TRANSPORT RESEARCH LABORATORY

The Polished Stone Value of aggregates and in-service skidding resistance

Prepared for Pavement Engineering Group, Highways Agency

P G Roe and S A Hartshorne

TRL REPORT 322

First Published 1998
ISSN 0968-4107

This report has been produced by the Transport Research Laboratory, under/as part of a Contract placed by the Highways Agency. Any views expressed are not necessarily those of the Agency.

TRL is committed to optimising energy efficiency, reducing waste and promoting recycling and re-use. In support of these environmental goals, this report has been printed on recycled paper, comprising 100% post-consumer waste, manufactured using a TCF (totally chlorine free) process.

Transport Research Foundation Group of Companies
Transport Research Foundation (a company limited by guarantee) trading as Transport Research Laboratory. Registered in England, Number 3011746.

TRL Limited. Registered in England, Number 3142272.
Registered Offices: Old Wokingham Road, Crowthorne, Berkshire, RG45 6AU.

CONTENTS

Page

Executive Summary

It has long been known that the aggregates in road surfacings are polished by the action of traffic, particularly commercial vehicles. Use of those types more susceptible to polishing can result in skidding resistance falling to a point where replacement becomes necessary before the surfacing has achieved its full potential. Consequently, for many years, aggregates for use in new surfacings have been chosen according to their ability to resist polishing, as determined by measuring their Polished Stone Value (PSV) in a standardised accelerated polishing test.

Since the time of the original research, traffic levels on many roads have increased significantly and design decisions are now having to be made for more heavily-trafficked roads than were included in the original work. Further, experience of applying the 1976 standard has suggested that expected performance is not always achieved in practice.

This report is the final report of a project commissioned by the then Department of Transport (now the Highways Agency, an executive agency of the Department of the Environment, Transport and the Regions, DETR). The object of the work was to review aggregate performance in service so that the Table in the Design Manual For Roads and Bridges Volume 7, which indicates the Polished Stone Value (PSV) required for given circumstances, could be revised to take account of present-day conditions and requirements.

Initially, the project was intended to provide information about skidding resistance in relation to PSV at heavy traffic levels. However, it rapidly became apparent that a more extensive review of requirements was needed and the project was expanded accordingly.

The study compared an analysis of skidding resistance measurements from in-service roads in order to determine their relationship to the polishing resistance of the aggregate and the level of traffic using the road.

This was supported by some limited laboratory studies of extended polishing. A database was established in phases to cover as extensive a range of aggregates, site categories and traffic levels as was practical. This was used to consider models for predicting skidding resistance from PSV and traffic data. A series of laboratory studies of polishing was then carried out to investigate some of the phenomena observed in the field data. Initial investigations of alternative PSV test regimes for small-particle size materials were also made. The interpretation of the results was supported by a background desk-top review of earlier research on the topic.

The study found that:

- The model on which the current specification for PSV requirements is based does not adequately reflect in-service performance for skidding resistance under present-day conditions.
- Different aggregates with the same polishing resistance provide a range of skidding resistances in practice and individual aggregates can deliver a range of skidding resistances, even at the same traffic level. In locations where additional braking or deceleration can be expected, for example on approaches to slip roads, lower values of skidding resistance may occur than on the rest of the mainline carriageway.
- Aggregates do not necessarily continue to polish as traffic levels increase; polishing and wearing actions may change relatively to maintain adequate skidding resistance under heavy traffic.
- Different relationships are found between PSV and equilibrium skidding resistance, depending on the type of site and the level of skidding resistance required. These relationships are of a linear-log form which show that skidding resistance increases with PSV and reduces with heavier traffic, but a constant term (representing properties of the material or road conditions) is the dominant factor. For a given PSV, increased traffic reduces skidding resistance rapidly at first and to a much smaller extent at heavy traffic levels.

At present, PSV is the only parameter relating to the microtexture properties of an aggregate which can be measured in a standardised manner and which has been related to traffic and site conditions. It therefore remains an appropriate property to use in specifications, provided that its limitations are recognised.

Working closely with the Highways Agency, it has been possible to include a Table giving the PSV required for a given category of site and traffic level. This is intended as a replacement for that already in the Design Manual for Roads and Bridges. The Table is based on the new relationships but targeted at the investigatory level requirements of the related Skidding Standards. In some cases, lower PSVs than previously specified are permitted, although in other situations current requirements are inadequate and have therefore been increased. A new category has been introduced to take account of the effect of increased polishing on the approaches to slip roads. Back-analysis of the data confirmed that, within the limitations of the database, there is only a small risk of materials failing to deliver the required MSSC in most circumstances.

There was some evidence from the study that, at present, materials are over-specified. The proposed new Table will allow some increased flexibility in the use of aggregates which will increase confidence in specifying the aggregates to be used, with consequent improvements in use of resources and reduced costs due to premature resurfacing. Nevertheless it is recognised that anomalies will remain, for example, for aggregate sources not included in the study. Further research is therefore needed in several areas, primarily: to explain the variations found in practice; to enable the performance of a wider range of sites, aggregates and their properties to be taken into account; to develop new or improved test procedures; to provide a more rigorous assessment of materials.

1 Introduction

It has long been known that the aggregates in road surfacings are polished by the action of traffic, particularly commercial vehicles. Use of those types which are more susceptible to polishing can result in skidding resistance falling to a point where replacement becomes necessary before the surfacing has achieved its full potential. Consequently, for many years, aggregates for use in new surfacings have been chosen according to their ability to resist polishing, as determined by measuring their Polished Stone Value (PSV) in a standardised accelerated polishing test.

However, since the time of the original research, traffic levels on many roads have increased to about twice the upper limit of those studied initially and design decisions are now having to be made for more heavily-trafficked roads than were included in the original work.

Further, experience of applying the 1976 standard has suggested that expected performance is not always achieved in practice.

This report is the final report of a project commissioned by the Department of Transport (now the Highways Agency, an executive agency of the Department of Environment, Transport and the Regions, DETR). The objective of the project was to review aggregate performance in service so that a revised Table to indicate the PSV required for given circumstances could be produced, which would take account of present-day conditions and requirements.

2 Background

2.1 Skidding resistance and polishing of roads

2.1.1 Skidding resistance

The skidding resistance of a road is a measure of the friction generated between the road surface and a tyre in wet conditions. In any particular location, the friction depends on properties of both the road and the tyre, with climatic factors also having an influence.

The key property of the road surface in generating skidding resistance is the microtexture of the material in the surfacing which is in contact with vehicle tyres. In asphalt and exposed-aggregate concrete surfacings, the microtexture is determined by the fine structure of the surface of the aggregate particles.

Skidding resistance is normally measured by a standardised method which controls many of the variables. In the UK this is done with SCRIM (Sideway-force Routine Investigation Machine) which uses a standardised tyre on a special test wheel skidding on a wet surface at an angle of 20 degrees to the direction of travel at a standard speed. Results are reported as a ‘SCRIM Coefficient’ (SC).

2.1.2 Polishing of a road surface

When a road is trafficked, its skidding resistance is reduced as a result of the polishing action of tyres on the microtexture in the surface. The effect of polishing on microtexture is illustrated in Figure 1, which shows comparative electron-microscope photographs taken during earlier studies of this subject.

Most of the polishing occurs in the summer period when the weather is predominantly dry; detritus on the road is ground to a fine size and acts as a polishing medium. During the winter, more frequent wet weather, frost action and the application of salt and grit combine to provide a more abrasive mix which causes the polished microtexture to roughen. Consequently, skidding resistance exhibits a seasonal cycle with low values in the summer and recovering to higher values during the winter.

In order to overcome the problem of seasonal variation, SCRIM measurements are made during the summer when skidding resistance is at its lowest. The Mean Summer SCRIM Coefficient (MSSC), the average of at least three measurements in the May-September period, is used as the basis for assessing roads against Standards; this is basis of the approach set out in the UK Overseeing Authorities Design Manual for Roads and Bridges (DMRB).

Over time, the winter recovery may not be sufficient to overcome all the summer polishing and so the skidding resistance falls to a level at which the polishing and recovery are in equilibrium. This equilibrium level will then be broadly maintained so long as the level of traffic remains constant. This value is represented by the average of MSSC over three or more years and is known as the ‘equilibrium SCRIM coefficient’ (ESC).

If the traffic level changes, this may be matched by a change in the equilibrium skidding resistance. However, the new level of skidding resistance will depend on a range of factors which will include not only the level of traffic but also the type of site, which influences the extent of braking and cornering.

2.1.3 The polishing mechanism

It has long been known that a ‘hard’, silicate-based aggregate will polish rather than wear and hence have a low PSV, while a ‘soft’, arenaceous aggregate will wear rather than polish and maintain an effective microtexture.

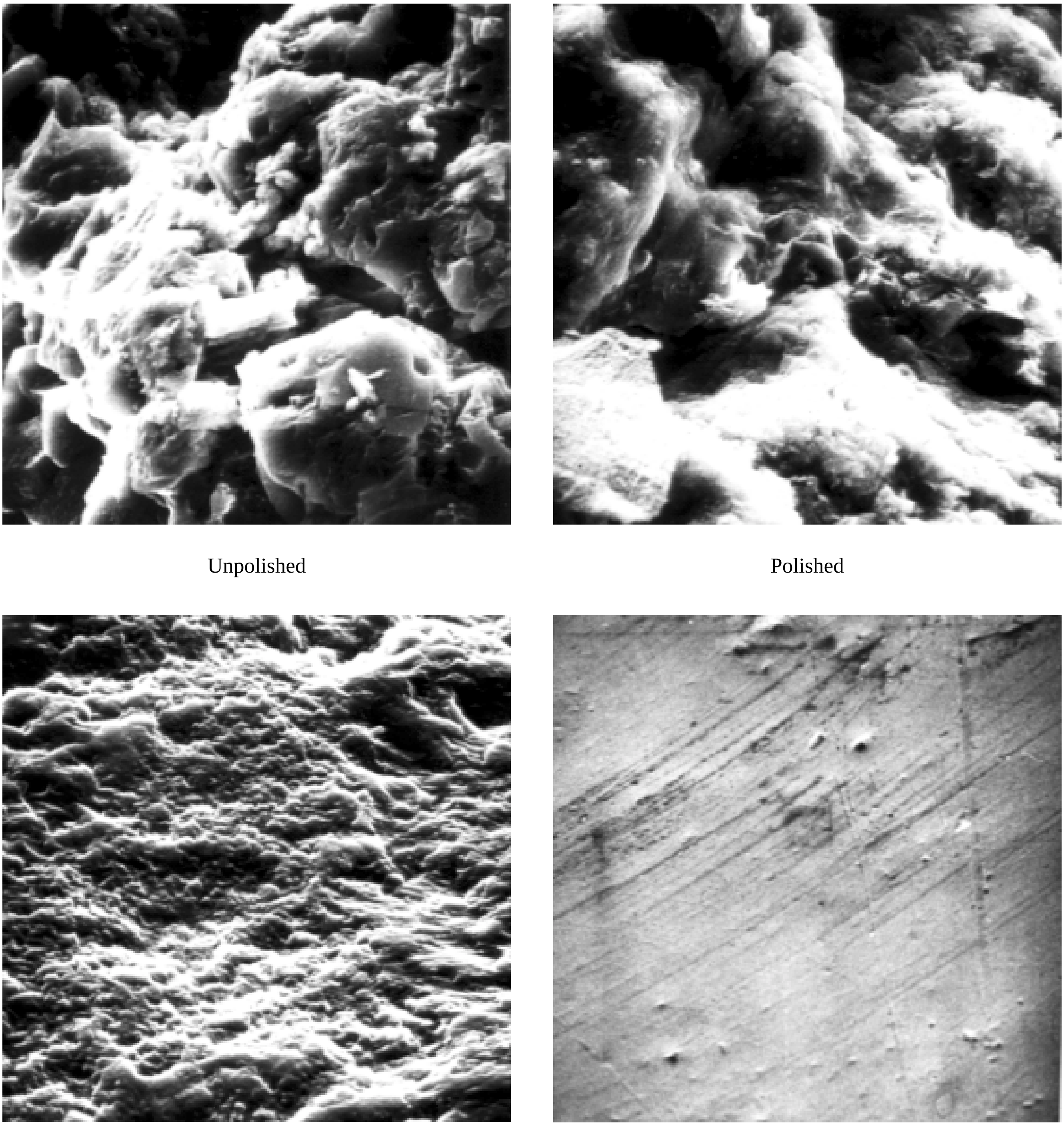
There are several theories (Van Der Wall 1992) that are used to explain how aggregates polish under the action of traffic.

Two that are among the more widely accepted are:

- *The wear theory:* polishing results from abrasion, which removes the microscopic protrusions on the surface of the aggregate that interact with vehicle tyres.
- *The wear-deformation theory:* polishing is a combination of microscopic wearing away of protrusions and the deformation of the crystalline structure within the surface layer.

The ability of an aggregate to resist polishing, is believed to be controlled by several factors within the aggregate. Among these are:

- *Composition and hardness of individual grains:* these provide the resistance to wear necessary for a durable aggregate.
- *Differential hardness of grains:* where there are two or more individual minerals, these can offer preferential failure surfaces or planes, thus creating microtexture.



Unpolished | Polished

Unpolished | Polished

Figure 1 Electron-microscope photographs of polished and unpolished aggregates

- *Porosity:* microtexture is provided by edges which are generated as voids become open at the surface of the aggregate.
- *Grain distribution and bonding:* if grains which are loosely cemented by a matrix softer than the grains become polished, they may be plucked from the aggregate particle under the action of traffic, so renewing the microtexture.

These ideas are illustrated by Figure 2, which is taken from a report in which Hosking (1976) proposed five theoretical types of polish-resistance roadstone.

Other factors in the overall process, which affect polishing but are independent of the aggregate, may include wheel loads, the height of chippings above the surface of the supporting matrix, and the presence of a polishing/grinding medium.

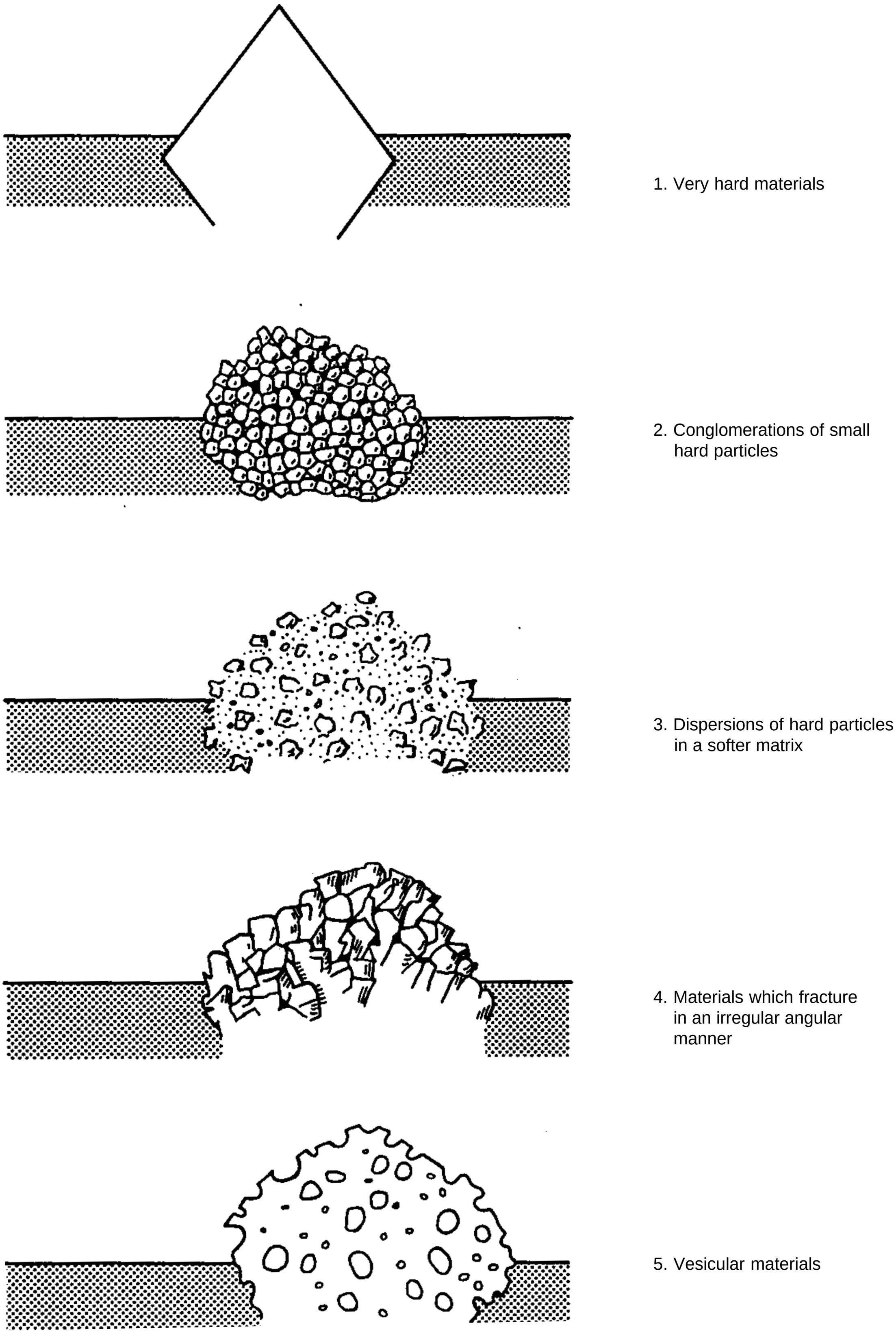


Figure 2 Five theoretical types of polish-resistance roadstone (after Hosking, 1976)

2.2 Polishing resistance of aggregates

2.2.1 The Polished Stone Value

In the 1950s, in unpublished work at TRL (then the Road Research Laboratory), Maclean and Shergold designed an accelerated polishing machine to assess the properties of different aggregates. This was developed later to provide what is now a standardised method of assessing the polishing resistance of aggregates, the Polished Stone Value test in British Standard 812 (British Standards Institution, 1989). In this test, samples of aggregate are set in resin to form specimens which are mounted on the circumference of a wheel. This is then rotated for a period of time while a rubber tyre is loaded onto the aggregate surface and a polishing medium trickled into the interface. Figure 3 shows the polishing machine with a loaded test wheel in place. At the end of the polishing process, the skidding resistance of the specimens is measured and compared with the results from specimens made with a control stone to calculate the ‘polished stone value’ (PSV).

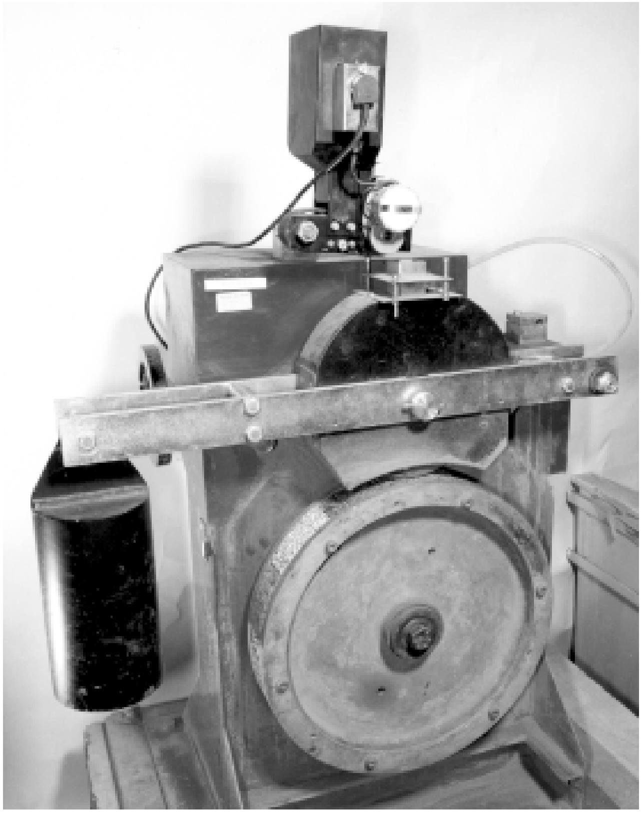


Figure 3 The polishing machine ready for a PSV test

The PSV test provides a standardised method of assessing polishing resistance. The two phases of the test (initial conditioning with corn emery followed by polishing with emery flour) can be considered to represent a period of trafficking, but they do not equate to a known level of traffic. Nevertheless, the test differentiates between aggregates in this standardised regime.

2.2.2 The use of PSV in construction standards

In the early 1970s, a relationship was established to predict skidding resistance (measured as mean-summer sideway-force coefficient) from the PSV of the aggregate and expected traffic level in terms of the number of commercial vehicles per lane per day (CVD). This was published in LR504 (Szatkowski and Hosking, 1972) and was subsequently used as the basis for the standards for construction of new roads.

The relationship was used to specify the PSV of the aggregate to be used in surfacings on trunk roads in the Departmental Standard HD 16/76. This was presented in the form of a Table giving the minimum PSV for given levels of traffic on different categories of sites. Following the introduction of in-service skidding resistance standards, modified requirements were introduced into the Design Manual for Roads and Bridges (DMRB, Department of Transport 1994), but these were still based on the original relationship.

Since the introduction of these standards, it has been found that, in some circumstances, the skidding resistance achieved in practice does not match that predicted by the relationship. Some aggregates perform better than expected whilst others appear to polish more and therefore give lower skidding resistance. This is not surprising because any relationship derived from physical data is an idealised model and will not apply exactly in all situations, but the discrepancies have given cause for concern. Further, present-day traffic levels frequently require extrapolation of the original formula beyond the range of the data on which it was based and this can lead to over-optimistic or pessimistic predictions of performance.

For these reasons, particularly with the need to provide materials which would give a satisfactory performance in terms of the skidding resistance standards, it was necessary to review the requirements in the light of experience.

2.3 The scope of this study

The objective of this project was, initially, to provide information about skidding resistance in relation to PSV at more heavily trafficked levels. However, it rapidly became apparent that a wider review of requirements was needed and the project was expanded accordingly.

The work was carried out in a sequence of phases:

- Initially, a study of the performance of aggregates at the highest-trafficked levels (over 4000 CVD) was carried out. This was a computer-based desk study of skidding resistance (which had been measured as part of the skidding standards procedures) and PSV, using information obtained from Department of Transport (DOT) Agent Authorities.
- The next stage was an examination of lower-trafficked sites using a similar approach.
- Because the data available from DOT Agents did not cover the full range of sites required, the database was extended by measuring skidding resistance with SCRIM on roads chosen to include sites and conditions not included in the first two phases.

- The combined database was used to consider models for predicting skidding resistance from PSV and traffic data;
- A series of laboratory studies of polishing was then carried out to investigate some of the phenomena observed in the field data. Initial investigations of alternative PSV test regimes for small-particle size materials were also made.
- The interpretation of the results was supported by a background desk-top review of earlier research in the field for comparison with current findings.

3 Studies of aggregate performance in-service

3.1 Initial study of performance under heavy traffic

3.1.1 Approach

The object of this phase of the work was to relate in-service skidding resistance to PSV for sites with traffic levels over 4000 CVD. Since the introduction of the Skidding Resistance Standards in 1988 (Department of Transport, 1987), the skidding resistance of the trunk road network has been regularly monitored. It was therefore possible to gather existing information on current levels of skidding resistance and on aggregates used from Agent Authorities. Three stages were followed to compile a database for analysis:

- Highly trafficked locations were identified from the DOT Network Information System (NIS).
- When locations with suitable traffic intensities had been selected, DOT Regional Offices and Agent Authorities were requested to provide the relevant information.
- Information was sorted to select unique occurrences of PSV, aggregate source and traffic intensity for subsequent analysis.

3.1.2 Collation of data

3.1.2.1 Aggregate information

The source and PSV of the aggregate used on each site for which skidding resistance data were available were identified from the Agents' records. It is known that PSV can vary with time for a given source and so it was important that PSV information related directly to the material as laid, rather than to more recent test results. In most cases, copies of appropriate laboratory test certificates were obtained.

It was also vital that the PSV information could be directly linked to specific locations on the road and hence to the corresponding skidding-resistance measurements. Not all of the information supplied was suitable. The number of locations which could be considered was therefore reduced by these limitations. Table 1 gives the geological descriptions of the aggregates which had been used. It can be seen that the Gritstone trade group predominated.

3.1.2.2 Traffic flow

Traffic levels recorded in the Network Information System (NIS) for 1988 were used to select the heavily-trafficked stretches of road for which skidding resistance and aggregate information would be obtained. The NIS data were recorded as the total commercial vehicle flow but MSSC is normally measured in lane 1 only. (Lane 1 is the leftmost running lane of a dual carriageway or motorway, often referred to colloquially as the 'slow' lane). It was therefore necessary to estimate the number of commercial vehicles per day (CVD) using lane 1 at each location and Rhodes' model (Rhodes, 1990) was used for this purpose.

For the main analysis, the standard DOT method given in Departmental Advice Note HA24/83 (Department of Transport, 1983) was chosen to determine lane 1 traffic levels because this was considered to be the model most familiar to engineers. For the purposes of this study, commercial vehicles were defined as all vehicles in excess of 1.5 tonnes unladen. For two- and three-lane carriageways, the proportion, P, of commercial vehicles using lane 1 was calculated from the 24 hr average annual daily flow (AADF) of commercial vehicles, F, using the formula $P = 0.97 - (0.385 \times 10^{-4})F$. The number of commercial vehicles using lane 1 per day (CVD) is given by $CVD = P \times F$.

Table 1 Geological descriptions of aggregates identified in heavy traffic study

Trade group	*Source code*	*Geological description*
Basalt	B1	Andesite Quartz Dolerite
	B2	Albitised Olivine Dolerite
Gritstone	G1	Silurian Greywacke
	G2	Ordovician Greywacke
	G3	Greywacke
	G4	Silurian Greywacke
	G5	Pre-Cambrian Greywacke
	G6	Pre-Cambrian Greywacke
	G7	Greywacke
	G8	Pennant Sandstone
	G9	Quartzitic Sandstone
Porphyry	P1	Porphyry

3.1.2.3 Skidding resistance

The best parameter to use for comparison with PSV and traffic would clearly be the equilibrium skidding resistance, but data from successive years were not available. However, because the surfacings at all of the sites had been in service for some time, it was assumed that the MSSC readings provided for a single year would be a reasonable approximation to ESC. Both the age of the surfacings and traffic intensity acting upon them suggested that this was a valid assumption. In order to harmonise the different levels of detail available for the various locations, MSSC values were calculated for successive 100m lengths.

3.1.2.4 Selection of unique sites

The completed database was searched to identify the number of unique combinations of PSV, source of aggregate, year of construction and traffic level. This search yielded 36 unique sites. All the sites identified were either main line motorway or dual carriageway trunk roads. Mean, minimum and maximum MSSC values were determined for each unique site. Table 2 gives the key data relating to the 36 unique sites.

Table 2 Summary data for unique sites identified for PSV/MSSC/Heavy Traffic study

Road and direction	*Survey year*	*Area*	*Site No.*	*Traffic flow (estimated) CVD lane 1*	*Aggregate code*	*PSV*	*Date laid*	*No. of 100m sections*	*minimum MSSC*	*mean MSSC*	*maximum MSSC*
M4 Westbound	1989	Berkshire & Wiltshire	3	5605	G4	60.0	1986	117	0.28	0.33	0.48
			4	4573	G3	60.0	1987	162	0.38	0.43	0.49
M4 Westbound	1991	Berkshire & Wiltshire	5	5816	G5	63.0	1982	9	0.46	0.53	0.61
			6	5609	G5	63.0	1982	29	0.43	0.47	0.54
			7	5607	G5	63.0	1982	12	0.42	0.44	0.47
			8	5607	G9	60.0	1982	16	0.39	0.47	0.50
			9	5607	G4	60.0	1986	8	0.41	0.42	0.44
M5 Northbound	1990	Hereford & Worcester	10	4974	G5	65.0	1979/80	22	0.37	0.38	0.40
			11	5389	G6	64.0	1987/88	16	0.41	0.44	0.48
			12	5389	G7	67.0	1985/86	9	0.48	0.51	0.52
			13	5389	G8/G7	67.0	1985/86	10	0.43	0.49	0.51
M5 Southbound	1990	Hereford & Worcester	14	5389	G8/G7	67.0	1985/86	11	0.41	0.45	0.50
			15	5389	G8/G6	71.0	1985/86	7	0.39	0.40	0.42
			16	5389	G6	64.0	1987/88	1	0.42	0.42	0.42
			17	5211	G6	64.0	1987/88	15	0.38	0.43	0.49
			18	4974	G5	65.0	1979/80	26	0.37	0.39	0.44
M6 Northbound	1987	West Midlands	19	5827	G7	67.0	1981	29	0.37	0.39	0.42
			20	5827	G7	67.0	1983	6	0.40	0.48	0.50
M6 Northbound	1987	West Midlands	29	5869	G8/G6	67.5	1982	24	0.34	0.44	0.52
	1988	(3 years data	1	5869	G8/G6	67.0	1982	13	0.33	0.38	0.50
	1990	at same site)	2	5869	G8/G6	67.0	1982	13	0.36	0.41	0.55
M6 Southbound	1987	West Midlands	23	6044	G7	67.0	1983	7	0.49	0.49	0.50
			24	6044	G7	67.0	1981	28	0.37	0.40	0.45
M6 Southbound	1988	West Midlands	25	6044	G6	67.0	1987	30	0.44	0.45	0.48
			26	6044	G7	70.0	1984	29	0.46	0.47	0.49
			27	6044	G7	70.0	1983	45	0.46	0.49	0.51
			28	6044	G7	70.0	1981	27	0.38	0.40	0.47
A5103 Eastbound	1990	Greater Manchester	30	4469	B2	63.0	1971	24	0.39	0.44	0.48
A5103 Westbound	1990	Greater Manchester	36	4469	B2	63.0	1971	24	0.38	0.44	0.51
M6 Northbound	1990	Cumbria	21	3291	G2	59.0	1982	28	0.34	0.37	0.39
			22	3291	G2	59.0	1987	24	0.32	0.35	0.39
M6 Southbound	1990	Cumbria	31	3291	P1	56.0	1971	3	0.33	0.33	0.34
			32	3291	G2	59.0	1982	16	0.32	0.35	0.38
			33	3291	G2	59.0	1985	32	0.32	0.36	0.42
A1(M) Northbound	1990	Durham	34	3738	B1	62.0	1980	81	0.43	0.46	0.49
A1(M) Southbound	1990	Durham	35	3738	B1	62.0	1980	89	0.40	0.43	0.47

3.1.3 Initial analysis

As an initial analysis, graphical techniques were used to assess general trends and patterns within the data. The extent of the variation of MSSC, both along and between sites, was examined using bar plots of the MSSC for each unique site. It was found that, even though aggregate type and traffic level were constant along a given site, MSSC could vary considerably. Some sites were consistent throughout, with very small changes in MSSC along their length; others showed noticeable variation. Figure 4 compares two examples typical of the range of variability observed.

Figure 5 is a graphical representation of the data in Table 2, comparing MSSCs obtained from the different sites with their respective traffic flows. Sites with the same aggregate have been grouped together in order of increasing traffic flow; aggregate sources are grouped in order of increasing PSV. It was found that the same source often had differing PSV values reported, so for the purpose of this initial view, an overall mean for each source was used. The wide range of MSSCs obtained for each source is apparent and, at first sight, there seems to be a general trend for skidding resistance to increase with PSV.

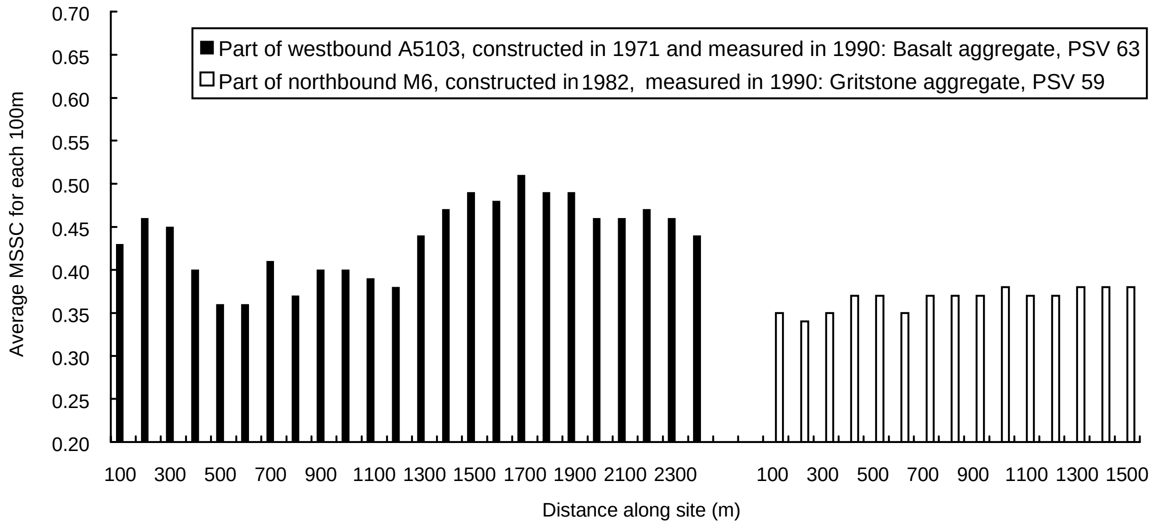


Figure 4 Comparison of variation of MSSC on two unique sites

3.1.4 Further analysis

The effect of traffic on MSSC is not clear from Figure 5. Further investigation showed that MSSC was not dependent on the traffic flow at the high traffic levels although, as expected, higher PSVs tended to give higher MSSCs. Further, above PSV 60, all aggregates seemed to perform similarly. It appeared, therefore, that the behaviour of the higher-PSV aggregates under heavy traffic was different from that expected from the original research in LR504. A relationship for comparison with that quoted in LR504 was determined using multiple linear regression; this confirmed the dependence of skidding-resistance on both PSV and traffic, but with a much reduced influence from traffic at the high traffic levels.

The new relationship and the LR504 equation were used to estimate mean MSSCs for each of the 36 unique sites, which were then compared with the measured values and the traffic flow information. It was found that the two equations operated in a broadly comparable manner at lower traffic levels, but the LR504 formula did not reliably predict MSSC where traffic was in excess of 4000 CVD, tending to under-estimate.

The roads included in this phase of the study were all motorways or dual carriageways. Nevertheless, as is illustrated by Figure 4, there was clear evidence that the same aggregate on the same road can give different performance with a change in traffic behaviour such as braking approaching a slip road. Site category could therefore be of importance in determining the way in which an aggregate performed in terms of skidding resistance. It was also observed that the majority of aggregates used on the roads in this phase of the study were of the gritstone group. However, it was considered that different aggregate types might exhibit different behaviour under heavy traffic. The study was therefore extended to include a wider range of rock types and site categories.

3.2 Performance of wider range of aggregates and sites

The early phases of this work were directed primarily at more-heavily trafficked roads and therefore the data represented a limited range of site categories. For the next phase, it was decided to make direct measurements of skidding resistance on a selected network, primarily on county roads, in order to widen the study to include a greater range of sites and, possibly, rock types,.

3.2.1 Approach

A Local Authority provided information on traffic levels and PSV on its network and a SCRIM survey was designed which would cover a range of these factors in as many site categories as was practical. Three summer surveys were made to provide MSSC values.

The data were combined to produce a number of 50m sections, with known traffic and PSV, each being assigned to an appropriate investigatory level band.

Sections with surfacings which were known to be less than 3 years old (that is, unlikely to have reached their equilibrium value) or which used artificial aggregates, were excluded from the analysis in order to ensure that the results were representative of the MSSC equilibrium skidding resistance of the natural aggregates. The data from this survey were combined with those from the previous phases to produce a single large database.

3.2.2 Comparison of database with the current model

The relationship currently used to predict MSSC from the PSV of the aggregate and the traffic level (in CVD), taken from LR504 is:

$$\text{MSSC} = 0.98 \times 10^{-2}\ \text{PSV} - 0.664 \times 10^{-4}\ \text{CVD} + 0.033$$

The first stage of the analysis, therefore, was to compare the MSSC predicted by this equation with the values recorded in practice, using a simple graphical approach.

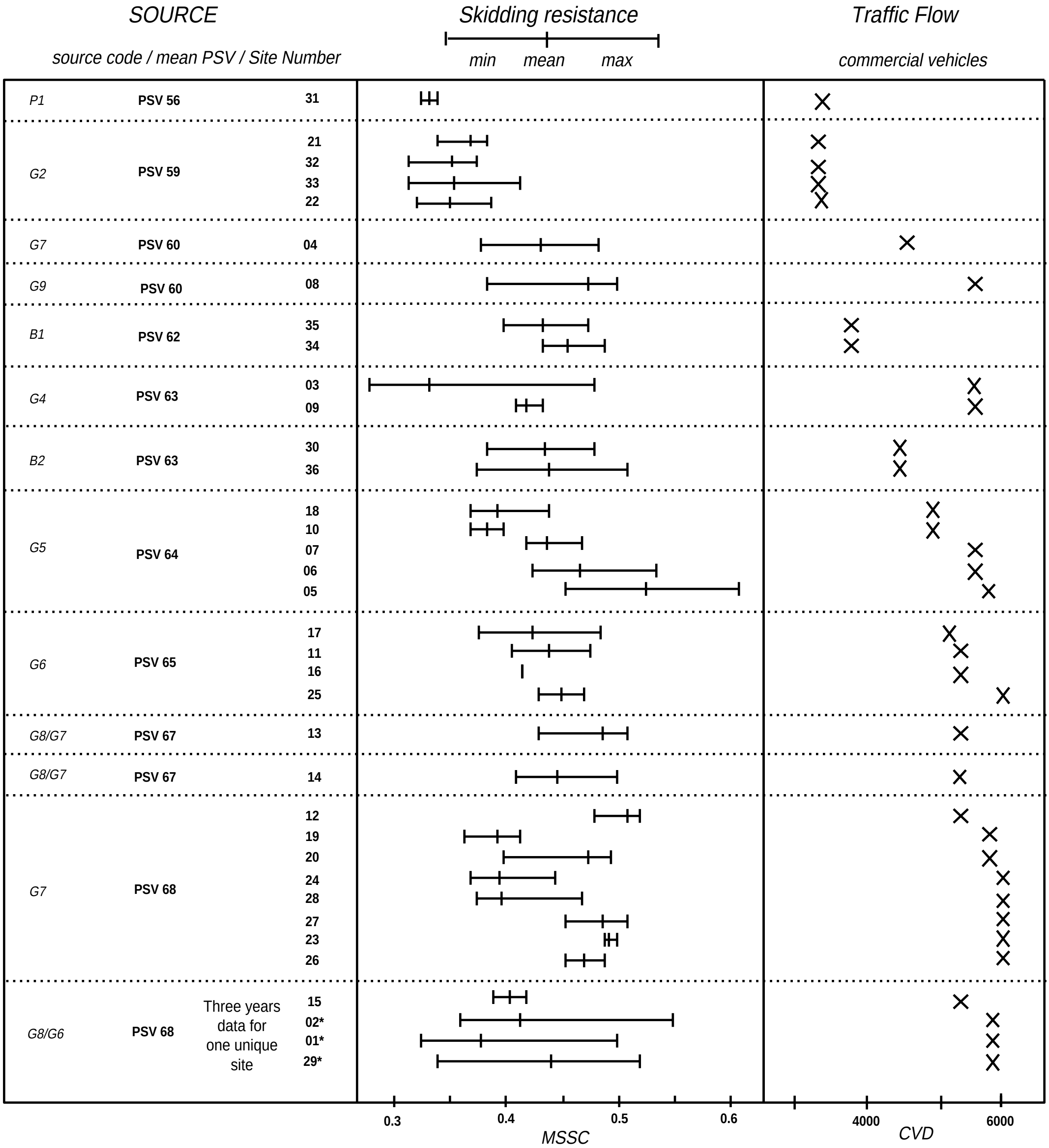


Figure 5 Graphical representation of summary data

The database was searched to find all unique combinations of PSV, aggregate source, year of construction and site category. This established criteria which would be used to generate summary statistics for each of these ‘unique sites’ that could then be included in the graph.

Figure 6 shows the distribution of the measured MSSC for the unique sites, plotted against CVD. The corresponding values predicted from the PSV and CVD using the LR504 formula are shown in line form for comparison.

Figure 6 demonstrates the effects found in the first phase of the study, namely, that the LR504 formula underestimates the MSSC achieved in practice at higher traffic levels while, at lower traffic levels, it predicts consistently higher values than are actually found. In the centre of the traffic level range, the model worked moderately well, but there was still a wide spread of actual measured values.

3.2.3 Alternative models

It would have been possible to derive a new general relationship from the new database but it was clear (as illustrated by Figure 4, for example) that the same aggregate could produce different skidding resistance for the same traffic level but under slightly different site conditions. Therefore, it was likely that different polishing regimes were in operation at sites in different categories of road and that this should be taken into account when considering alternatives to the LR504 model.

Each site category defined in Table 3.1 of Chapter 3 of

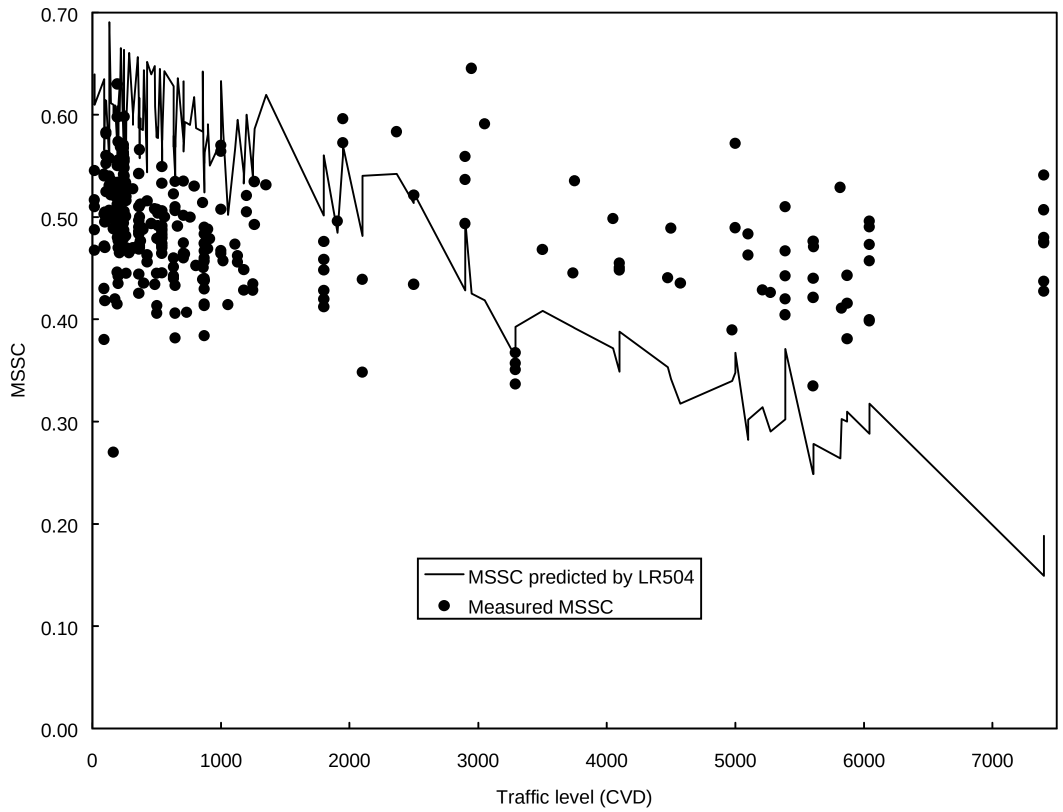


Figure 6 Comparison of measured MSSC with predictions using LR504 model

HD28 in the DMRB is assigned a risk rating and a corresponding investigatory level (IL) for MSSC. (The investigatory level is the MSSC below which investigation of the site and assessment of any need for remedial work is initiated). Several categories have the same investigatory level and can therefore be grouped into corresponding bands. Therefore, for the next stage of analysis, multiple regression analysis was used to explore alternative models, based on each investigatory level band separately. The investigatory level bands are defined in Table 3.

Table 3 Definition of investigatory level bands

IL Band	*Site Categories*	*Investigatory Level*
I	A,B	0.35
II	C,D	0.40
III	E,F,G1,H1	0.45
IV	G2	0.50
V	J,K	0.55
VI	H2	0.60 (at 20km/h)
VII	L	0.55 (at 20km/h)

Initially, PSV and CVD were used as independent variables and MSSC was the dependent variable.

However, it was found that more of the variation could be explained by expressing traffic in terms of the natural log of CVD (ln(CVD)).

For each investigatory level band an equation was determined of the form:

$$MSSC = [A \times PSV] - [B \times \ln(CVD)] + K$$

The results of this analysis are summarised in Table 4.

There were insufficient data to determine relationships for Bands VI and VII with confidence.

Both PSV and traffic play an important part but it can also be seen from the R^2 values that only about 10% of the total variation has been explained by these factors. However, it was considered appropriate to use the models because they involved the two factors that were readily available to the highway engineer designing the surfacing. The constant term, K, is the dominant component in all the models.

This term represents the influence of the various unidentified factors which influence the way in which the skidding resistance of a particular surfacing is established.

The influence of traffic in the model for Band V is noticeably less than for the other bands. This may be due in part to the limitations of the available data when relatively few locations are involved.

Table 4 Models of the form MSSC = [A x PSV] - [B x ln(CVD)] + K for individual IL bands

Band	*IL*	*A (x 10^{-3})*	*B (x 10^{-2})*	*K*	*No of Sections*	*R^2*
I	0.35	6.18	2.25	0.252	2431	0.11
II	0.40	3.90	1.95	0.377	4073	0.13
III	0.45	2.94	1.70	0.407	1749	0.09
IV	0.50	5.81	1.46	0.193	82	0.11
V	0.55	4.73	0.98	0.231	43	0.08

3.3 Relating skidding resistance to PSV and traffic.

3.3.1 Predicted MSSC using the new models

In order to assess the contributions of traffic and PSV to the MSSC achieved, the models in Table 4 were used to plot graphs of predicted MSSC. For each of the investigatory level bands, the predicted MSSC was calculated over the traffic range found in the data for PSV values from 50 to 70 in steps of 5. The results are shown in Figures 7. Each graph shows predicted MSSC plotted against CVD as a family of curves corresponding to the different PSV levels. For comparison, the straight line predicted by the LR504 formula at PSV 60 has also been drawn on each graph, together with the target investigatory level for the corresponding investigatory level band.

The relative effects of the two known factors can clearly be seen in each graph. Increasing PSV results in an increase in predicted MSSC; the influence of traffic is marked at lower traffic levels and decreases in relative

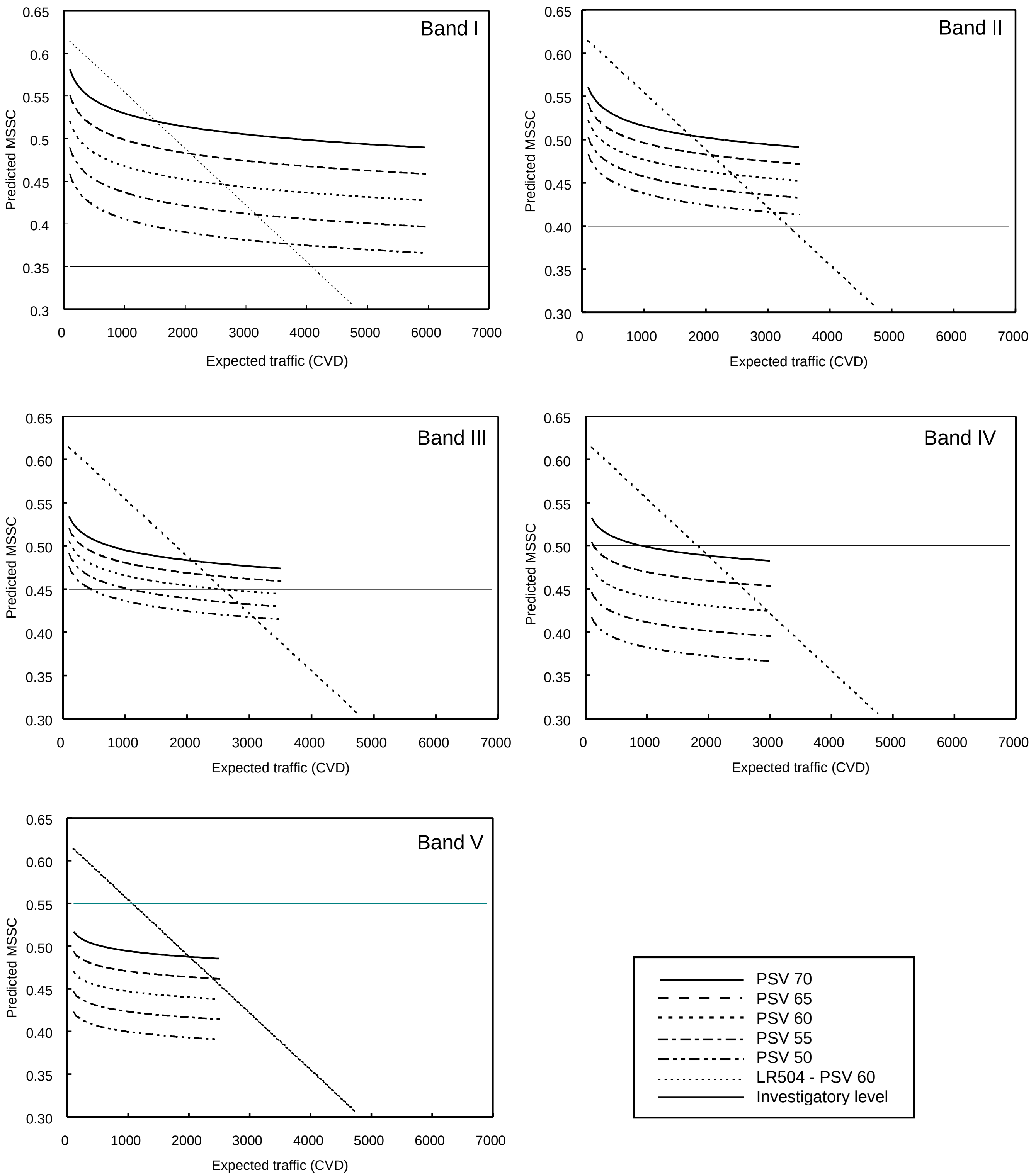


Figure 7 Predicted MSSC for different PSV levels and investigatory level bands

importance at the higher levels. Perhaps of greater practical significance is the position of the curves relative to the investigatory level for the band. At lower-risk sites (Bands I and II), all the lines are above the investigatory level, which is just maintained by a PSV of 50. For Band III only the higher PSVs lead to MSSC above investigatory level. For the two most difficult bands, no materials perform as required and PSV has a greater influence on the range of MSSCs obtained, which are also generally lower than those for Bands I - III.

It is important to bear in mind that this analysis was confined to the ranges of PSV and traffic found in the data. It should not be assumed that, for example, the linear contribution by PSV also relates to lower-PSV aggregates.

3.3.2 Using the new models to specify PSV

Having derived new models linking MSSC to PSV and traffic, an assessment was made of the way in which they would predict PSV requirements for use in a specification, compared with the current approach.

At present, the DMRB specifies the minimum PSV values to be used in a new surfacing in Table 2.1 of HD28/94, which is divided up into traffic levels. When this Table was prepared, the PSVs required were determined by using the LR504 formula to calculate the PSV needed to deliver an appropriate MSSC for each site category at each traffic level. Initially, target MSSCs were defined by adding 0.05 to the investigatory level for each site category.

This was done in order to set a target just above the investigatory level in an attempt to ensure a reasonable service life for the road surface.

However, in order to allow for reasonable use of resources, sites with similar requirements were grouped together into bands within the Table and, within each of these bands, the traffic levels were divided into blocks with a common PSV level. As a result, the grouping of site categories in the Table, did not correspond with the investigatory level bands as defined for the purposes of this study.

In order to assess the new models, comparative values of the PSV required to achieve IL + 0.05 for the ranges of traffic levels in the database were calculated.

For each investigatory level band, the LR504 general relationship and the appropriate new model (having re-arranged the formulae and substituted the corresponding target MSSC value) were used to calculate the PSV. The results of this analysis are shown graphically in Figure 8. The graphs also include lines representing the levels specified in HD28, using an approximate estimate where the investigatory level bands and PSV blocks do not correspond exactly.

Figure 8 shows that, while the requirements of HD28/94 follow the general line of the LR504 formula, it is only in Band II where these approach the values suggested by the new model.

In Band I the new model predicts considerably lower values for the required PSV whereas for Bands III and above the new models require higher values of PSV. The implications of this analysis, particularly in regard to the preparation of a new specification for PSV requirements, are discussed in the next section.

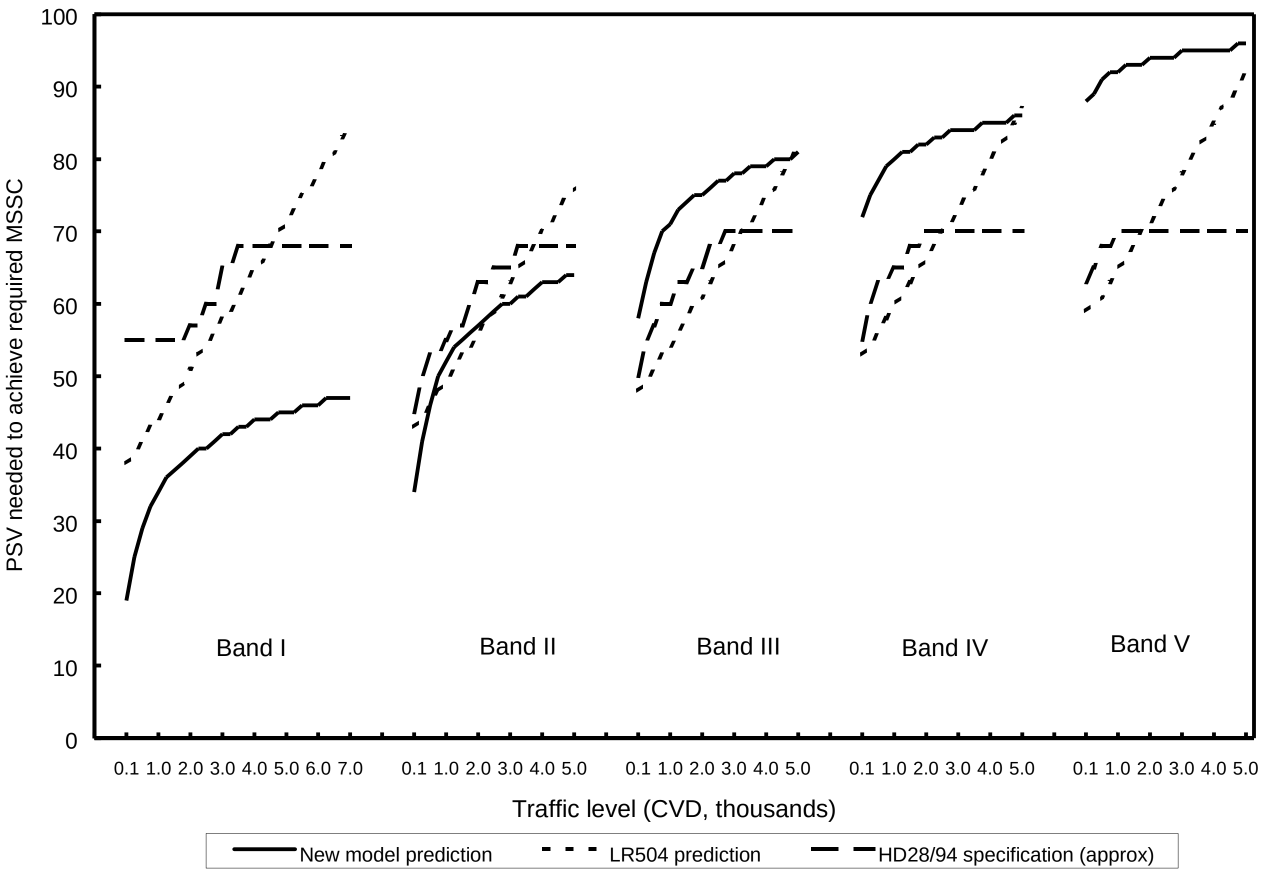


Figure 8 Comparison of PSV values required to achieve MSSCs at IL + 0.05

4 Discussion - implications of desk studies

4.1 The relationship between MSSC, PSV and CVD

The results of the desk studies have confirmed that both the polishing resistance of the aggregate and the level of traffic influence the equilibrium skidding resistance obtained. The results are in accord with the two well-established principles that the polishing action of traffic causes skidding resistance to fall and that higher PSV aggregates give higher skidding resistance for a given level of traffic.

However, it is clear that the generalised relationship on which current specifications are based does not accurately reflect performance under present-day conditions. Better correlations are obtained when categories of sites with differing requirements and subject to different trafficking conditions are considered separately. Further, the influence of traffic, particularly at the higher traffic levels experienced on some present-day roads, is less than previously assumed and is better modelled using a logarithmic transform.

It has been seen that in the new models, the largest contribution to MSSC comes from the constant term. This represents the combined effects of factors other than PSV and traffic which are involved in developing skidding resistance, for example, surfacing type, rate of spread of chippings and particle size. There are also differences in the relative contributions of PSV and traffic on the different types of site, which can be seen in the graphs in Figure 7. Although it is not possible to explain these effects conculsively, some tentative ideas to account for them can be suggested.

The relative influence of traffic level (coefficeint *B* in Table 4) diminishes as the investigatory level band increases. This might be expected because the nature of the sites changes with investigatory level band; heavy traffic levels tend to be be lower on single carriageways, for example, than on motorways.

The effect of PSV (coefficient A in Table 4) appears to be of greater significance to skidding resistance in Bands I, IV and V than for the two intermediate bands. This is not surprising for sites in Bands IV and V because these are, by definition, at hazards such as bends, traffic lights and roundabout approaches where there will inevitably be greater stresses from turning and braking affecting the aggregate. On the low investigatory level, Band I sites, however, different conditions apply. The traffic action is generally rolling in a straight-line and therefore aggregates in these locations may not be polished as much as at places where frequent braking or cornering is involved. However, on such roads heavy vehicle speeds are generally 25 percent or more higher than on single-carriageways and therefore significantly more energy is input into the polishing process as the vehicle tyres impact upon the road.

There may also be an equilibrium interaction between polishing and abrasion that comes into play at heavy traffic levels.

It is also possible, but not capable of analysis in the current data, that sites of the higher-risk type tend to have similarities in surfacing characteristics which reduce the number of factors contributing to the constant term and hence the greater apparent influence of PSV. A similar comment could be made regarding Band I. (It should be borne in mind that high-skid resistance surfacings using artificial aggregates have been excluded from this analysis.)

4.2 Specifying PSV requirements

The work described so far has confirmed that the existing requirements need revision. However, one of the difficulties associated with the present Table and which, as Figure 4 shows, would apply equally to a revised version based on this study, is the spread in the range of MSSC found for any given PSV/CVD combination. This will inevitably result in individual sites not necessarily performing as expected and so careful consideration needs to be given to the way in which materials are specified.

There is some evidence, from the limited number of rock types used in the database, that engineers may compensate for the uncertainties in the present position by selecting higher-performance materials than the minimum specified. Further, in part resulting from this tendency, there is very limited data available for the lower-PSV aggregates.

Polished Stone Value is actually a measure of skidding resistance on a small sample of surface with a 100% stone coverage, having been subjected to a standard period of polishing. It is probable that some aggregates, with comparable measured friction after the standard polishing period, may continue to polish at different rates in service. This could give rise to some of the spread found in the data.

Figures 5 and 6 show that some attempt could now be made to address the apparent over-specification in some categories. For investigatory level Band I sites, a reduction in the minimum PSV at high traffic levels could be considered. Caution should be exercised at this stage, however, because it is uncertain whether the degree of polish applied in the standard PSV test is sufficient to reflect the effects of heavy traffic.

Figure 8 also shows that, for investigatory level Bands III IV and V, the current specification is probably inadequate and that aggregates with a very high PSV (80 or more) are needed to deliver MSSC above the required investigatory levels. Such values are beyond those achievable using natural aggregates. This is already recognised for investigatory level Bands VI and VII, for which special skid-resistant surfacings using materials such as calcined bauxite are specified currently. The results of this project suggest that such a requirement may need to be extended to investigatory level Bands IV and V and, possibly, to Band III for more heavily-trafficked sites. However, it may be that some other factors, such as aspects of the surfacing design or careful selection of aggregate for such sites, could be found so that this step would not be necessary.

5 Laboratory studies of polishing mechanism

5.1 The object of the laboratory work

The desk studies had shown two important effects:

- the response of an aggregate to traffic is not linear and the skidding resistance as measured by SCRIM does necessarily fall continuously with an increase in traffic levels;

- the same aggregate and traffic level on the same road can produce markedly different levels of MSSC when there is a change in traffic behaviour, such as at the approach to slip roads or on higher-stress locations.

Therefore, before proceeding to redefine the specification requirements, it was decided to carry out some small-scale experiments in an attempt to demonstrate these effects in the laboratory and therefore give greater confidence in any new specification. Three groups of tests were carried out, which are described fully in Appendix A. The key objectives were:

- to examine the effect of increased traffic on equilibrium skidding resistance using extended polishing on the accelerated polishing machine;
- to assess the possibility of different skidding resistance levels occurring with the same material under braking, by introducing controlled slip between test wheel and road wheel into the polishing process;
- to assess an alternative test regime for materials used in the road in smaller sizes than in the standard PSV test.

5.2 Discussion of laboratory trials

These experiments (Appendix A) were based on two key assumptions, namely:

i increased time on the polishing machine is equivalent to heavier traffic flow in a polishing season;

ii that the introduction of fixed slip simulates to some extent the effect of braking or deceleration.

Clearly, a more extensive study (which would need to include a simulation of winter recovery) would be needed to provide a more comprehensive laboratory simulation of conditions on the road. Nevertheless, the results of the tests should provide some evidence to assist in the interpretation and application of the initial phases of this project.

5.2.1 Extended polishing

The extended polishing tests showed that, overall, skidding resistance initially fell rapidly with increased trafficking but, as the test time was extended, polishing slowed down or did not change. This is consistent with the predictive models derived from the field measurements of skidding resistance (Figure 7).

The tests have also confirmed that aggregates with similar characteristics do not necessarily polish in the same way.

5.2.2 Controlled slip

The controlled slip experiment provided an indication that, in areas where stresses such as braking frequently occur, an aggregate will give a lower skidding resistance than would be expected where traffic is free-rolling.

As with the extended polishing test, the results imply that increased weight of traffic does not necessarily result in a continuous decrease in skidding resistance.

5.2.3 Small particle sizes

The results of the tests with smaller-size particles showed, as expected, that using smaller sizes on the PSV machine is practical but the results are very different from those obtained with standard-sized particles.

It is not clear at this stage whether increased pendulum values in the PSV test represent a real improvement in skidding resistance brought about by the use of small particles. It is likely that the results are, in part, a response of the pendulum tester to the harsh surfaces which result from this process with the slider meeting more and sharper edges or angles than on the carefully aligned, smoother standard specimens.

The smaller size bauxite aggregates tested were very hard, mineralogically homogenous aggregates which perform well at the normal sizes. It would be unwise to assume that any aggregate in the standard size would provide greater skidding resistance or polishing resistance in the smaller size. Also, the materials had grain sizes significantly smaller that the minimum particle size used in the polishing tests. There is no information to show what happens as the grain size approaches the test particle size as could occur, for example, in aggregates with large crystalline components.

5.3 Implications for a new specification

On the basis of these results, it would be reasonable to use the principles suggested by the new models (Table 4) in developing a revised specification. This implies allowing slightly lower PSV values in some cases and not increasing the PSV requirement at heavy traffic levels. The slip tests, as with the sample road measurements (see Figure 5), also suggest that an additional category may be necessary to take account of braking areas on motorway mainline sections.

For the time being, standard PSV test values will have to continue to be used to specify aggregates for high-demand sites, where natural aggregates are unlikely to provide sufficient performance and artificial aggregates in small sizes will probably be used. The results of these laboratory tests suggest that materials such as calcined bauxite which are to be used in small sizes on the road can vary markedly in performance, even though they have high PSVs in the standard test. Further work should be carried out to investigate more fully an appropriate test regime for assessing such materials.

6 Developing a revised standard

6.1 Initial discussion

The work reported above has shown a number of key points which should be taken into account when considering any revision of the current requirements for the PSV of aggregates used in new construction:

- The existing requirements do not model what is happening in practice sufficiently reliably across the full range of traffic encountered on present-day roads in the UK.
- Aggregates with the same PSV do not necessarily yield the same skidding resistance under similar conditions.
- An individual aggregate may give a range of levels of skidding resistance, even for the same traffic level, especially where higher stresses are involved.
- For many aggregates there is a limit to the extent to which they will continue to polish as traffic levels increase.
- The relative contribution of PSV to in-service skidding resistance varies depending on the type of site.

Nevertheless, PSV is the only parameter relating to the microtexture of an aggregate which can currently be measured in a standardised manner and which has been related to traffic and site conditions. It therefore remains an appropriate property to use in specifications, provided that its limitations are recognised.

The greatest constraints influencing the development of a new standard based on the present study are the range of aggregates and types of site available. This is to some extent a result of the introduction of the existing standard and of engineer's policies in implementing it. This point is illustrated in Figure 9, which shows the number of sites in the database distributed by reported PSV and aggregate source. Even though the roads studied were in a number of geographical areas, the aggregates used were dominated by two particular sources. Nevertheless, there were a range of PSVs used, although some of these may have been at individual locations.

It has clearly been common practice to use high-PSV aggregates, even when lower values are permitted at present, and therefore there is little information available for low-PSV aggregates. Further, some combinations of site category and traffic level are rare and therefore a shortage of appropriate data is inevitable.

There is sufficient evidence from the present study to move towards a revised standard. However, the results of this work will have been influenced to some extent by the limitations of the available data (as was the case in the original work of the 1970s) and this must be taken into account in developing new proposals.

6.2 Using the new models and back analysis to define requirements

6.2.1 Defining initial requirements

Initially, a revised version of the Specification Table was drawn up. For this purpose, the new models were used (as described in Section 3.3.2.) to calculate the PSV which could be expected to provide an MSSC 0.05 above the investigatory level for each investigatory level band at the various traffic levels.

In some instances the predictions were clearly unrealistic. For example, according to the models, some of the lowest risk categories had MSSC requirements that could have been met by aggregates of a PSV as low as 35.

However, this was regarded as inappropriate, because rocks with such a low PSV tend to have other disadvantages which make them unsuitable for use in wearing courses. An underpinning level of PSV 50 was therefore set. Conversely, the required PSVs for higher-risk categories were beyond those achievable with natural aggregates to a far greater extent than in the current Standard.

Also, the PSVs were banded to provide a realistic potential Table in which the different levels of PSV specified would reflect the practicability of the PSV test to discriminate between them.

6.2.2 Performance of sites within the database.

It was decided to test the effectiveness of the proposed new Table by back-analysis, using the information in the database from the desk study. This was searched to find

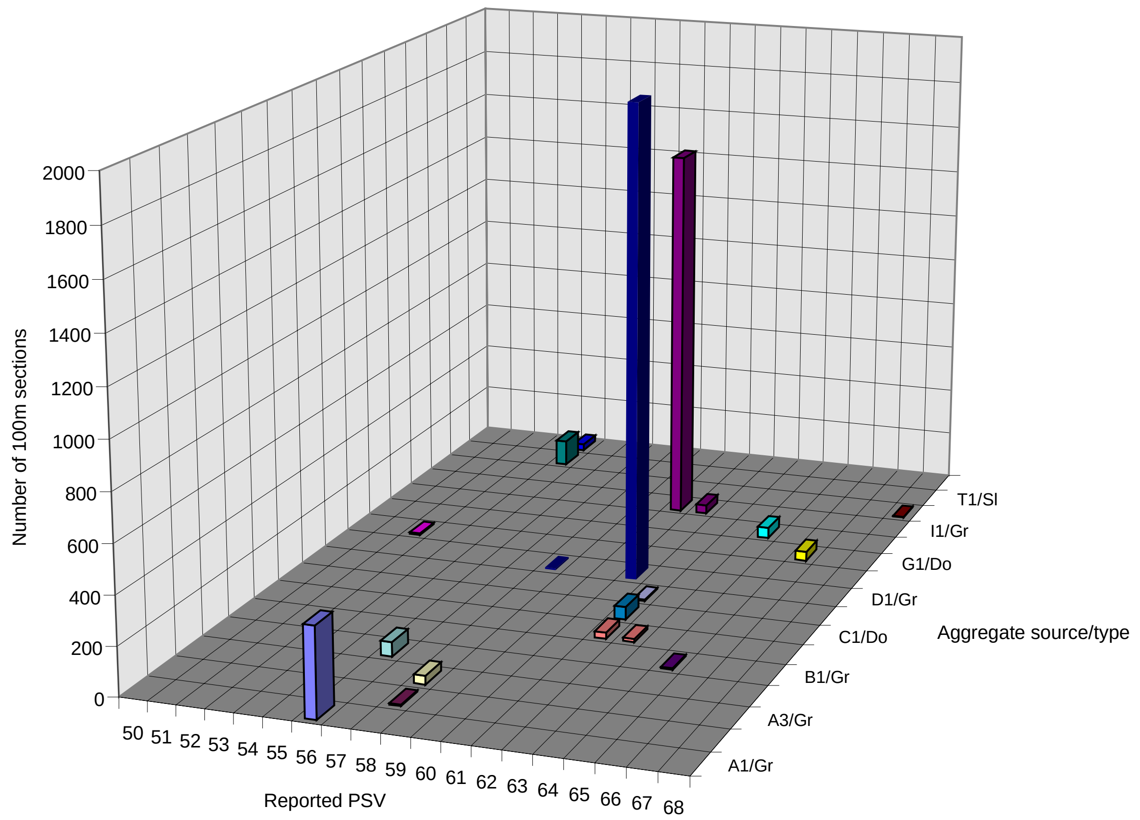


Figure 9 Distribution of 100m sites in the database by PSV and source

out whether materials which would have met the proposed new requirements had performed satisfactorily in practice. This would give an indication of the risks of materials with the 'right' PSV failing to provide the required MSSC.

Thus, for each of the proposed investigatory level bands in the new Table, the database was searched for sites where the aggregate used met (or exceeded) the proposed PSV requirement at each traffic level. From these, the proportions falling into MSSC bands similar to the risk-rating levels in HD28 were calculated. For investigatory level Bands II - V there were no data available at higher traffic levels and so the effectiveness of the proposed PSV could not be tested. However, it should be borne in mind that in practice site categories in these investigatory level bands are unlikely to be found on the most-heavily trafficked roads. Further, for investigatory level Bands IV and V, the new suggested minimum PSV was higher than had been used in most of the sites in the database so in these cases the highest available PSV was used for comparison. The results of the analysis are given in Table 5.

This analysis showed that, for Bands I, and II, most of the sites meeting the suggested PSV requirement provided MSSCs at or above the investigatory level for the band. However, it should be borne in mind that the suggested minimum PSV was chosen to deliver MSSCs one band higher than the investigatory level. This strategy worked well at the lower traffic levels in these bands but, at higher traffic levels, a significant proportion of sites yielded MSSCs lower than the target, although remaining at or above investigatory level. It should also be recognised that the PSVs available in the database were well above the suggested minimum levels, possibly because many of the sites were over-specified initially.

The results for Band III, however, showed a large proportion of sites failing to provide MSSC at or above investigatory level, even at low traffic levels. In Band IV the required MSSC was provided only at the lowest traffic levels whereas at higher traffic levels, and for all of Band V, none of the aggregates performed satisfactorily. This latter observation was to be expected because the minimum required PSV for these cases was well above that available.

The foregoing analysis confirmed that the suggested revisions to the PSV requirements for new construction were reasonable. However, it is clear that the work been constrained by the limited range of aggregates used in the data for this study and there remains a risk of individual aggregates failing to deliver the required MSSC.

6.3 Requirements for a revised table

On the basis of the analysis above, it is now possible to propose a revised Table of PSV requirements to replace Table 2.1 of HD28 which will go some way to addressing the current difficulties.

Table 5 Distribution of MSSCs of sites meeting possible new PSV requirements *(figures in bold–italics represent sites at or above investigatory level for the IL band)*

IL Band	*Traffic level (CVD)**	*suggested minimum PSV***	*PSV range of sites in database*	*No. of sites ≥minimum PSV*	*Percentage of sites with acceptable PSV in MSSC bands* below 0.30	*0.30 0.34*	*0.35 0.39*	*0.40 0.44*	*0.45 0.49*	*0.50 0.54*	*0.55 and over*
I	0-250	50	54-68	1984	0	0	***1***	***5***	***23***	***41***	***30***
	250-500	50	54-66	384	0	0	***1***	***7***	***36***	***44***	***12***
	500-1000	50	56-62	806	0	0	***3***	***21***	***48***	***24***	***4***
	1000-2000	50	59-60	75	0	0	***0***	***61***	***39***	***0***	***0***
	2000-3000	55	*no sites in database for Band I at this traffic level*								
	3000-4000	60	56-60	170	0	0	***0***	***42***	***58***	***0***	***0***
	4000-5000	60	60-65	258	0	0	***16***	***58***	***25***	***1***	***0***
	5000-6000	65	60-68	122	0	3	***14***	***42***	***24***	***17***	***2***
	over 6000	65	66-68	166	0	0	***13***	***22***	***51***	***14***	***0***
II	0-250	50	58-60	2217	0	0	1	***6***	***23***	***42***	***28***
	250-500	50	56-63	264	0	0	1	***5***	***34***	***50***	***9***
	500-1000	50	56-65	265	0	1	4	***13***	***15***	***53***	***14***
III	0-250	55	54-66	617	0	2	5	17	***22***	***34***	***20***
	250-500	60	56-65	72	0	0	3	24	***28***	***44***	***1***
	500-1000	60	56-66	60	0	0	0	15	***12***	***63***	***10***
IV	0-250	60	56-68	16	0	0	0	0	38	***31***	***31***
	250-500	59**	59 only	1	0	0	0	0	100	***0***	***0***
	500-1000	59**	56-59	26	0	0	0	24	74	***3***	***0***
V	0-250	59**	56-59	11	0	0	0	18	73	9	***0***
	250-500	65**	59-65	2	0	0	0	50	50	0	***0***
	500-1000	60**	56-60	6	0	0	67	33	0	0	***0***
	over 1000	60**	59-60	4	0	0	75	25	0	0	***0***

* *There were no sites in the database for the higher traffic levels in Bands II - V*

** *At these bands and traffic levels the models call for higher PSVs than were available in the database. The highest PSV available in the data was therefore used here for comparison.*

For consistency, the new Table should be based upon the site categories and default investigatory levels in Table 3.1 of HD28. Further, it is proposed that PSV bands based on five-unit increments should be used in order to reflect the recognised limitations in the precision of the PSV test. This approach will inevitably lead to different cell boundaries compared with the current version of the Table.

Also, a new Table should take into account the different results which the same aggregate can produce under the same traffic load where additional polishing action may be involved. For this reason, it is proposed that an additional investigatory level band and site category (Ia, category A1) should be introduced to cover junction and slip-road approaches on motorways and dual carriageways. This category would have the same MSSC requirements as at present covered by category A but recognises the need for a slightly higher PSV to resist the increased polishing action likely at such sites.

The Table should also take account of the fact that, for some site categories, the models may suggest values for PSV which are plainly unrealistic or which experience may have shown would be unnecessarily demanding. This is most likely to be the case for the higher-risk sites where the database from which the models have been derived was limited and for which PSVs in excess of 70 are likely to be predicted. It is known that, on roundabouts for example, local engineers will be aware of materials which have performed satisfactorily and any proposals must allow engineers to use their judgement in such circumstances.

Some situations could be expected to require a PSV in excess of 70 and in such cases it is assumed that this would have to be provided by an artificial aggregate. There will also be combinations of conditions (high-risk, heavily-trafficked sites) for which there is no need to suggest PSV values because they are unlikely to exist in practice.

7 Proposed revision to HD28

The purpose of Chapter 2 of HD28 is to provide advice to engineers on what materials to use in order to provide road surfacings that can be expected to deliver skidding resistance which will meet the requirements of the skidding standards. In other words, the MSSC should remain above the investigatory level which has been defined for a site for a reasonable working life.

It will need to be accepted that, in practice, there will be many situations where the MSSC falls rapidly to a point close to the investigatory level but then remains in that condition for many years. This is perfectly acceptable in terms of the standard, provided that there is no evidence of a problem with wet skidding accidents.

Before selecting the aggregate to use in the surfacing, the engineer must consider the general category of site as defined in the skidding standards and then set an accident ‘risk rating’ for the particular location following the advice given in the standards. This (by reference to Table 3.1 of HD28) will provide a target investigatory level for MSSC. In most cases this will be the default value suggested but there will be occasions where local circumstances or experience suggest that a different risk rating and corresponding investigatory level would be appropriate.

Having established the investigatory level of skidding resistance which is expected to apply to the site, and knowing the level of traffic expected to be using the road at its design life, the engineer then would select the aggregate by reference to Table 6 below. If the investigatory level is the default for the site category, then the row of the Table corresponding to the site category should be used. If a different investigatory level has been defined for the site, the row corresponding to the appropriate investigatory level would be used.

The values in Table 6 have been arrived at working closely with the Highways Agency. The values are based on the new models and the discussion in Section 6 of this report. They are default values which should, in most cases, provide the required skidding resistance and therefore are the values to use if no other information is available. However, it is important to bear in mind that the objective is *to deliver and maintain in-service skidding resistance above investigatory level* and therefore, if the engineer has good evidence that an aggregate with a lower PSV than Table 6 suggests has performed satisfactorily in a similar context, he is free to specify it. Similarly, if he has evidence that a particular aggregate with the required PSV will not perform in a particular situation he must consider alternatives.

In all cases, the monitoring process, which is an integral part of the skidding standards, can be expected to detect sites which eventually fail to meet the MSSC requirements. The information gained in such instances can be used in selecting (or rejecting) aggregates for any resulting remedial work. The emphasis is on the engineer using the advice wisely and using his judgement and experience to select the most appropriate materials without unnecessary over-specification.

For the reasons already given, this proposal must be regarded as an interim measure. No attempt has been made to take into account any commercial or resource implications of changed bandings or PSV level boundaries. It is recognised that idiosyncrasies will continue to occur with individual aggregates in particular situations. An obvious example is at roundabouts (Band VI, site category L), where, on the basis of the models, a PSV greater than 70 would be required but in a great many cases natural aggregates with lower PSVs are known to be satisfactory. For this reason Table 6 suggests a range of PSVs, leaving the engineer to make the final judgement depending on local circumstances.

It is not possible to make a direct comparison with existing requirements within Table 6 because the PSV levels and traffic level Bands do not correspond exactly to those of the 1994 version of the Table. However, in order to give an indication of the changes, a table has been provided in Appendix B which is based upon an expanded version of Table 2.1 of HD28/94 and includes both old values and the new equivalents.

Further research is needed to produce more definitive advice; the areas which should be addressed are discussed in the Section 8.

Table 6 Minimum PSV required for new wearing courses - proposed revision to Table 2.1 of HD 28/94

IL band	*Default IL*	*Site categories*	*Site definitions*	*Traffic (cv/lane/day) at design life* 0-250	*251-500*	*501-750*	*751-1000*	*1001-2000*	*2001-3000*	*3001-4000*	*4001-5000*	*5001-6000*	*over 6000*
I	0.35	A,B	Motorway (mainline), Dual carriageway (non-event)	50	50	50	50	50	55	60	60	65	65
Ia	0.35	A1	Motorway mainline, 300m approaches to slip roads	50	50	50	55	55	60	60	65	65	65
II	0.40	C,D	Single carriageways (non-event), dual carriageway approaches to minor junctions	50	50	50	55	60	65	65	65	65	70
III	0.45	E,F, G1,H1	Single carriageway minor junctions, approaches to and across major junctions, gradients 5-10% >50m (dual, downhill only; single, uphill and downhill), bends <250m radius >40mph.	55	60	60	65	65	70	70	70	70	70+**
IV	0.50	G2	Gradients >50m long >10%	60	70	70	70+	70+	70+	70+	70+	70+	70+
V	0.55	J,K	Approaches to roundabouts, traffic signals, pedestrian crossings, railway level crossings and similar.	70	70	70	70+	70+	70+	70+	70+	70+	70+
VI	0.55 (20km/h)	L*	Roundabouts	50-70+	55-70+	60-70+	60-70+	60-70+	65-70+	65-70+			
VII	0.60 (20km/h)	H2*	Bends < 100m radius	55-70+	60-70+	60-70+	65-70+	65-70+	65-70+	65-70+			

* *For sites in these categories a range is given and the PSV should be chosen on the basis of local experience of material performance. In the absence of other information, the highest values should be used*

** *Here, and throughout the Table, '70+' means that specialised high skidding-resistance surfacings complying with the Specification (MCHW1) Clause 924 will be required*

8 Further research

This work has shown that it would be worthwhile making amendments to the existing specification. This would bring the requirements closer into line with the in-service performance of materials needed to deliver the skidding standards and, at the same time, provide greater flexibility in the use of materials without significant loss of performance. However, it is also clear that more research is needed to improve further the way in which aggregates are specified in order to provide adequate in-service skidding resistance. The main difficulties at present are:

- the range of skidding resistance delivered by any one aggregate or by a range of ostensibly similar aggregates under apparently similar conditions;
- the range of skidding resistance provided by the same aggregate under different conditions;
- the need to have a simple way of assessing aggregates;
- limitations of current test procedures.

In order to make progress and to build on the work reported here, further research is needed into aspects of the topic outlined below. At the time of writing, work commissioned by the Highways Agency, in collaboration with CSS (formerly the County Surveyors Society) and the Quarry Products Association, is in hand which concentrates on the first three of these aspects:

- *A better understanding of the polishing mechanism.* If the way in which different rock types provide and maintain effective microtexture were better understood, the variations in performance could more easily be explained. Improved or alternative strategies for testing and specifying aggregates could then be developed.
- *Further studies of in-service performance.* Since the work reported here was undertaken, greater experience of monitoring surfacings has been gained and more data should be available to fill the gaps in the information on which this study was based. This is clearly vital if specifications and in-service performance are to match more closely than is possible at present.
- *Development of test procedures for natural aggregates.* Further developments of the current test procedures (for example longer polishing or slip action) should be considered and alternative test methods could also be assessed. The objective of this work would be to ensure that the test procedure provides a straightforward, standardised assessment which is a reasonable simulation of potential road conditions.

- *Consideration of the way in which surfacing type affects the skidding resistance that an individual aggregate can achieve.* It is possible that surfacings which contain a higher proportion of aggregate may deliver a better low-speed skidding resistance than those in which the chippings are more broadly spaced. However, it should be borne in mind that all surfacings must have sufficient texture depth to maintain skidding resistance at high speed. Other factors, such as particle size and shape, may also be of significance in this context. More knowledge of these aspects could allow for a closer match between the specification for the aggregate and the surfacing material being considered.
- *Development of test procedures for artificial aggregates.* As has been shown here, the current test procedures may not be appropriate for assessing artificial aggregates; modifications to the tests or alternative approaches to assessment should therefore be developed. This is needed in order to ensure that test results generally reflect road performance and that they adequately distinguish between notionally similar materials from different sources.

9 Conclusions

This study of the in-service performance of road surfacings has enabled the relationship between polishing resistance (as measured in the PSV test) and achieved skidding resistance (measured as MSSC) to be reassessed. Laboratory tests have also been carried out to assess some of the indications of the performance studies.

The following conclusions have been drawn:

1 The model on which the current specification for PSV requirements is based does not adequately reflect in-service performance for skidding resistance under present-day conditions.

2 Different aggregates with the same polishing resistance provide a range of skidding resistances in practice.

3 Individual aggregates can deliver a range of skidding resistances, even at the same traffic level. In locations where additional braking or deceleration can be expected, for example on approaches to slip roads, lower values of MSSC can occur than on the remaining mainline carriageway.

4 Aggregates do not necessarily continue to polish as traffic levels increase; polishing and wearing actions may equilibrate to maintain adequate skidding resistance under heavy traffic.

5 Different relationships are found between PSV and equilibrium skidding resistance, depending on the type of site and the level of skidding resistance required. These relationships are of the form $MSSC = (A \times PSV) - (B \times \ln(CVD)) + K$. Increased traffic reduces MSSC, for a given PSV, rapidly at first and then to a lesser extent at higher traffic levels.

6 In some situations, lower PSVs than currently specified could be used, although in others current requirements are inadequate. There is also some evidence that materials are currently over-specified and a limited number of types of aggregate are used.

7 Working closely with the Highways Agency, a new Table, to replace that in the DMRB, has been developed as an interim specification. This is based on the new relationships but targeted at the investigatory level requirements of the Skidding Standard. Back-analysis of the data confirmed that, within the limitations of the database, there is only a small risk of materials failing to deliver the required MSSC, in most circumstances.

8 Although problems remain in using PSV to characterise aggregates, at present, it is the only parameter relating to the microtexture of an aggregate which can be measured in a standardised manner and which has been related to traffic and site conditions. It therefore remains an appropriate property to use in specifications, provided that its limitations are recognised.

9 Further research is needed to explain the variations found in practice and to enable the performance of a wider range of sites, aggregates and their properties to be taken into account. Some of this is already in hand.

10 Acknowledgements

The work described in this report was carried out in the Civil Engineering Resource Centre (Resource Centre Manager Mr P Jordan) on behalf of the Highways Agency. The Quality Review Officer was Mr D M Colwill. The authors would like to thank Mr J C Bullas who made a significant contribution to the initial parts of this work

11 References

British Standards Institution (1989). *Testing Aggregates: Method for determination of the polished stone value.* BS 812 (1989) Part 114. BSI, London.

Department of Transport (1983). *Departmental Advice Note HA 24/83*. Department of Transport, London.

Department of Transport (1987). *Design Manual for Roads and Bridges. HD28 Skidding resistance. (DMRB 7.3.2).* Stationery Office, London.

Hosking J R and Szatkowski W S (1972). *The effect of traffic and aggregate on the skidding resistance of bituminous surfacings*. LaboratoryReport LR504. Transport Research Laboratory, Crowthorne.

Tubey L W and Jordan P G (1973). *The reproducibility and repeatability of the PSV determination.* Laboratory Report LR552. Transport Research Laboratory. Crowthorne.

Hosking JR and Tubey L W (1972). *Aggregates for resin-bound skid-resistant road surfacings.* Laboratory Report LR466. Transport Research Laboratory, Crowthorne.

Hosking J R and Tubey L W (1974). *Effect of turning and braking on the polishing of roadstone by traffic.* Supplementary Report SR103 UC. Transport Research Laboratory, Crowthorne.

Hosking J R (1976). *Aggregates for skid-resistant roads.* Laboratory Report LR693. Transport Research Laboratory, Crowthorne.

Rhodes A H (1990). *Reducing whole life costs*. Highways and Transportation, November 1990 , pp 53-55.

Van der Wall A R G (1992). *The polishing of aggregate used in road construction.* Memoirs of Centre for Engineering Geology in the Netherlands. Faculty of Mining and Petroleum Engineering. Delft University of Technology. TU Delft.

Appendix A: Laboratory studies of polishing mechanism

A1 The basis of the laboratory work

A1.1 Extended polishing

As it currently stands, the polishing process of the PSV test represents only a single level of traffic. There has been very little reported work examining the behaviour of aggregates during the polishing phase of the test or for longer timescales than currently used.

Most studies have been concerned with the values that result from the standard test and to relating these back to the composition of the aggregate, its physical characteristics or some combination of physical and mechanical properties.

Therefore, for this additional work it was decided to study the behaviour of a small selection of aggregates in a standard PSV test and then to continue to monitor the same samples through an extended period of polishing. This approach would mimic to some extent the effect of heavier traffic by simulating the passage of more vehicles during a polishing phase on the road. This technique does not simulate an increased period of time because an aggregate in a road surfacing would have a period during the winter when recovery of skidding resistance would take place, which is not represented in the test procedure.

A1.2 Controlled slip

It was also desirable to make a comparison between polishing by free-rolling traffic with that occurring where some deceleration or braking is involved. In the latter case, on the road there would be small amount of slip between tyre and road surface (although wheels would be rotating rather than skidding). To mimic this effect an accelerated polishing machine was modified so that it could provide slip between the ‘road wheel’ and the test tyre during the polishing procedure.

Something similar to this was done many years ago at TRL (then the Road Research Laboratory) by Maclean and Shergold. In the unpublished work, they used a hydraulic means to retard the tyre and they concluded that limited slip had no appreciable effect on the rate of polishing. However, the tests used water as a lubricant but did not include a polishing medium (the PSV test uses both). Also, the purpose of the tests described here was to see whether slip would alter the ultimate level of skidding resistance rather than change the rate of polishing. Figure A1 shows the modified polishing machine.

A1.3 Particle size

In addition to the issue of performance in the road, questions have often been raised regarding the use of PSV values for assessing materials, such as calcined bauxite, which will be used on the road as much smaller particles sizes than are normally used in the test. This was recognised when resin-bound surfacings were first being developed (Hosking and Tubey, 1972) but in the absence of an alternative method, such materials have been specified in terms of PSV measurements combined with a good resistance to abrasion.

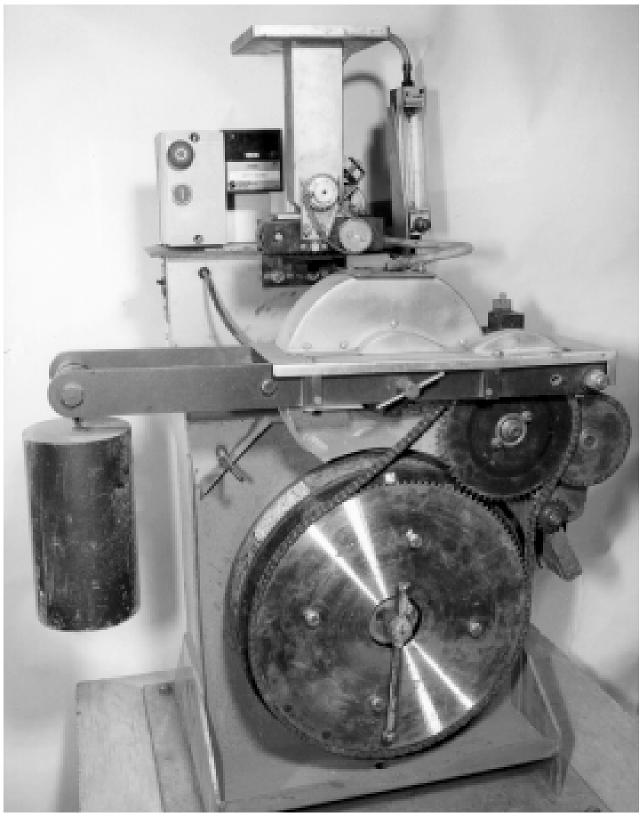


Figure A1 Polishing machine modified to give controlled slip between the ‘road wheel’ and test tyre

The PSV test assumes that an aggregate can be obtained in the necessary size and shape for a PSV test to be performed on it. It is, however, difficult to acquire calcined bauxite in the necessary size to test. Further, it has sometimes been suggested that there are significant differences in the properties of large and small particles of artificial aggregate due to the methods of manufacture. The laboratory work therefore included some tests to compare the performance of standard-size aggregate particles with smaller sizes, using calcined bauxite and a natural aggregate.

A2 Methodology

A2.1 Aggregates used

For tests with standard-size aggregate particles, the rocks used included diorite, dolerite and andesite from the igneous trade groups and gritstone and greywacke from the sedimentary groups.

The three igneous aggregates belonged to the basalt trade group and were similar chemically and mineralogically but differed in their mineral grain size, diorite being the coarser and andesite the finer. The two arenaceous aggregates differed in their grain:cement ratio; the gritstone had mostly mineral grains supporting cement whereas the greywacke comprised mostly cement supporting grains. In addition to these five aggregates, an igneous gravel mix and the standard PSV control stone (a gritstone) were also used.

The work to examine the effects of particle size was primarily aimed at calcined bauxite aggregates, which are used in high skid resistance surfacings. Samples from the three common sources of bauxite (Guyana, Brazil and China) were used. The performance of these materials was compared with a natural aggregate in an equivalent size. Control stone, suitably crushed and graded, was used for this purpose.

It should be noted that, although the PSV control stone was used within this series of experiments, it has been treated as another test aggregate.

This is because its properties outside the ‘normal’ test regime are not known, and so cannot be used as a reference measure to standardise results from other aggregates.

A2.2 Extended polishing regime

For this part of the work, four PSV specimens were made from each of the seven aggregates and mounted on two ‘road’ wheels to provide two replicates for each aggregate on each wheel and a replicate test, as in a normal PSV test. Each wheel was given three hours of conditioning using coarse emery (as is normally done in the PSV test) before polishing for nine hours using flour emery. The wheel was removed from the machine and the pendulum number on each specimen was measured after the coarse-emery conditioning and after each hour during the polishing stage.

A2.3 Induced slip regime

The object of these tests was to assess the effect of adding slip between tyre and road into the polishing regime. A PSV machine was modified so that the polishing tyre ran at a slightly slower rate than the road wheel. This was accomplished by an arrangement of chain-drives which retarded the polishing tyre by 1.5%.

The same test wheels which had been subjected to the extended polishing were used for these tests. This approach was chosen in order to observe whether aggregates that had already reached a state of approximate equilibrium would polish further under more stressful conditions.

Because the specimens were already in a common condition, the roughening phase was omitted and the specimens were polished with the controlled slip in place for a further nine hours. Following experience with the extended polishing tests, rather than measure the pendulum values on the specimens every hour, for this experiment the wheels were removed from the machine for pendulum measurements after 1, 2, 3, 6 and 9 hours of fixed-slip polishing.

A2.4 Small particles

This part of the test programme repeated the previous groups of tests, that is extended polishing and controlled slip, on smaller-size chippings. In addition to the 3mm size grits used in resin-based surfacings, 6mm size chippings were also compared. However, a method was needed for preparing specimens which could be mounted on the polishing machine’s road wheel and provide an even running surface for the test tyre.

In their early work on artificial aggregates Hosking and Tubey (1972) successfully used a modified form of the test, gluing natural roadstone chippings to PSV-test blanks. A similar approach was therefore used here. It was found that this procedure worked well for the smaller 1-3 mm size particles.

Initially, the 6mm specimens were made using the conventional technique but it was found that there was insufficient resin surrounding the particles to hold them in place and they were plucked out during the conditioning phase. Further, they presented an uneven surface to the pendulum tester. The technique used for the 3mm samples was followed, using slightly thinner blanks to accommodate the larger particles. This was more successful but there remained a tendency for individual chippings to be stripped off during the test. It was found that, although it was almost impossible to prepare 6mm specimens which presented an even face to the pendulum tester, abrasion during the conditioning phase ameliorated this to some extent.

For these tests, each wheel carried two specimens of the following:

- glued to blanks:

  Guyanan bauxite, 3 mm size;
  Chinese bauxite, 3 mm size;
  Brazilian bauxite, 3mm and 6mm sizes;
  Control stone, 3mm and 6mm sizes;

- conventional PSV specimens:

  standard size control stone.

A3 Results

In interpreting the results of these experiments, the precision of the PSV test must be taken into account. Tubey and Jordan (1973) provided estimates of repeatability and reproducibility of the PSV test of 4.9 and 6.0 respectively which would have been the precision of the test at the time of the original research on which LR504 was based. There have been changes to the test method since then; the current procedure given in British Standard 812 (1989) gives values of 3 for repeatability and 6 for reproducibility.

The tests described here went beyond the British Standard procedure and therefore the above figures can be used only as a guide. In assessing the results, a change of more than 3 units was considered to be significant as a rule of thumb.

A3.1 Extended polishing

The results of the extended polishing are given in Table A1. The values reported are the averages of the four specimens (two per wheel) for each aggregate. As-measured pendulum numbers (using the normal PSV scale for the small slider) have been used without correction to control stone values. In the Table, the aggregates have been ranked in order of decreasing pendulum value at the end of the conditioning period.

The following observations may be made regarding the results in Table A1.

- For all the aggregates, most of the polishing occurred in the first three hours of treatment and then continued at a decreasing rate.
- There was some suggestion of a slight downward trend into the extended period for some materials: two aggregates fell by four units and one by three units between three and nine hours of polishing.
- The ranking of the aggregates did not change much between the conventional three and the extended nine hours, except for the coarse-grained diorite, which polished more rapidly and to a greater extent than the other aggregates and had moved to last position after the first hour of polishing.
- The three basalt trade group aggregates, although very similar chemically and physically, showed markedly different responses to the polishing action. This is possibly associated with differences in the grain sizes in these igneous rocks.

A3.2 Effects of limited slip

The results of the limited slip tests are given in Table A2, with the aggregates ranked according to their starting pendulum values. In the event, some of the specimens fractured during these tests and it was not therefore possible to measure their pendulum values. The results reported are the averages of only those specimens which survived the full experiment. For this reason, the initial values may not correspond to the equivalent values after nine hour of extended polishing in Table A1.

With the slip introduced, in all cases the aggregates polished below the equilibrium value produced by the extended polishing, losing between three and six units in pendulum value. As with the initial experiment, most of the new polishing occurred in the early stages.

A3.3 Effects of particle size

The results of the tests with reduced-size particles in the test specimens are given in Table A3. As mentioned in Section A3.2, some of the 6mm specimens suffered from stripping of aggregate particles during the tests. The results in Table A3 for this particle size are the averages of the specimens which satisfactorily survived to the end of experiment, and should therefore be viewed with some caution.

The following key points emerge from the results in Table A3.

- Results for the standard-size control stone are comparable with those in Table A1.
- The smaller-size particles yield markedly higher pendulum values. The increase in pendulum values with decreasing particle size is readily apparent for the control stone.
- All materials showed some tendency to polish, although the relative changes for the Guyanan and Chinese bauxites were much smaller than for the other materials.
- As with the standard sizes, an equilibrium or reduced polishing rate emerged after three hours. Although the 3mm Chinese bauxite appeared to continue to polish significantly (a fall of 4 units from 3 to 9 hours), this material nevertheless had values markedly greater than the natural control stone in all its sizes.
- The 6mm Brazilian bauxite did not yield such high values as the other bauxites. However, at 6mm size the Brazilian material performed better than the 6mm control stone and similarly to the 3mm control stone.

A3.4 Effects of size and slip

The small-size specimens were transferred to the controlled-slip machine in the same way as for the standard-size specimens, giving the results in Table A4. As with the standard-size aggregates, there was some difficulty with specimens breaking under the increased stress, particularly for the 6mm material. Only those specimens that survived to the end of testing have been included in the averages in Table A4.

As with the standard-size materials, the introduction of slip caused some further degree of polishing to occur. The standard-size control stone again behaved similarly to the earlier tests. The 3mm specimens continued to give higher pendulum values and, as before, the Brazilian material gave similar results to the control stone, in this case some 15 units lower than the other two bauxite materials at the end of the test.

Table A1 Results of polishing of standard-size aggregates

Aggregate	*After conditioning for 3 hours*	*Average pendulum value at time given after polishing for the given hours*								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Gravel mix (igneous)	74	66	65	62	61	61	60	61	61	60
Greywacke	72	65	63	60	60	60	59	59	60	59
Carboniferous gritstone	71	64	60	59	57	57	57	57	57	57
Control stone (fine-grained gritstone)	69	61	57	56	55	55	56	55	54	53
Diorite (Basalt, coarse-grained)	66	57	51	50	48	48	49	48	47	46
Dolerite (Basalt, medium-grained)	66	58	56	54	51	51	51	51	50	50
Andesite (Basalt, fine-grained)	65	61	57	54	53	54	53	54	54	52

Table A2 Results of continued polishing of standard-sized aggregates with added limited slip

Aggregate	*After extended polishing*	*Average pendulum value at time given after polishing at 1.5% slip for the given hours*								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Gravel mix (igneous)	64	62	60	62			60			58
Greywacke	59	60	58	58			55			54
Andesite (Basalt, fine-grained)	58	56	56	56			56			55
Carboniferous gritstone	57	55	53	54			52			52
Control stone (fine-grained gritstone)	53	54	54	51			50			49
Diorite (Basalt, coarse-grained)	52	50	50	50			49			46
Dolerite (Basalt, medium-grained)	50	47	47	47			47			44

Table A3 Results of extended polishing of small-sized aggregates

Aggregate	*After conditioning for 3 hours*	*Average pendulum value at time given after polishing for the given hours*								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Guyanan bauxite (3mm)	92	82	80	78			82			80
Chinese bauxite (3mm)	90	87	86	85			85			81
Brazilian bauxite (3mm)	83	74	76	72			72			70
Control stone (3mm)	80	75	72	71			72			68
Control stone (6mm)	80	74	70	67			63			58
Brazilian bauxite (6mm)	75	79	78	77			72			69
Control stone (standard)	67	60	59	56			54			50

Table A4 Results of continued polishing of small-sized aggregates with added limited slip

Aggregate	*After extended polishing*	*Average pendulum value at time given after polishing at 1.5% slip for the given hours*								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Guyanan bauxite (3mm)	82	80	76	79			75			76
Chinese bauxite (3mm)	81	78	74	78			72			74
Brazilian bauxite (3mm)	69	62	58	62			60			59
Control stone (3mm)	68	62	61	62			60			59
Control stone (standard)	50	48	47	46			46			45

Appendix B: Comparison of PSV requirements in HD28/94 with proposed replacement

Site category		*Site definition*		*Traffic (cv/llane/day) at design life*																		
				20 100	*101-250*	*251-500*	*501-750*	*751-1000*	*1001-1250*	*1251-1500*	*1501-1750*	*1751-2000*	*2001-2250*	*2251-2500*	*2501-2750*	*2751-3000*	*3001-3250*	*3251-3500*	*3501-4000*	*4001-5000*	*5001-6000*	*over 6000*
		Motorway (main line)	*current*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*57*	*57*	*60*	*60*	*65*	*65*	*68*	*68*	*68*	*68*	*68*
			proposed	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**55**	**55**	**55**	**55**	**60**	**60**	**60**	**60**	**65**	**65**
			change	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	A1	Motoway mainline, 300m approaches to slip roads	*current*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*57*	*57*	*60*	*60*	*65*	*65*	*68*	*68*	*68*	*68*	*68*
			proposed	**50**	**50**	**50**	**50**	**55**	**55**	**55**	**55**	**55**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**65**	**65**	**65**
			change	-	-	-	-	=	=	=	=	-	+	=	=	-	-	-	-	-	-	-
	B	Dual carriageway (all pupose) non-event sections	*current*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*57*	*57*	*60*	*60*	*65*	*65*	*68*	*68*	*68*	*68*	*68*
			proposed	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**55**	**55**	**55**	**55**	**60**	**60**	**60**	**60**	**65**	**65**
			change	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D	Dual carriageway (all pupose) minor junctions	*current*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*55*	*57*	*57*	*60*	*60*	*65*	*65*	*68*	*68*	*68*	*68*	*68*
			proposed	**50**	**50**	**50**	**50**	**50**	**60**	**60**	**60**	**60**	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**70**
			change	-	-	-	-	-	+	+	+	+	+	+	+	=	=	-	-	-	-	+
II	C	Single carriageway non-event sections	*current*	*45*	*50*	*53*	*53*	*55*	*57*	*57*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	*68*	*68*	*68*	*68*	*68*
			proposed	**50**	**50**	**50**	**50**	**55**	**60**	**60**	**60**	**60**	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**70**
			change	+	=	-	-	=	+	+	=	-	+	=	=	-	-	-	-	-	-	+
	E	Single carriageway minor junctions	*current*	*45*	*50*	*53*	*53*	*55*	*57*	*57*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	*68*	*68*	*68*	*68*	*68*
			proposed	**55**	**55**	**60**	**60**	**65**	**65**	**65**	**65**	**65**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**>70**
			change	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
III	F	Approaches to and across major junctions (all limbs)	*current*	*50*	*55*	*57*	*60*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*
			proposed	**55**	**55**	**60**	**60**	**65**	**65**	**65**	**65**	**65**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**
			change	+	=	+	=	+	+	+	=	=	+	+	-	-	-	-	-	-	-	-
	G1	Gradient 5% to 10%, longer than 50m (Dual downhill; single uphill and sownhill)	*current*	*50*	*55*	*57*	*60*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*
			proposed	**55**	**55**	**60**	**60 `**	**65**	**65**	**65**	**65**	**65**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**
			change	+	=	+	=	+	+	+	=	=	+	+	-	-	-	-	-	-	-	-
	H1	Bend (not subject to 40mph or lower speed limit) radius 100-250m	*current*	*50*	*55*	*57*	*60*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*
			proposed	**55**	**55**	**60**	**60**	**65**	**65**	**65**	**65**	**65**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**
			change	+	=	+	=	+	+	+	=	=	+	+	-	-	-	-	-	-	-	-
	L	Roundabout	*current*	*50*	*55*	*57*	*57*	*57*	*63*	*63*	*65*	*65*	*68*	*68*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*
			proposed	**50-70**	**55-70**	**55-70**	**60-70**	**60-70**	**60-70**	**60-70**	**65-70**	**65-70**	**65-70**	**65-70**	**>70**	**>70**	**>70**	**>70**	**>70**	.	.	.
			change	~	~	~	~	~	~	~	~	~	~	~	=	=	=	=	=	.	.	.

IV	G2	Gradient >10%, longer than 50m (Dual downhill; single uphill and downhill)	*current*	*55*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*
			proposed	**60**	**60**	**70**	**70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**
			change	+	=	+	+	+	+	+	+	=	=	=	=	=	=	=	=	=	=	=
	H2	Bend (not subject to 40mph or lower spoeed limit) radius <100m	*current*	*55*	*60*	*63*	*63*	*65*	*65*	*68*	*68*	.	.	.	.	.	.	.	.	.	.	.
			proposed	**55-70**	**55-70**	**60-70**	**60-70**	**65->70**	**65->70**	**65->70**	**65->70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	.	.	.
			change	~	~	~	~	~	~	~	~	.	.	.	.	.	.	.	.	.	.	.
V	J/J	Approach to roundabout, traffic signals, pedestrian crossing, realway level crossing ,etc.	*current*	*63*	*65*	*68*	*68*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	*>70*	-	-	-	-	-	-	-	-
			proposed	**70**	**70**	**70**	**70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**	**>70**
			change	+	+	+	+	=	=	=	=	=	=	=	+	+	+	+	+	+	+	+

Figures in *italics* are the requirements of Table 2.1 in HD 28/94
Figures in **bold** type are values given as new proposals in Table 6 of main report
Shaded areas are new to the new proposals and are not separately defined in HD28/94

Key to change indicators

= no change
- minimum PSV reduced
+ minimum PSV increased
~ now choose from a range

Abstract

For many years, aggregates for use in new surfacings have been selected according to their ability to resist polishing, as measured by their Polished Stone Value (PSV). However, decisions are now having to be made for more heavily-trafficked roads than were included in the original research and experience has suggested that expected performance is not always achieved in practice. A database of skidding resistance, aggregate properties and traffic levels was used to review aggregate performance in service. From an analysis of these data, new models for predicting skidding resistance from PSV and traffic data were derived. A series of laboratory studies of polishing was also carried out to investigate some of the phenomena observed. The study found that the current specification for PSV does not adequately reflect in-service performance for skidding resistance under present-day conditions. A Table to replace that in the Design Manual for Roads and Bridges, has been proposed as an interim specification. This is based on the new relationships but targeted at selecting aggregates which will meet the investigatory level requirements of the Skidding Standards. The work has shown a need for further research to provide a more rigorous assessment of materials.

Related publications

TRL367 *High and low-speed skidding resistance: the influence of texture depth* by P G Roe, A R Parry and H E Viner. 1998 (price £20, code E)

TRL125 *Trials of high-friction surfaces for highways* by J C Nicholls. 1998 (price £20, code E)

TRL176 *Laboratory tests on high-friction surfaces for highways* by J C Nicholls. 1997 (price £30, code H)

LR 466 *Aggregates for resin-bound skid-resistant road surfacings* by J R Hosking and L W Tubey. 1972 (price £10, code AA)

LR 504 *The effect of traffic aggregate on the skidding resistance of bituminous surfacings* by W S Szatkowski and J R Hosking. 1972 (price £10, code AA)

LR 552 *The reproducibility and repeatability of the PSV determination* by L W Tubey and P G Jordan. 1973 (price £10, code AA)

LR 693 *Aggregates for skid-resistant roads* by J R Hosking. 1976 (price £10, code AA)

SR 103 *Effects of turning and braking on the polishing of roadstone by traffic* by J R Hosking and L W Tubey. 1974 (price £10, code AA)

Current Topics in Transport: abstracts added to TRL Library's database

CT89.1	Aggregates in road construction (1996-1998)	price £15
CT67.1	Road surface noise update (1994-1997)	price £15
CT68.1	Deterioration of road surfaces update (1994-1996)	price £15

Prices current at August 1998

For further details of these and all other TRL publications, telephone Publication Sales on 01344 770783 or 770784, or visit TRL on the Internet at http://www.trl.co.uk.