossings in London have been treated with epoxy resin/calcined bauxite which has reduced accidents by 31 per cent or about 2,500 per annum, at the treated sites.
6. The economics of this form of treatment are shown to be exceptionally favourable and an expenditure of £3m over a 10 year period is estimated to produce a saving in accident costs of at least £24m at 1970 values.
7. The localised treatment of city road junctions could well be a successful method of accident reduction in many major cities.

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