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Tire wet-pavement traction management for safer roads

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Abstract

The first part of this paper includes a summary of the most relevant studies on the relationship between accidents and indicators of tire-pavement traction. The results of this research are the basis for the design standards in various Countries in the world for the management of road surface and for defining threshold levels of skid resistance.
The second part of this work proposes a review of levels of skid resistance for an existing road and introduces a relationship between the SFC (Sideway-Force Coefficient) parameter and road geometry (radius of curves, superelevation, design speed), and, consequently, with the demand of traction.

Keywords: road pavement skid resistance; road safety; surface friction, microtexture; macrotexture.

1. Introduction

Road accidents remain a significant problem for transportation safety; numerous road crash investigations and statistical analyses have been done to overcome this problem.

Traffic accidents are considered a unique, random, multi-factor event that often takes occurs in a context in which one or more persons have failed to cope with the surrounding environment. The most frequent factors are the driver, the vehicle, and the roadway, each containing multiple sub-variables. Because of this complexity and owing to the difficulty of identifying the human-factor elements (i.e., human behaviour at the time of crash), most crashes are considered to be the result of a driving error. Therefore, the role of the transportation engineer is to improve the roadway system so that the consequences of driving errors are minimized. Roadway system improvements involve a comprehensive analysis of all prevailing factors at the time of crash, including those related to the frictional properties of the pavement surface, in order to determine the countermeasures (i.e., safety improvements) necessary to prevent crash reoccurrence.

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Measurements of skid resistance and surface texture are used to characterize the road surface and assess the need for maintenance. This paper is organized into three parts. The first part gives an overview of the state of road surface characteristic and traffic safety. These studies suggest that a pavement with high skid resistance properties give a significant contribution in reducing the likelihood of a crash, even if the data analysis does not always indicate a statistically significant relationship between crash frequency and asphalt pavement skid resistance.

The second part contains the most important directions regarding the standards of skid resistance policies in different countries of the world. Some Agencies have established threshold levels for general categories of highway classes, highway alignment, highway features/environment and highway traffic characteristics. However, the number of site categories is kept reasonably small so that a sufficient number of sections are available for each category, from which investigatory and intervention friction levels are determined; moreover, the various agencies do not have the same value for the threshold levels. Because conditions and circumstances along a highway change, there is no unique friction level that defines the threshold between “safe” and “potentially unsafe.” Although the ideal situation is to have friction “supply” meet or exceed friction “demand” over the entire system, such practice would be prohibitively expensive (as well as largely unnecessary) and would not generate the cost-benefits associated with a better-targeted strategy.

In the last part of this paper a practical approach to friction management and design is developed and presented. It is based on the principle that an appropriate level of pavement friction must be maintained across all pavement sections within a given highway network. The level of friction which is considered appropriate must be determined on the basis of each section’s friction demand and it is imperative that the available friction level equals or exceeds the required friction at all times. This design approach should ensure the provision of adequate friction levels economically for a variety of roadway geometries (intersections, approaches to traffic signals, tight curves) and traffic conditions across a given network.

2. Road surface characteristics and traffic safety

As previously indicated, the relationship between pavement surface friction and crash risk is difficult to quantify; however, there has been some evidence suggesting that the number of wet-pavement skid crashes increases as the skid friction value decreases; therefore, it is widely agreed that, if the roadway is wet, the accident risk is correlated to surface characteristics.

While the exact relationship between wet-weather crashes and pavement friction is difficult to quantify, several experimental studies [1] have been carried out, showing that the number of wet crashes increases as pavement friction decreases.

Skid resistance is currently the road surface feature which has a very well established relationship to crash risk. Other surface characteristics such as macrotexture, differential skid resistance and rutting are currently monitored as part of general roadway condition surveys. Limited works [2] suggest a relationship between macrotexture and crash occurrence. Less evidence is available on the relationship between roughness or rutting and crashes; only a few studies have evaluated the differential skid resistance between the two wheelpaths in relation to accidents. Moreover it is more difficult to identify a quantitative relationship between threshold levels and crash growth.

Thus, there is a need for in-depth knowledge and understanding of the relationship between the two factors so that engineers can develop effective solutions to potentially hazardous situations.

A summary of the published research findings is presented below.

2.1. Friction and crash

Rizenbergs et al. [3] analyzed crash and friction on rural two-lane roads in Kentucky. The results of this analysis, reported in figure 1, show that the ratio of wet – to - dry pavement accidents versus Skid Number (SN) does not have any correlation with AADT stratification; however, if the data were grouped by averaging the SN, a threshold approximately equal to 40, can be found. The correlation coefficients, however, were low (less 0.430).

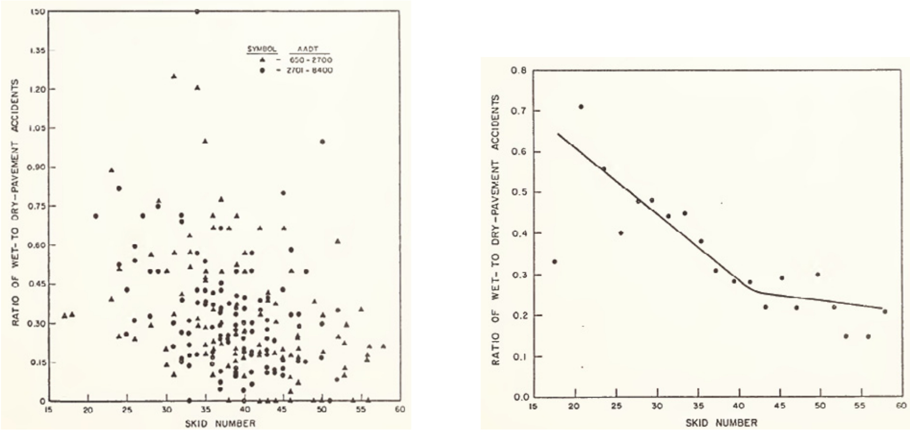

Fig. 1. Ratio of wet – to-dry pavement accidents versus Skid Number, (a) with AADT stratification, (b) grouped by Skid Number.

The literature relating skid resistance to crashes was comprehensively reviewed by Cairney [1], who identified three classes of studies to evaluate a relationship between skid resistance and crashes: before - after studies, comparison with the studies, regression studies.

Cairney analyzed seven before - after studies, which focus on a change in crash numbers or rates in consequence of increased skid resistance. All studies showed a reduction in crashes following resurfacing. In three studies, the author reported wet weather and dry weather crashes separately. In two cases, dry road crashes fell by 28% and 21% respectively, while wet weather crashes decreased by 63% and 71%. In one case, dry road crashes increased by 16%, while wet road crashes fell by 68%. He concluded that increasing low skid resistance is likely to result in decreases in wet accidents, and no single value for surface friction can be selected as critical.

Cairney analyzed, even, two studies which used sites where crashes have occurred with a random sample of control sites or with all non-crash sites along the study route or routes. In Giles, Sabey, and Cardew [4], as reviewed by Cairney, it was found that the risk of a skid-related crash (ratio of the proportion of skid-related crash sites to the proportion of control sites for different skid-resistance categories) was small for friction values (British Portable Number) above 60 but increases rapidly for skid resistance values below 50. Gordon [5] conducted a similar study based on SFC (Side Force Coefficient) measurements and wet pavement accidents, and found a similar pattern of results, although the relative risk did not grow significantly for SFC above 0.45.

Cairney analyzed eight regression studies. Although all studies agree that the proportion of wet accidents increases as skid resistance decreases, there appears to be no consensus as to whether the relationship is linear or exponential, and consequently whether there is some inflexion point beyond which the proportion of wet accidents increases drastically. For instance Schulze et al. [6] plotted the ratio wet accidents/total accidents against skid resistance and, although no statistical analysis is presented, there is a very clear trend showing that the proportion of wet accidents tends to increase as the skid resistance is reduced (Figure 2).

More recently, Seiler et Scherer [7] analyzed a large data set investigating freeways in Switzerland and a pilot study was carried out on main roads in order to identify a relationship between skid resistance and accident occurrence either for wet or dry pavements. For freeway networks the fundamental conclusion of the study was that no quantifiable correlation could be found. For main roads 55 selected intervals were analysed in the Zurich Canton and a direct correlation between skid resistance and accident occurrence could not be determined. However for a given skid resistance, an increase in the number of accidents could be observed by larger curvatures in the trendline. As the database is very small, further investigations are necessary for main roads. Also, Lindermann [8] analyzed the relationship between skid resistance and wet-accident on the whole Swiss national freeway; no statistically significant relationship was found.

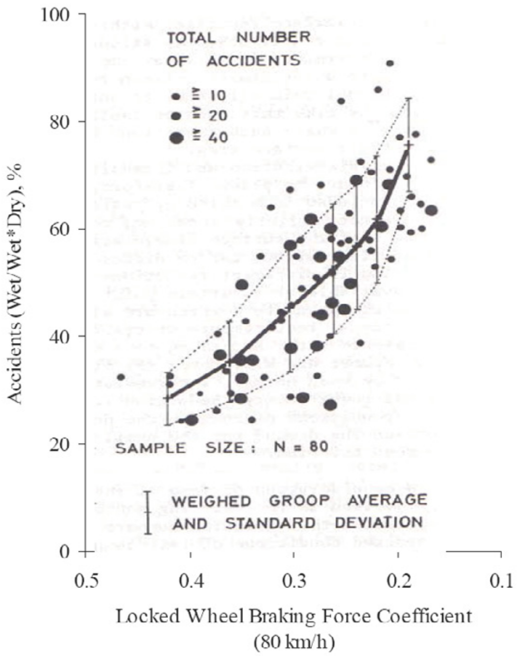

Fig. 2. Ratio Wet-Pavement Accidents/ total accidents and Friction

An extensive study was undertaken to quantify the relationship between skid resistance and wet weather crashes for data in Virginia [9]. The study indicated that there was a statistically significant effect of skid resistance on wet crash rate but skid resistance information by itself did not explain the variability in the wet crash rates.

Kennedy et al. [10] analyzed the relationship between skid resistance and accident rate for local roads in the South West of England. In dual carriageways non-event it has been found an increase of the accident rate as the skid resistance decreases, but the relationships are very weak; in contrast, for single carriageway non-event roads a correlation was found with a minimum R2 of 0.78. Bends with different radius ranges were analyzed (less than 100 m, from 100 m to 250 m, from 250 m to 500 m), and a significant correlation, R2> 0.9, was found for bends that have radii < 100 m, and between 100 m and 250 m (Figure 3). For bends having radius between 250 m and 500 m the minimum correlation was associated with R2> 0.7, but was still reasonable.

The literature review suggests, especially on curves with sharp radius, that low skid resistance results in an increased numbers of wet pavement accidents. Some studies have found a linear relationship of increasing wet weather crashes rates with decreasing skid resistance. Other studies suggest that the relationship may be non-linear, with the slope increasing with decreasing skid resistance. The common point is that a decrement in pavement skid resistance will likely result in an increment in crash risk, whereas it is more difficult to find a threshold where the proportion of wet accidents increases dramatically.

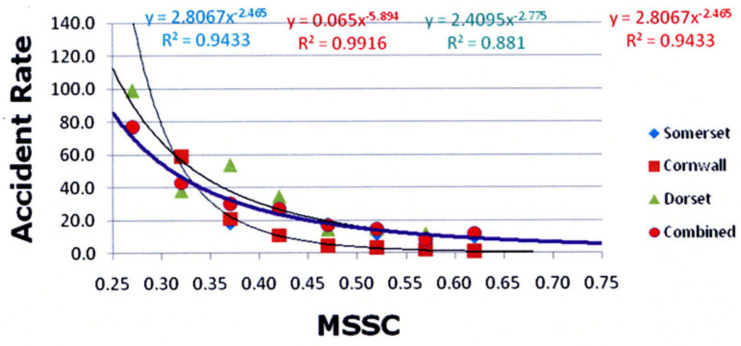

Fig. 3. Accident rate versus skid resistance for bends with radius between 100 m and 250 m.

2.2. Macrotexture and crash

Roe, Webster and West [11] examined the relationship between macrotexture and crashes on three high speed road networks. Their technique relied on comparing the percentage of crash sites in each class interval for macrotexture (SMTD, Sensor Measured Texture Depth), and then comparing the same quantity with the percentage of all sites in that macrotexture class interval. The results from Network C are shown in Figure 4. Similar patterns of results were found on the other two networks.

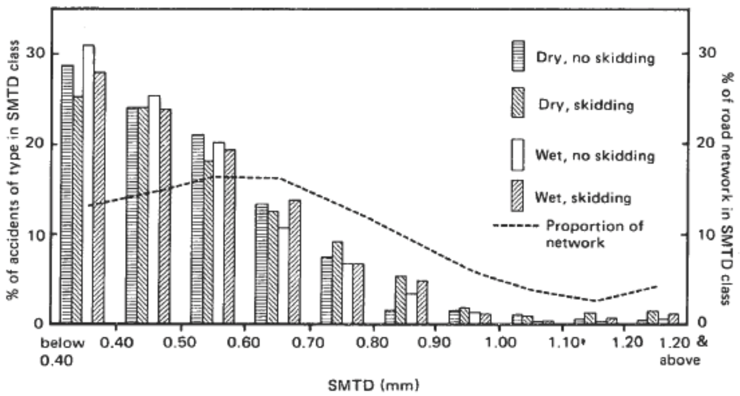

Fig. 4. Relationship between macrotexture at crash sites and skid resistance at all sites on Network C

The principal findings were: both skidding and non-skidding accidents, in both wet and dry conditions, are lower if the macrotexture is coarser; this was observed at all levels of underlying skid resistance; the texture level, below which the accident risk begins to increase, is about 0.70 mm (sensor-measured texture depth).

Cairney and Styles [12] also conducted an investigation on the relationship between crash occurrence and macrotexture on rural roads in Australia. Three routes were studied, in Western Australia, South Australia and Victoria. The principal findings were: for all rural routes, the low SMTD class intervals had a higher percentage of crash sites than other sites and the high SMTD class intervals had fewer crash sites than other sites. As for Roe et al.'s findings, there were differences in the threshold value at which crash risk increased, 0.3 mm on the Princes Highway West, 0.3 and 0.4 on the Great Eastern Highway, and 0.4 and 0.5 on the Dukes Highway.

2.3. Differential skid resistance and crash

Differential skid resistance is of concern as greater stopping forces on one side of a vehicle have the potential to generate a turning moment, which will tend to direct the vehicle off to the side of the wheelpath with higher friction, possibly causing the vehicle to enter another lane or to leave the carriageway. If the turning moment is sufficiently large in relation to the available pavement friction, the vehicle may spin out of control.

The only publication concerned with this topic, was by Marsh, Knight and Hillier [13]. The authors acknowledge the problem of quantifying differential skid resistance. They point out that no consensus was reached on the following issues: whether differential friction is more critical in straight line braking or cornering, how different vehicles and their stability systems respond to differential friction, and what level of differential has to be reached before remedial action should be reconsidered.

3. Skid resistance policy

As seen in the first part of this paper, the provision of a road surfacing, which has adequate skid resistance, is of prime importance for road safety.

Any responsible authority should develop strategies for the management of the skid resistance of their road network taking the prevailing operating conditions and available resources into consideration. In several Countries of the world there are reports, standards and guides, which regulate this activity. Below a comparative analysis of the mandatory standards in various countries is shown.

3.1. HD28/04

The background to the skid resistance policy in the UK is relevant to this part of the paper. Almost all Countries that have adopted the SCRIM (Side force Coefficient Routine Investigation Machine) to assess the state of the pavements have followed the model used in UK standards. The SCRIM was developed at TRL (formerly the Road Research Laboratory) and was introduced in the early 1970s. At the same time as the implementation of this method, the concept of setting different skid resistance levels in relation to accident risk was developed. In the early 1970s Salt and Szatkowski [14] introduced a concept of 'risk rating' for the different categories of sites to allow ranges of skid resistance levels to be assigned to a network.

The Highways Agency that is responsible for trunk roads in the UK (long distance, heavily trafficked, strategic routes) introduced the new standard for in-service skid resistance in 1988 [15]. By 1999, the results of some research projects indicated the need for a review [2]. This review included a full study of the link between skid resistance and accidents on the modern UK network, and the introduction of alternative approaches to the problem of monitoring and dealing with seasonal variations. In October 2004 the Design manual for roads and bridges was published as HD28/04 [16] (Table 1).

The most important observation, derived from this study, is the definition of site category and the introduction of a range of investigatory levels. The site category was extended to include radius-of-curvature values less than 500 m, and separate investigatory levels are given for single and dual carriageways. For most site categories, a range of investigatory levels were designated in place of the single default category, as there was a range of accident risks observed for different sites within the same category and a significant source of accident records [17]. For the categories, where a range of investigatory levels is defined, it is recommended that the investigatory level would normally be set at the lower limit.

The standards indicate the circumstances that would enforce a higher investigatory level. Below, the most significant ones are described:

- Accesses onto the main carriageway, if these are busy (e.g., for a service station) or have poor advance visibility, or if the speed of leaving or joining traffic creates conflict with other traffic on the main carriageway.
- Low texture depth (less than 0.8 mm measured as SMTD) except for High Friction Surfacing materials.
- Bends where the traffic speed and/or geometry is judged to give rise to added risk. This could apply to some sites in non-event categories as well as sites in the bend categories.
- For pedestrian crossings: poor advance visibility; high approach speed.
- Known history of accident occurrence being more frequent than normal, particularly in wet conditions or where skidding is reported.

Table 1. Comparison of HD28/88 with HD28/04 (Highways Agency, 1988/2004)

Site category and definition	Investigatory level (at 50 km/h)	
	HD28/88 (preceding)	HD28/04 (current)
A - Motorway	0.35	0.35
B - Dual carriageway non-event	0.35	0.35 – 0.40
C - Single carriageway non-event	0.40	0.40 – 0.45
Q - Dual carriageway (all purpose) – minor junctions	0.40	0.45 – 0.55
Q - Single carriageway minor junctions & approaches to and across major junctions (all limbs)	0.45	-
Q - Approach to roundabout	0.55	-
K - Approaches to pedestrian crossings and other high risk situations	0.45	0.50 – 0.55
R - Roundabout	0.45	0.45 – 0.50
G1 - Gradient:5 – 10% longer than 50 m	0.45	0.45 – 0.50
G2 - Gradient ≧ 10% longer than 50 m	0.50	0.50 – 0.55
S1 - Bend radius < 500 m – dual carriageway	0.45 – 0.50	0.45 – 0.50
S2 - Bend radius < 500 m – single carriageway	-	0.50 – 0.55

In each case a review of the investigatory level shall be carried out when a significant change to the network is made (addition or improvements of junctions, or increasing traffic level, or change of land use).

The measurements shall be made with a SCRIM. This equipment can be used to calculate the SFC. After collection, survey data will be validated and subject to processing to determine the CSC (Characteristic Scrim Coefficient) values, which will be used for comparison with investigatory level. Typically, processing will include:

- application of correction factors, e.g. in circumstances where it was not possible to maintain the specified standard test speed;
- calculation of the CSC;
- aggregation of raw data to longer averaging lengths, typically 100m or 50m.

The standards HD 28/04 indicate two procedures for assessing the pavement condition during the year: Single Annual Survey Method and Mean Summer SCRIM Coefficient Method. The latter method uses the MSSC to represent the equilibrium summer level of skid resistance; this value takes the place of the CSC used in the Single Annual Survey method.

3.2. Current Australian state road authority approaches

All six states of Australia use a SCRIM program on the high risk portions of their network. The method is based on the UK approach but was specifically adapted to the Australian environment. The investigatory levels are in SCRIM units (SFC50, SFC at 50 km/h), and although originally obtained from UK practice, they were adapted to the Australian conditions in 1982. They were revised by the 1996 RTA/VicRoads Guide [18], and then incorporated into the Austroads Guidelines [19].

The differences between the policies of the different states and the UK standard are given below. For all primary roads, and for secondary roads with more than 2500 vehicles per lane per day, a fixed investigatory level is defined. The sites are divided into different categories; curves with radius less than 250 m are introduced. For the first time importance is given to the measure of both wheel paths; the difference in sideway force coefficient values between wheelpaths (differential friction levels) should be less than 0.10 where the speed limit is over 60 km/h; or less than 0.20 where the speed limit is 60 km/h or less. Some states also include assessments of the surface texture (macrotexture). The most obvious differences are found in different management policies.

3.3. New Zealand approach

The NZ Transport Agency [20] has a highly developed SCRIM program for the state highway network, which has been active since the mid 90's. It is based on the UK approach but was specifically adapted to the New Zealand environment.

The major difference is the introduction into these standards of both an Investigatory Level and a threshold level. The threshold level is the trigger level at which urgent remedial work should to be taken. The threshold level is currently set at 0.10 below the investigatory level.

3.4. U.S. approach

The reference document for the US is Guide for Pavement Friction in 2008 [21]. For high speed friction measurement, the locked-wheel friction tester is the most predominant device. This requires a tow vehicle and a locked-wheel skid trailer using either a standard ribbed tyre (more sensitive to microtexture changes) or a standard smooth tyre (more sensitive to macro-texture changes), and water supply. Results are reported in units of Friction Number, (FN).

Table 2. Skid numbers adopted by Washington State (AASHTO 2008)

Skid number	Comments
< 30	Take measure to correct
> 30	Acceptable for low volume roads
31 – 34	Monitor pavement
> 35	Acceptable for heavily travelled roads

AASHTO [21] gives formulae and calculation methods for both FN and IFI (International Friction Index), which appear to be the two key indices used. Following the philosophy of the Austroads Guidelines for the management of road surface skid resistance [22], AASHTO [21] provides guidelines for site identification and establishes Investigatory and Intervention Levels for pavement friction management. The following table presents typical skid numbers used in the Washington State.

3.5. European approach

The situation in Europe is more complex than in the USA and the Commonwealth Countries. There are many Countries and several types of equipment are used to assess the state of road surfaces. A first significant step was taken in 1995 with the PIARC experiment to define an international scale of friction indices which was called IFI [23].

The European Union has not implemented a harmonized policy regarding skid resistance, yet. Some European Countries do not have any policy regarding skid resistance. Others have at least one policy only for principal roads. The policies concerning skid resistance are mainly set by road authorities. For motorways and primary roads, the majority of EU countries have introduced policies or standards which are legally enforceable.

In Germany the standard indicates two values: warning value and threshold value. The values are different for motorways, primary roads and secondary roads.

In France, indicative values of the investigatory levels are only given for the motorways. The parameter is SFC.

In Italy there are only generic recommendations [24], without any details on the category of the site. Furthermore, the limit value of 0.35, for SFC, seems to be completely inadequate.

4. Evaluation of a road

Since in previous studies has not been established that skid resistance is a statistically significant factor in explaining accidents, and threshold levels for skid resistance were not univocally identified in various standards, a survey was made to find a relationship between skid resistance and accidents of a road.

The road under investigation belongs to the category “dual carriageway” with two lanes in each direction. The road, designed in accordance with the CNR 80 Standards (Italian road design standard), is of type III with design speed in the range of 80 – 100 km/h. The horizontal alignment should ensure bends with minimum radius of 250 m. In the first section of the road under test, some bends have a radius less than the minimum (180 m). The superelevation in the curves is always much lower than the one provided by standards, 7%. The average values are 3%. This means that, at the same operating speed, there is a greater request of friction. The wearing course of the pavement is open-graded type.

Measurements were carried out by means of the SCRIM device (Sideway-force Coefficient Routine Investigation Machine) with the aim of monitoring the in-service skid resistance.

The SCRIM device uses the sideway force principle to measure the skid resistance on both wheel paths: two freely rotating wheels, fitted with a smooth rubber tyre, are mounted in-line with the nearside wheel track and angled at 20° to the travel direction of the vehicle.

Following the test protocols of CNR Bulletin N. 147/1992 [25], the test speed was fixed at 60 km/h, with significant values for each 10 m section. The measurements, collected at a speed of 60 km/h, were subsequently corrected to a speed of 50 km/h for comparison with UK Investigatory Levels. A temperature correction was also performed (temperature of 20° Celsius). In each 50-meter long road section the average value of five collected measurements was determined.

4.1. Collected data analysis

For instance, Figure 5 reports the evolution of the SFC in the two wheel paths and the Differential Wheel Path (DWP) values, as a function of the distance from a reference point (origin). The figure refers to the right carriageway and the lane which is most heavily used by commercial vehicles. On the same figure the values of the Investigatory Level are also shown.

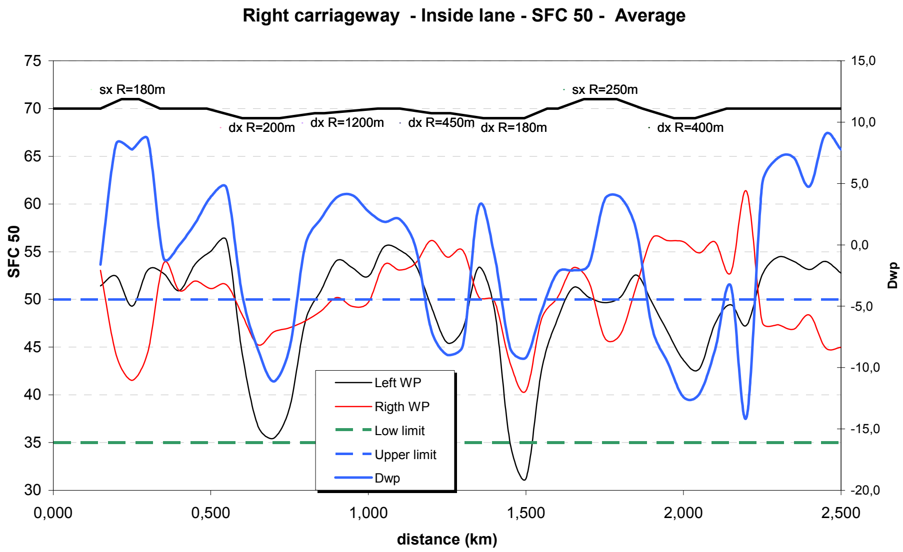

Fig. 5. Trend SFC and differential SFC on distance

In order to facilitate the analysis, all the collected data were divided into three groups: bends with radius R<250, bends with R<500 and tangents. Table 3 shows this separation with the mean values, standard deviation and differential SFC. It may be noted that the average value in the bends is well below the investigatory level for the specific road category.

Table 3. Average values, standard deviations, differential Wheelpath values.

Elements	SFC		
	Average	STDEV	DWP
Tangents	47.1	5.2	± 3.6
Bend radius < 500	44.3	6.3	± 5.0
Bend radius < 250	39.6	5.1	± 4.9

4.2. Accident analysis

If the procedures for deriving and interpreting skid resistance measurements on UK trunk roads were employed, in almost all curves of this case study, the SFC values would be below the assigned Investigatory Level. Therefore, a site investigation would be necessary to determine whether a treatment to improve the skid resistance is required or whether some other intervention is needed. The most important aspect of the site investigation, for this example, is an accurate accident analysis in order to justify the need for treatment to increase skid resistance. The accident analysis for the investigated road is reported here.

First of all, it was necessary to evaluate any potential link between the skid resistance of the road and the number of occurred accidents. A number of factors were considered: macrotexture was high along all this road and considered constant; each 50-meter section of the road was associated with an SFC value; an accident zone was defined as being 200 metres long and centred on the accident location, as indicated by the police report; for every accident zone, the minimum SFC value among all the 50-meter sections within the accident zone was considered or, if the accident zone was included within bends, the minimum SFC value of the bend was used; in every accident zone the SFC values were linked with the number of total accidents and wet accidents as well.

Figure 6 shows the relationship between (100 x SFC) and accidents on bends with radius less than 500 metres. The relation is separately shown, for Total Accidents (TA) and Wet Accidents (WA).

It is clear that there is a strong increase of accidents for SFC values less than 0.38, whereas for SFC values above 0.38, the number of accidents can be considered constant.

The SFC, rounded, value of 0.40 can be considered as a threshold level; this level is compatible with the intervention level of New Zealand standards for bends with radius less than 500 m, noting that the threshold level for intervention is given by the investigatory level of 0.50 minus 0.10; the result is in contrast with the Italian standards that features a threshold level for intervention equal to 0.35, which is a general level for every kind of roads.

It is also clear, from the analysis of figure 6, that a similar threshold can be seen for bends with radius less than 500 m, but not for higher values. Moreover, there is not a good correlation between accidents and SFC. Weaker correlations and no clear thresholds were found for cumulative data over the whole road. Therefore the absolute friction level is not the only cause of accidents.

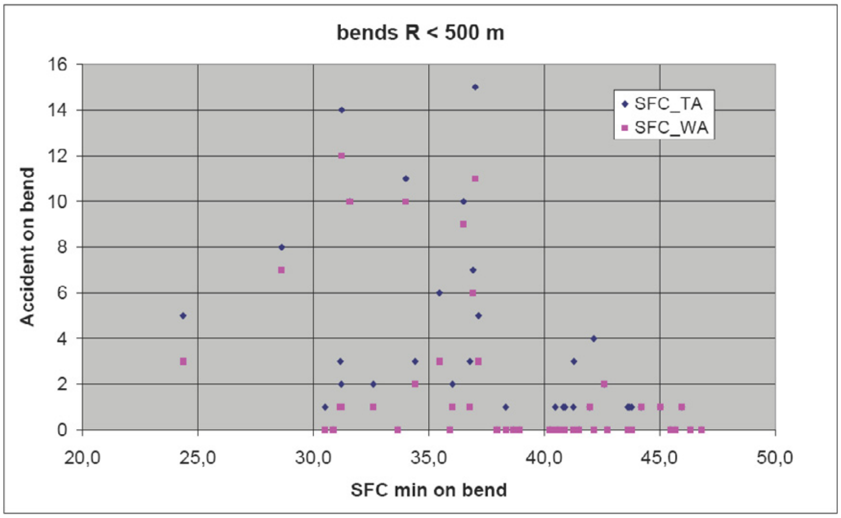

Fig. 6. Accidents versus SFC

Because conditions and circumstances along a highway change, there is no unique friction level that defines the threshold between “safe” and “potentially unsafe.” Ideally, the best situation is to have the measured (available) friction coincident with or larger than the friction demand for every different situation. This approach ensures adequate friction levels for a variety of roadway (intersections, approaches to traffic signals, tight curves) and traffic conditions.

The last analysis was carried out for the bends of the road under investigation.

In horizontal curves the relationship between side-force friction demand, vehicle speed, radius of curvature and superelevation was defined as:

$$f_d = \frac{V^2}{127 \cdot R} - q \tag{1}$$

where:

fd: side-force friction demand;

q: superelevation;

V: design speed of curve [km/h]

R: curve radius [m]

The ratio between the minimum SFC (average values on 50 m sections) on bend and the friction demand was linked with accidents; results are reported in Figure 7. The analysis was made for total accidents and wet accidents. The friction demand was calculated for a design speed of 80 km/h, which is the lower limit of the design speed for this road category.

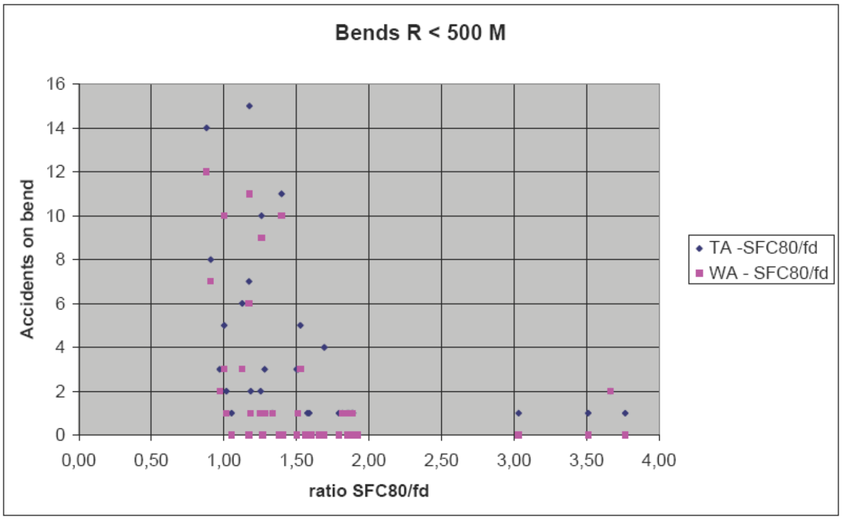

Fig. 7. Accidents versus ratio between SFC and friction demand

The data points are less scattered than those in Figure 6; moreover, there is a strong increment of accidents for ratio values less than 1.5 whereas for ratio values above 1.5 the number of accidents can be considered constant. This ratio could even fall below the unit value for the real speed of the users for this type of road.

A skid policy would fix a ratio threshold to have a uniform risk of skidding accidents across road, without indicating a site category, to align the skid resistance with risk.

If the IFI was used instead of the SFC, a quick assessment of friction and texture measurements could be made to determine if the skid resistance is adequate for various design speeds, using a unique threshold and any measurement equipment.

5. Conclusions

This paper describes a preliminary investigation on the relationship between skid resistance and accident and the appropriate threshold levels of skid resistance can be established for managing pavements.

Past studies indicated that: accidents increase with decreasing skid resistance, even though it was not always found that skid resistance is a statistically significant factor in explaining accidents; also, it is difficult to indicate a threshold level of skid resistance below which accidents considerably increase. More recent studies suggested that grouping accident sites by similar characteristics provides a better correlation between accidents and skid resistance; the latter observation is confirmed by the present study.

In almost all the countries that were considered, an investigatory level is defined for monitoring pavements. Typically, this indicator is the SFC.

The UK standards set limit values not only for each category of the site but also as a function of the geometry of the elements (gradient, bend radius). This aspect means considering friction demand.

Only the Australian standards give importance to the difference between the SFC values found in the two Wheel Paths.

The New Zealand standards include, in addition to the investigatory level, a threshold level.

The analysis of data, collected on an existing road, produced the following results:

- In the absence of studies on this topic, the same limits as those included in the UK standards, based on the Investigatory Level, can also be applied in Italy;
- With regard to the threshold value, its use and correct implementation is more complicated. A different threshold value is necessary for every site with similar characteristics;
- The Italian standard threshold for managing skid resistance is rather inadequate;
- Alternatively, it is possible to use a unique threshold defined by the ratio between available skid resistance and friction demand.

In perspective, a more extensive database, which includes roads of different category, will possibly allow us to identify more accurate limits of the ratio between the available friction and friction demand. In addition, the difference between the SFC values in the two Wheel Paths should be considered.

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