TRANSPORT RESEARCH LABORATORY
Department of Transport

STATE-OF-THE-ART REVIEW 4

ROAD AGGREGATES AND SKIDDING

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ii Density of water-saturated and dried samples.

Petrographic examination included the recording of the following:

i Size of largest fragments and average grain size of all constituents.
ii Total percentages of fragments and matrix.
iii Individual percentages of the following components irrespective of size: quartz, feldspar, calcite, clay minerals, lithic fragments and any other minerals found in appreciable quantities.

Five of the 86 samples were found to combine an AAV of 10 or less with a PSV of 70 or more, and a further 18 samples were found to have a PSV within the range 65-69. A further 17 samples had PSVs greater than 60.

The main findings of the survey were:

i Great Britain has potentially large resources of high-quality road-surfacing aggregates. Much of this material would meet more stringent requirements than were currently being implemented.
ii The best materials came from Wales; very good material was found in Northern Ireland, southern Scotland, and the English counties of Shropshire, Devon and Cornwall.
iii The petrographic studies indicated that the degree of consolidation of an arenaceous rock is more important than composition and grain size in determining the specific values of mechanical and physical properties.

2.1.6.2 Calcined bauxites

Bauxite (a rock consisting largely of hydrated aluminium oxides) is best known as an ore of aluminium. However certain bauxites are used to manufacture refractory and abrasive materials by calcination at high temperatures. Some of these calcined bauxites are of value as polish-resistant road aggregates.

a. Use in conventional surfacings

Three full-scale road experiments included sections of surface dressings using calcined bauxite aggregate (a refractory grade known as “RASC grade”). All sections showed an exceptionally high resistance to skidding. Details are given in Chapter 5.5.

The calcined bauxite chippings for these experiments involved the screening of large quantities of material. RASC grade calcined bauxite is manufactured for refractory purposes and, for this reason, is quenched in water. The result is a shattered material mostly too small in size to be used in conventional surfacings. Unless calcined bauxite is specially manufactured for roadmaking purposes it is unlikely that it will be available in sufficient quantity to be of importance in conventional surfacings.
b. Use in resin-bound skid-resistant surfacings

High-quality refractory-grade calcined bauxite from Guyana, when used as a 3 mm grit in resin-based binders, was found to maintain an exceptionally high resistance to skidding under the most severe traffic conditions (Road Research Laboratory, 1970). However, material from this source was expensive and, because of the demands of the steel industry, it was in very short supply. Work was therefore been undertaken with the object of finding other calcined bauxites that would serve the same purpose.

As part of this research, seven samples of high-temperature calcined bauxite from Guyana of different chemical and mineralogical compositions were selected from a batch of refractory-grade bauxite. These were examined and tested in the laboratory and then tried under actual road conditions at two heavily trafficked sites. Other calcined bauxites and other materials were also studied in a similar way; results showed that the best performance was achieved with materials containing a high proportion of small strongly bound alpha-alumina (corundum) crystals.

A further study (Tubey and Hosking, 1972) showed that abrasion- and polish-resistant properties were associated with materials containing numerous small (15 μm to 70 μm) corundum crystals bonded by a moderate quantity of glassy “cement” to give an open-textured granular surface. Chemical analyses of these materials showed a high alumina content, a low silica content, a fairly low iron content and a negligible loss on ignition. The corresponding mineral analyses showed abundant corundum, little or no mullite, and no significant quantities of other crystalline materials.

This work showed that other bauxites, if calcined under appropriate conditions, could have equally satisfactory properties. Bauxites from Australia, Ghana, and Northern Ireland were therefore calcined in the Laboratory’s rotary furnace at temperatures up to 1600 degrees C. These trials (Hosking and Tubey, 1973) showed that one (from Ghana) was as good as RASC grade bauxite, another (from Australia) was nearly as good and a third (from Northern Ireland), although poorer than the others, was better than any natural roadstone. This work also indicated that a suitable minimum alumina content would be 65 percent and that the silica content should be less than 10 percent. Moreover it also showed that a fairly high iron content was not detrimental, indeed the presence of iron was found to improve the product and reduce the temperature needed for calcination.

2.1.6.3 Synthetic aggregates of high polish-resistance

High resistance to polishing is generally associated with low abrasion resistance but the latter property is important at heavily trafficked sites. Such aggregates are scarce and high haulage costs make them very costly in some regions of the country. The highest polished-stone value (PSV) for a natural roadstone suitable for use in surfacings is about 70, but the abrasion resistance of such stone is only marginally acceptable.

Calcined bauxite has a very high PSV (75) and is very durable but it is very expensive and in short supply. A search for a cheaper substitute was made in the mid-1960s but, although synthetic roadstones with even higher PSVs were investigated, they were either more costly or lacked adequate abrasion resistance.
dressing provides an alternative. The technique had been successfully used during the 1939-1945 war for a different purpose - to disguise a concrete road in Kent that was being used by German bombers to guide them to London.

Clemmer was one of the first to report that it is necessary to use aggregates of a higher quality when surface dressing concrete rather than a flexible material (Clemmer, 1943). More recently the problem was the subject of further study (Wright, N., 1976). Results from five full-scale road experiments carried out between 1969 and 1975 were analysed. They demonstrated the feasibility of applying single surface dressings to concrete roads carrying traffic in Category 1 (over 2000 commercial vehicles a day in one traffic lane in one direction). The preferred chipping size was found to be 10 mm. The problems of loss of texture depth by embedment of chippings, often associated with bituminous surfacings, did not arise when surface dressing these hard unyielding concrete roads. But aggregates used for surface dressing high-speed concrete roads were found to require greater strength in order to resist wear under the action of heavy traffic to maintain their roughness. Recommendations were made for the maximum permissible aggregate abrasion value for chippings selected for surface dressing on concrete: like Clemmer, Wright found that they needed to be more stringent than those applicable to bituminous surfacings carrying similar traffic loads.

3.1.4 Resin-bound surfacings

Following success by American workers with synthetic resins, James carried out a trial in 1959 on Trunk Road A4 (James, 1960; James and Lamb, 1974). An area of the Coinbrook By-pass was surface-dressed using an extended epoxy-resin mixture with 1/8 inch to 1/16 inch (3 mm to 1.5 mm) grit. A range of five types of natural roadstone grit was compared with a range of seven types of abrasive grit, which included a refractory grade of calcined bauxite. It was concluded that the method would be satisfactory with normal roadstones, and that a very high skid-resistance could be obtained with a refractory grade calcined bauxite (see Fig. 7).

The specification for aggregates for use in resin-bound surfacings has been largely a matter of agreement between the few suppliers and their customers. However the Department of Transport have published a specification (Department of Transport, 1986) entitled “Resin-based high skid resistant surface treatment” which requires the aggregate to be calcined bauxite, that it should be clean and free from foreign matter, and that not more than 5 per cent is retained on a 3.55 mm British Standard test sieve and not more than 5 per cent is passed by a 1.18 mm British Standard test sieve.

Further information on resin-bound and other skid-resistant surfacings is given in Chapter 5.3.1.

3.1.5 Setts and pavers

A few roads are still surfaced with stone setts for ornamental purposes. These are mainly second-hand setts recovered from city streets supplemented by imports from Portugal. The appropriate British Standards specification is BS 435:1975 “ Specification for dressed natural stone kerbs, channels, quadrants and setts”. The manufacture of setts and other dressed stone products is a
5.2.3 Black deposits

Black deposits have appeared on heavily trafficked sections of motorways after spells of dry weather. They reduced the resistance to skidding and were also thought to contaminate streams after subsequent rain. The problem was studied (Green, 1974) and the deposits were found to consist mainly of a mixture of oil, tyre-rubber and dust. The basis of formation of these deposits was found to be the lubricating oil dropped by vehicles. It was considered that prevention rather than remedial action would be the more effective method of dealing with the problem. Contacts were established with the motor industry and modifications were discussed which would reduce the degree of oil spillage, both from poorly maintained sources (sumps, gearboxes, etc) and from automatic chassis lubrication systems which are designed on the total-loss principle. The problem has now largely disappeared as vehicles have been re-designed.

5.3 Aggregates in other road materials

5.3.1 Resin surfacings

5.3.1.1 General

An outline of the development of this method of achieving an exceptionally high resistance to skidding is given in Chapter 3.1.4.

Following the early success with resin-bound surfacings on the Colnbrook By-Pass in 1959 and successful trials on bridge decks, a calcined-bauxite/epoxy-resin (CBER) dressing was successfully used on Haven Bridge at Yarmouth in 1961. The dressing was carried out in situ and suffered to some extent because of wetness of the wood-block bridge deck at the time of laying. In 1962 a similar dressing was used on Tower Bridge, London in the form of pre-treated wood blocks to avoid the problem of wetness (James, 1963). It is interesting to note that the re-paving of this bridge with a light-weight polyurethane base covered by the dressed wooden blocks enabled it to support the increasing traffic loads. A very high skidding resistance was maintained on this bridge for a very long time. Many other bridges have been treated similarly with CBER dressings, in order to obtain a highly skid-resistant surface with little increase in weight.

In the mid-1960s, Hatherley of the Greater London Council’s road department observed that about three-quarters of traffic accidents took place on urban roads, London’s roads constituted a high proportion of the country’s urban roads, and that a considerable proportion of London’s road accidents occurred at a relatively small number of “black-spots”. This led him to believe that the special treatment of relatively few road sites would lead to a significant reduction in the number of the country’s skidding accidents. After consulting the Road Research Laboratory as to the best means of achieving a very high skid-resistance, Hatherley considered that very worthwhile reduction in accidents could be achieved by resurfacing the black spots with CBER surface dressings.
Collaborative work by Greater London Council, TRRL, Shell-Mex & BP Ltd., Prismo Universal Ltd and the London Borough of Lambeth led to a number of trials being laid on roads in London in 1967 with a CBER dressing system known as “Shellgrip” (Hatherley and Lamb, 1970). The sites were selected because of their high risk of accidents. After the treatment the reduction in accidents was spectacular and led to the widespread use of this and similar surfacings in London and, later, elsewhere. The cost of the treatment was high but it had the advantage of being able to be laid during a few hours overnight and so cause few delays to traffic. An additional advantage was that because it was a thin surfacing, it could be applied without the need to excavate existing material.

The success of the CBER dressings is considered to be a result of several contributing factors:

i The high polishing resistance of RASC-grade calcined bauxite (PSV = 75).

ii The small size of the “chippings” (2.8 mm to 1.2 mm).

iii The “edge-on” effect of the chippings which are firmly fixed in the rigid binder. This contrasts with thermo-plastic binders such as bitumen, where chippings tend to be orientated into the most stable position - with a face rather than an edge at the surface.

iv The rigid nature of the binder which resists embedment of the chippings by traffic.

Junctions in London that had been surfaced with “Shellgrip” maintained an exceptionally high resistance to skidding over many years. Fig. 38 shows the high sideways-force coefficients measured during the first four years of their life.

5.3.1.2 Aggregate requirements

A study (Hosking and Tubey, 1972) of the performance of a wide range of aggregates in resin surfacings was made by the TRRL in collaboration with the Greater London Council, Shell Mex and BP Ltd, Shell Research Ltd. and Prismo Universal Ltd. The results showed that the standard BS 812 tests for aggregates were not suitable for assessing aggregates for use as 3 mm grit. However good performance was found to be associated with aggregates with a minimum PSV of about 70 combined with an aggregate abrasion value of 5 or less.

(Author’s Note: It must be stressed that considerable damage to the abrasion lap can occur when testing calcined bauxite and other very hard materials, and so such a test is not recommended for such materials. Tests with a Taber “Abraser” (used in some American standard test procedures) were encouraging, but more study is needed before recommendations can be made.)

Fig. 39 shows the correlation that was obtained between PSV and mean “road rating” (a measure of resistance to skidding based on skid-resistance value). Aggregate impact tests on 3.2 mm to 2.4 mm grit were found to yield meaningful results when the fines were separated with a 600 μm test sieve, rather than the standard test sieve. A value of 25 or less was found to indicate a satisfactory strength performance.
Fig. 38  Performance of "Shellgrip" at road junctions.
6.3 Skidding accidents: causes and costs

6.3.1 The causes of road accidents

Factors known to contribute to accidents include driver behaviour, road lay-out, vehicle design, vehicle condition, road lighting, tyre/road adhesion and many other factors. These factors have been the subject of studies that have eventually led to remedial measures and/or legislation for blood alcohol limits, seat belt requirements, annual “MOT” tests on road vehicles, tyre tread depths, safety helmets for motor-cyclists and speed limits. One of the first of these factors to be studied was tyre/road adhesion; it is important because it determines the resistance to skidding, that is not only a principal cause of accidents, but can also affect the severity of accidents resulting from other causes.

The effect of implementing all the many measures to reduce accidents has been impressive. In the year 1909, when road accident statistics were first collected, there were 1,070 accidents involving one or more fatalities and 101,000 motor vehicles in our roads. In contrast, in 1986 there were 4,895 accidents involving one or more fatalities (a 4.6-fold increase) with a 214-fold increase on motor vehicles to 21,700,000. (Department of Transport, 1987c).

Studies have been made of both tyres and of road surfacings in order to obtain a better understanding of the problem of tyre/road adhesion. Work on tyres has led to the introduction of high hysteresis rubber for the lighter categories of road vehicle and legislation with regard to tyre-tread depth.

Two other main lines of research have been the design of instruments for the measurement of resistance to skidding of road surfacing and the study of the various factors that affect the measured skid-resistance.

The development of instruments for measuring resistance to skidding has led to sophisticated machines such as SCRIM that are suitable for monitoring large road networks.

The research on the various factors that affect skid-resistance has led to an increased understanding of the skidding problem. It has been found that measured values are usually uniformly high under clean dry road conditions, but measurements under wet conditions can show a great deal of variation. Also, the measured values depend on factors such as water film depth and season of the year in addition to the nature of the road surface itself. Moreover the skid-resistance of a road surface has been found to be affected not only by the type of the surfacing material (asphalt, coated macadam, concrete, etc.), but also by the characteristics of the basic materials (aggregate, binder, etc.). Other contributory factors include the type of road site (hill, bend, junction, etc.) and the trafficking history.

6.3.2 The magnitude and cost of road accidents

Some statistics on road accidents appear in the Department of Transport’s “Road Accidents: Great Britain 1986: The Casualty Report” (Department of Transport, 1987c). It is recorded that
TABLE 20
Average cost (£) of road accidents in Great Britain: 1986

<table>
<thead>
<tr>
<th></th>
<th>Fatal injury</th>
<th>Serious only</th>
<th>Slight</th>
<th>All</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost output</td>
<td>151,203</td>
<td>1,982</td>
<td>28</td>
<td>3,473</td>
<td>-</td>
</tr>
<tr>
<td>Medical &amp; ambulance admin</td>
<td>1,174</td>
<td>2,069</td>
<td>105</td>
<td>587</td>
<td>-</td>
</tr>
<tr>
<td>Police &amp; insurance admin</td>
<td>347</td>
<td>277</td>
<td>208</td>
<td>227</td>
<td>69</td>
</tr>
<tr>
<td>Damage to property</td>
<td>1,982</td>
<td>1,568</td>
<td>1,116</td>
<td>1,239</td>
<td>583</td>
</tr>
<tr>
<td>Pain, grief and suffering</td>
<td>145,134</td>
<td>12,287</td>
<td>229</td>
<td>5,922</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>299,840</td>
<td>18,182</td>
<td>1,686</td>
<td>11,448</td>
<td>652</td>
</tr>
<tr>
<td>Total (revised)*</td>
<td>522,400</td>
<td>18,180</td>
<td>1,690</td>
<td>15,840</td>
<td>658</td>
</tr>
</tbody>
</table>

* A new fatal casualty valuation of £500,000 was proposed by the Minister for Roads and Traffic in 1988. The published revised costs are shown here.

There were 248,000 road accidents in Great Britain in 1986, in which there were 5,382 fatalities, 69,000 serious injuries and 247,000 slight injuries. A total of 321,000 casualties in all.

This Casualty Report also states that the total cost of all road accidents in 1986 was estimated to be £3,800m (revised to £4,890m after re-assessment in 1987). The average costs for each class of accident are detailed in Table 20.

6.3.3 Relation between skid-resistance and accident rate in Great Britain

There have been many attempts to quantify the effect of changes in SFC (and other measures of skid-resistance) on accident frequency. Studies have been complicated by the many other factors that can affect accident frequency and by the relative infrequency of accidents. Most of the successful attempts have taken the form of before-and-after studies, where the change in accident frequency has been related to measurements of skid-resistance before and after re-surfacing with a skid-resistant surfacing. However the most comprehensive study to date was that reported in the TRRL’s Research Report 76 (Hosking, 1986). The method used excluded the other possible causes of accidents. Very good correlation was found between changes in SCRIM coefficient (see Fig. 50) and the wet-road skidding rate and also, rather surprisingly, good correlation between SCRIM coefficient and dry-road skidding rate. The most likely explanation of the latter effect was thought to be the reporting of accidents as being on a dry road when, in fact, the road was slightly damp (this is because very slight dampness greatly lowers skid-resistance). It was also thought likely that a surface with a low wet-road skid-resistance would be more slippery under conditions such as when the road is contaminated by oil, dust or other materials.

In Research Report 76 the effect of increasing the skid resistance is quantified in terms of reduction in skidding rate. Skidding rate is a parameter commonly used for assessing skidding accident frequency. It is defined as the number of accidents in which one or more vehicles are reported to have skidded expressed as a percentage of all accidents. In addition to an overall skidding rate there can be separate assessments of wet-road skidding rate and dry-road skidding rate. A conclusion of the study was that an average increase in average SCRIM coefficient of 0.10
was accompanied by a reduction in wet-road skidding rate of 13.2. (A reduction of from 35.4 to 22.2).

A further conclusion was that an average increase in average SCRIM coefficient of 0.10 was accompanied by a reduction in dry-road skidding rate of 5.9. (A reduction of from 16.0 to 10.1). Although this reduction was less than the benefit to the wet-road skidding rate, the overall importance is as great because of the larger number of accidents reported on dry roads.

The total number of accidents in Great Britain for 1986 under wet conditions was 83,813 and under dry conditions was 121,452. From these figures it can be estimated that the reduction in number of accidents corresponding to each improvement in SCRIM coefficient of 0.01 would have been 1,106 and 716 respectively for wet and dry roads, giving a total saving of 1,822 personal injury accidents for the country in the year.

A study of the same problem has also been made by Young of Greater London Council (Young, 1985), but was confined to urban classified roads. His figures show an annual saving of 420 accidents on wet roads for an improvement of 0.01 in SCRIM coefficient on urban roads alone.

### 6.3.4 Some accident/skidding studies made overseas

Examples of some of the studies of the skidding problem that have been conducted in a number of countries are outlined below.
6.3.4.1 The Netherlands

In the Netherlands (State Road Laboratory, 1973) all accidents on state roads in 1965 and 1966 were used in a statistical analysis of the relationship between skid-resistance and accident rate. The accident rate was derived from the number of accidents during a certain period on a selected section of road and the total number of kilometres travelled by vehicles over the section of road during the same period. Friction coefficients for each road section were recorded by the Dutch standard test method (a braking-force coefficient with the test wheel under 84 per cent braking-slip). Relationships were established between friction level and accident rate for both motorways and for other roads under wet conditions.

6.3.4.2 Czechoslovakia

In Czechoslovakia (Zelina, 1973) a statistical analysis covering 24 skid-prone sections of road was made, using the locked-wheel braking force coefficient at 40 km/h to measure skid-resistance. It was found that the percentage of accidents decreased with increasing frictional level of the road surface (see Table 21).

**TABLE 21**
Friction levels and the percentage of accidents on 24 sections of road in Czechoslovakia

<table>
<thead>
<tr>
<th>Frictional level (Braking-force coefficient)</th>
<th>&lt; 0.40</th>
<th>0.41-0.50</th>
<th>&gt; 0.51</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of road sections</td>
<td>14</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Percentage of accidents</td>
<td>64</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Mean BFC</td>
<td>0.30</td>
<td>0.44</td>
<td>0.54</td>
</tr>
</tbody>
</table>

6.3.4.3 The Federal Republic of Germany

In the Federal Republic of Germany (Beckmann, 1964) a relationship between skid-resistance and accidents was established in 1964 when, in an investigation covering 32 sections of road, the proportion of accidents that occurred under wet conditions was correlated with locked-wheel braking force coefficients. On most road sections the proportion of accidents in the wet was found to vary between zero and approximately 50 per cent, and averaged about 33 per cent over the whole road network. It was found that sections of road which exceeded this average proportion were likely to have low friction levels.

A later survey (Schulze et al, 1974) covering 80 sections, each of 1-8 km in length, of motorways and main roads yielded a relationship between accidents and wet-friction level.

6.3.4.4 Italy

In Italy a particular interest has been taken in British experience with calcined-bauxite/epoxy-resin surface dressings. This led to the issue of the following circular by the Italian Ministry of
Public Works: "At particular spots (bends, intersections, critical points, etc.) carry out special anti-skid treatment with aggregates of high hardness index fixed to the existing surface by means of epoxy resins. This technical measure is especially recommended for city streets, in front of the more dangerous pedestrian crossings, and wherever experience has shown the high incidence of slipperiness to be one of the causes of accidents".

Before-and-after skid-resistance measurements and accident studies demonstrating the effect of the anti-skid treatment are shown in Table 22.

**TABLE 22**
Comparative figures showing the effect of anti-skid treatments in Italy

<table>
<thead>
<tr>
<th>Skid resistance (TRRL pendulum)</th>
<th>Average reduction in the total number of accidents during one year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before</strong></td>
<td><strong>just after</strong></td>
</tr>
<tr>
<td>33</td>
<td>88</td>
</tr>
<tr>
<td>46</td>
<td>87</td>
</tr>
<tr>
<td>63</td>
<td>97</td>
</tr>
<tr>
<td>52</td>
<td>96</td>
</tr>
</tbody>
</table>

**6.3.4.5 Japan**

In Japan (Ichihara, 1973) about 50 per cent of road traffic accidents were found to occur at intersections. Therefore a survey was made of the effect of anti-skid surface treatments on a number of intersections where a high proportion of the accidents (over 30 per cent) were "head to tail" collisions in wet weather. Skid-resistance measurements were made using the locked-wheel braking force method of the Public Works Research Institute. The increase in frictional levels achieved by the anti-skid treatments are shown in Table 23. Accident figures for two

**TABLE 23**
Head to tail collisions at 12 intersections before and after skid-resistance treatment

<table>
<thead>
<tr>
<th>Site</th>
<th>Number of head to tail collisions</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Before</strong></td>
<td><strong>After</strong></td>
</tr>
<tr>
<td>1</td>
<td>2 Dry 4 Wet 2 Dry 1 Wet 0 Dry -3 Wet -8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7 Dry 9 Wet 4 Dry 1 Wet -6 Wet -13</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>9 Dry 15 Wet 3 Dry 2 Wet -9 Wet -13</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10 Dry 1 Wet 1 Dry 0 Wet +1 Wet 0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1 Dry 0 Wet 2 Dry 0 Wet +1 Wet 0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4 Dry 1 Wet 4 Dry 0 Wet -1 Wet 0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1 Dry 1 Wet 2 Dry 0 Wet +1 Wet -1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1 Dry 4 Wet 2 Dry 0 Wet +1 Wet -3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1 Dry 2 Wet 3 Dry 0 Wet +2 Wet -2</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>16 Dry 16 Wet 6 Dry 0 Wet 0 Wet -16</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>3 Dry 6 Wet 5 Dry 1 Wet -1 Wet -2</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>13 Dry 13 Wet 3 Dry 3 Wet -3 Wet -10</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>64 Dry 69 Wet 47 Dry 9 Wet -17 Wet -60</td>
<td></td>
</tr>
</tbody>
</table>
comparable 4 month periods before and after treatment demonstrated a significant reduction in "head to tail" collisions in wet weather (average 87 per cent) and even in dry weather (average 27 per cent).

6.3.5 The saving in accidents and their cost by improvements in skid-resistance in Great Britain

An estimate has been made of the reduction in road casualties that can be achieved by improving the skid-resistance of our trunk road network (Department of Transport, 1988). Preliminary figures indicated that up to 1800 casualties could be saved each year by the introduction of new requirements for the skidding resistance of trunk roads. Implementation of these requirements was expected to contribute to the Department of Transport’s target of cutting road casualty figures overall by one third by the year 2000.

The additional cost of implementation was estimated to be about £9 million a year for the first four years and about £2.5 million a year thereafter. When fully implemented it was estimated that financial benefits from accident reductions on trunk roads would be about £35 million a year, representing a return of £5.50 for every £1 spent.

These standards (see Chapter 7.1.1.4) were introduced early in 1988. Experience after two years (Transport and Road Research Laboratory, 1990) suggests that these preliminary figures may be an under-estimate. At some sites accidents in wet conditions have been reduced by 50 per cent.

6.4 Traffic noise

A review of research (Salt, 1979) indicated that evidence pointed to the interaction between tyre and road surface as being the principal cause of the rolling noise generated by traffic. In the case of lighter road vehicles rolling noise is the main source of total traffic noise and makes a significant contribution to the total noise generated by the heavier vehicles.

In the case of dry roads it is believed that the impact of the tyre on the road is the principal cause of tyre/road noise, this is augmented by the noise produced by radial and tangential oscillations. The relative importance of these three factors is determined by the texture of the road surface. For example a transversely grooved concrete would have a different effect from the random projections in a surface dressing.

Although no general correlation has been found between surface texture and the noise produced, significant correlation has been observed for particular classes of surfacing. Examples are given in Fig. 51 for various bituminous surfacings and concrete surfacings in Great Britain (Salt, 1979). In this paper Salt also reported a finding of great practical value. This was the significant correlation between the noise generated on a surfacing and the loss in skidding resistance when speed is increased from 50 to 130 km/h (Fig. 52). The value lies in enabling test requirements to be formulated which are equitable to both bituminous and concrete surfacing interests, and at the same time strike a balance between road safety and noise.