Papers

SKIDDING ACCIDENTS, FRICTION NUMBERS, AND THE LEGAL ASPECTS INVOLVED REPORT OF THE PIARC TECHNICAL COMMITTEE ON SLIPPERINESS AND EVENNESS

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Because of various other factors involved in skidding accidents, friction numbers as measured under standardized conditions of test cannot be expected to give a clear-cut ranking to surfaces according to their safety to traffic under wet conditions. Nevertheless, the concept of standardized test conditions is inevitable from a practical point of view. Regression type analyses compare accident figures or rates with friction numbers (examples from the Netherlands, the F.R. of Germany, and France). The most striking evidence of the important role slipperiness can play in wet-road accidents is yielded, however, by reliable before-and-after studies (examples from Italy and Great Britain). The establishment of standard, guide or minimum friction numbers is mainly based on regression type analyses. From country to country such values are quite different in character and significance. They support highway authorities in decisions on maintenance and renewal work but only in Belgium, the Netherlands, and Switzerland they serve as an acceptance criterion for road works. Current practice is described. For the suppression of black spots in wet conditions the two approaches are systematic routine measuring campaigns and evaluations of the accident statistics, the latter preferably based on the proportion of wet-road accidents. Interdisciplinary work is necessary to elaborate proposals for remedial measures which will generally include factors other than slipperiness (e.g. Safety Operation No. 6 in France). Juridical aspects in skidding cover the contractor's liability, the liability of the highway administrations, and the personal liability of their civil servants. Despite of the great variety in legal conditions. some general remarks can be made.

Preface

In the course of the preparation of the Second International Skid Prevention Conference, a number of non-American experts have been invited to present contributions. Most of these experts, however, are members of the PIARC (Permanent International Association of Road Congresses) and, in particular, of the Technical Committee on Slipperiness and Evenness. During its meeting in Berlin in November 1974, then the Committee decided to propose collective contributions to the Subcommittee on "Pavements" and the Subcommittee on "Accidents and Human Factors" of the international conference.

To characterize PIARC it should be mentioned that it is its main function to organize World Road Congresses to be held every four years in one of the member countries, and to enable a certain number of Technical Committees to work. PIARC (General Secretariate: 43, avenue du Président Wilson, F-75775 Paris Cedex 16, France) includes 59 countries, and 47 of them are member countries, that means that their governments are PIARC members. The financial resources of the Association are limited to the contributions of the members, which are individual or collective members (governments, administrations, ...). The PIARC Technical Committees cover the following subject areas: concrete roads, road tunnels, flexible roads, low cost roads, testing of road materials, winter maintenance, road traffic and safety, economic questions and the questions of slipperiness and evenness.

The Committee on Slipperiness was officially founded in 1949 in order to enable the Permanent International Association of Road Congresses to present an exchange of views on the skid-resisting properties of roads to the IXth Road Congress held in Lisbon in 1951. At the present time the Committee acts as a forum of exchange and discussion among experts in the fields of road skid resistance and evenness. It presents a report to each of the PIARC World Road Congresses outlining the evolution in research, knowledge, and experiences in its field. The Committee is in close contact with other organizations and experts working in the same field of skid resistance and evenness.

Based upon the Report of the Technical Committee on Slipperiness and Evenness to the XVth World Road Congress in Mexico-City 1975 (1) and supplementary material, this contribution has been drafted in accordance with the aim of the Skid Prevention Conference. The specific questions to be treated are:

1. Accident experience related to friction numbers.
2. Establishing guide or minimum friction numbers.
3. Spot detection and decisions on remedial measures.
4. Juridical aspects in skidding.

Human factors are not dealt with in this contribution because specific work on this question has not been done yet in the member countries of the PIARC Technical Committee on Slipperiness and Evenness.

This report has been written by the authors with the help of the Committee members among which Messrs. A. Pasquet (France, Chairman of the Technical Committee), P.M.W. Elsenaar (Netherlands), J.P. Leyder (Belgium) and J. Lucas (France) should be especially mentioned.

This report includes information available up to the 1st of June, 1976, unless otherwise stated within the text of the report.

Background and History

In the historical view, the first activity in the skidding field was measuring friction numbers, and a variety of different methods of test have been developed in the various countries since the early thirties. Although it seems impossible to establish an internationally standardized method of test, useful work in preventing skidding accidents can be done by the application of any one test method if it satisfies the following three criteria (C.G. Giles in line with the Report of the PIARC Technical Committee on Slipperiness to the XIIIth World Road Congress in Tokyo 1967 (2, 3)):

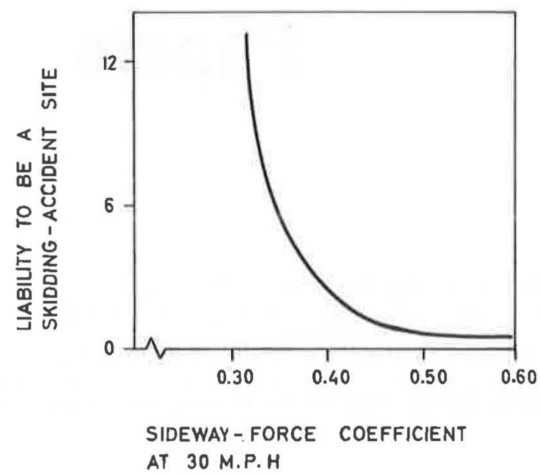
1. That it must be shown to give consistent results.
2. That sufficient tests must have been made over the full range of surfacings under the same test conditions to give a representative background of data with which subsequent results can be compared.
3. That a systematic series of measurements on skidding accident sites must have been carried out so that the readings may be appropriately correlated with the risk of skidding accidents.

That the methods of test employed in the various countries do satisfy these criteria is mostly owing to the strict control of the test conditions. In particular it is essential that the test vehicle incorporates a watering system capable of regulating very precisely the outflow of water in front of the test wheel.

The first efforts to establish a direct relationship between accidents and the skid-resisting properties of roads date back to the end of the fifties when in Great Britain it has been found that many skidding accidents tended to cluster at a few "difficult" places on the busiest roads where the skid resistance was low (C.G. Giles 1957)(4). From a comparison of the skidding resistance as measured with the sideway force method of test in wet weather at skidding accident sites (mean sideway-force coefficient 0.36 at 48 km/h (30 mph)) with that of a random selection of other heavily trafficked road sites (mean coefficient 0.50) the "relative liability of a surface to become the scene of repeated skidding accidents in wet weather" has been calculated (Figure 1). The sharply increasing risk at the lower values of coefficient was so great that in practice it seemed the dominant factor, outweighing the effects of differences in road layout or in the amount of traffic to a considerable degree (4).

These early findings could be confirmed in several subsequent investigations carried out in different countries on a more or less similar basis of skid resistance measurements and accident analyses, but since that time more and more difficulties arose in interpreting the results of skid resistance measurements and in using them for decisions on remedial measures.

Figure 1. Sideway-force coefficient and the relative liability of a surface to become the scene of repeated skidding accidents in wet weather (4).



There are two main factors contributing to these difficulties:

1. The increasing formation of ruts in the wheel tracks - either by abnormal road wear or by unexpectedly large permanent road deformations under heavy vehicle loads - promoted the appearance of thick water films on our roads. At the same time, due to increased vehicle speeds, thick water films got more dangerous than in the past, so that today the actual water film thickness on the road is a tantamount factor in determining the friction level actually available.
2. Road users, and their insurance companies, getting more and more conscious of the important role the frictional resistance of the road surface can play in wet weather accidents, increasingly frequently attempt to hold responsible the road authority "for lack in safety". This tendency, on the other hand, and depending on the legal conditions in each individual country, sometimes calls for a more conservative attitude of the road administration towards establishing minimum or guide values of skidding resistance, taking into account that it is indeed practically impossible for a road authority to guarantee, against the public, that all roads will offer at least "this" level of tire-to-road friction at any time.

These difficulties together with increased traffic flows and their deteriorating effect on the frictional resistance of road surfacings have rendered the idea of suppressing road lengths with insufficient resistance to skidding a complex matter.

Accident experience related to friction numbers

From experience it became more and more clear that two surfaces may be equally ranked by the results of skid resistance measurements, but one could be skid-prone and the other not depending on various other factors involved. These factors that weaken the significance of the skid resistance criterion (which is based on standardized conditions of test) can be grouped as follows:

1. Factors originating from the estimating character of each individual skid resistance measurement:

- The coefficient of friction/speed relationship is different from surface to surface.
- Road surfaces vary in their skid-resisting properties with time and under the influences of weather and traffic (including variations of the coefficient of friction/speed relationship).
- The skid-resisting properties vary also across the width of the road; the lowest value found in the most heavily trafficked wheel tracks may be equal for two sections of road, the overall level may not.

2. Factors originating from different characteristics of each individual site (site parameters):

- The frictional resistance is substantially variable with the actual water film thickness on the road. It would be wrong to identify the water film thickness chosen for testing (according to the standardized conditions of test) with that encountered by vehicles travelling along the same length of road during rainfall. Although the water film thickness used in testing is generally chosen as to simulate a relatively unfavorable surface condition within the spectrum of unfavorable conditions, the skidding resistance criterion determined in this way implies that it is not possible to discriminate between road sections which, during actual rainfall, exhibit unfavorable degrees of wetness like this only on isolated points and those sections where such conditions occur over a major part of their surface area.
- Frequency, distribution and intensity of rainfalls vary from place to place. Therefore, different road sections included in a skidding resistance/accidents survey are not strictly speaking, comparable.
- The effect of the surface irregularities on actual wheel load fluctuations can be different from road to road resulting in different reductions of the frictional forces available at a certain point of travel, apart from vehicle parameters which are also involved.
- The frictional requirements of traffic are different from site to site. According to a definition given by H.W. Kummer and W.E. Meyer (5) it is possible to distinguish between normal, intermediate, and emergency frictional requirements. Reduction in traffic safety in wet conditions depends on the degree of discrepancy between the demand and the availability of the tire-to-road friction.

From this consideration of some of the more important factors involved in the skidding accident problem it can be concluded that friction numbers as measured under standardized conditions of test cannot be expected to give a clear-cut ranking to surfaces according to their safety to traffic in wet conditions (or to the risk of skidding in the wet). On the other hand and from a practical point of view, it would by no means be advisible (if not impossible) to give up the concept of standardized conditions of test. To vary in routine skid-testing only a few of the parameters involved would not only cause immense additional work but also produce considerable new difficulties in interpretation because statistical distributions rather than individual figures for the friction numbers would be obtained.

Thus, in the view of the PIARC Technical Committee on Slipperiness and Evenness, there are, at present, still two practical approaches to establishing skidding resistance/accidents relationships: (1) regression analyses, (2) before-and-after-studies, with both of these approaches based on friction numbers as obtained under standardized conditions of test.

Regression Analyses

From a theoretical point of view a multiple regression analysis which includes some of the factors representing site parameters would offer the best chance of reaching a close relationship between relevant accident rate and skidding resistance. The site parameter of paramount importance would be a quantity related to water film thickness distribution (e. g. the average water film thickness at a representative rainfall intensity). Particularly prone to water accumulations are the transition areas between left-hand and right-hand curves (or vice versa) due to the directional change of the crossfall at the turning point by carriageway distortion. As it can be seen in Session 1 - Report of the Technical Committee on Slipperiness and Evenness on pavement characteristics and skid resistance - research work aimed at assessing the true surface drainage conditions of any given section of road is still in progress.

It is well possible, of course, to estimate, from empirically determined relationships (nomogram type (6)), for a given intensity of rain, the water film thicknesses and their distribution over a road section with known design features, assuming an ideally even surface. But this estimate will only indicate the general trend rather than express actual conditions which are complicated by tolerated deviations from the design figures and by the irregularities due to surface roughness and ruts in the wheel-tracks.

Therefore, at the present state, all the known relationships rely upon the skid resistance criterion only, since they compare simply accident figures or rates with friction numbers measured under standardized conditions of test. However, there is a practical way of discriminating between different frictional demands of traffic, that is by making separate studies for different types of road site (e.g. straight sections, sharp bends, approaches to traffic lights etc.). Such separate studies are less advisable on motorways and other high standard roads because of their more uniform design characteristics. Here, unforeseeable, sudden changes in the traffic situation can be considered the major cause of high frictional demands rather than different geometric design features. As a general rule, the number of emergency situations may increase with an increase in traffic flow.

Before-and-after Studies

Fundamentally different from regression analyses, before-and-after studies eliminate the majority of difficulties originating from the various parameters involved in the skidding accident problem. Before-and-after studies imply that there is, at least approximately, only one factor changed. This is the frictional level of the road surface as evaluated by the skid-testing technique employed. Therefore, reliable before-and-after studies yield the most striking evidence of the important role that skidding resistance plays in the complex system.

Examples of Relationships

Regression Type Analyses. In the Netherlands all accidents on state roads during two years have been used in a regression type survey. The accident rate was derived from the number of accidents during a certain period on a selected section of road and the total number of kilometers travelled over that section of road during the same period. Friction numbers for each road section were measured by the Dutch standard test method (i.e. test wheel under 86 per cent slip). Wet friction numbers were used for all accidents that occurred in wet weather, dry-friction numbers for those accidents that occurred in dry conditions. A relationship was established between friction level and accident rate (Figure 2)(1).

In the Federal Republic of Germany a regression type analysis between friction numbers and accidents was based on the proportion of accidents that occurred under wet conditions. In general, on most road sections the proportion of accidents in the wet, i.e.

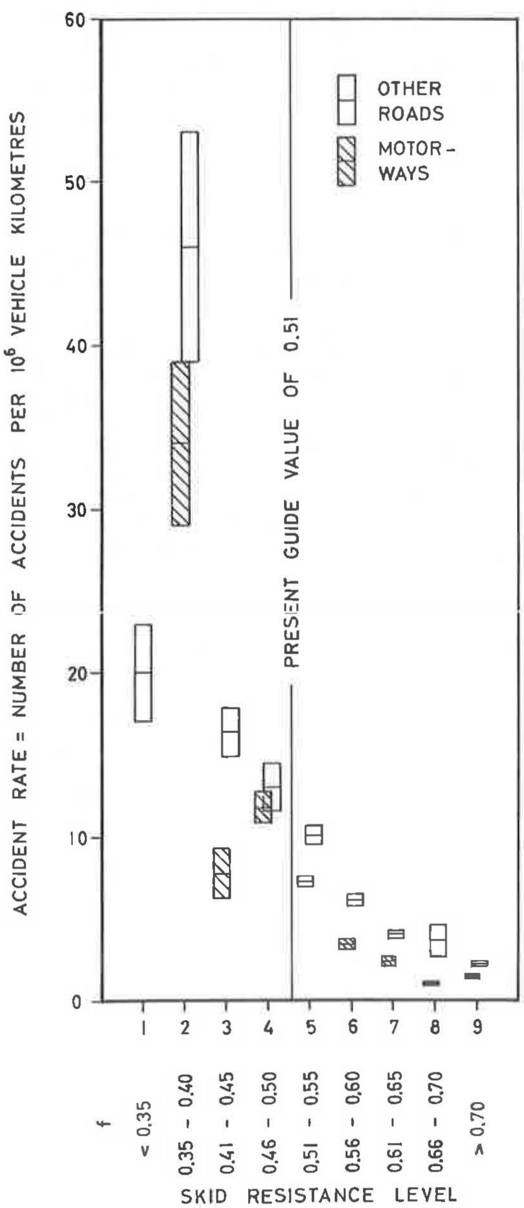
$$P_w = (A_w/A_t)\cdot 100 \quad (\%)$$

A_w Number of accidents in wet conditions

A_t Total number of accidents (in wet and dry conditions)

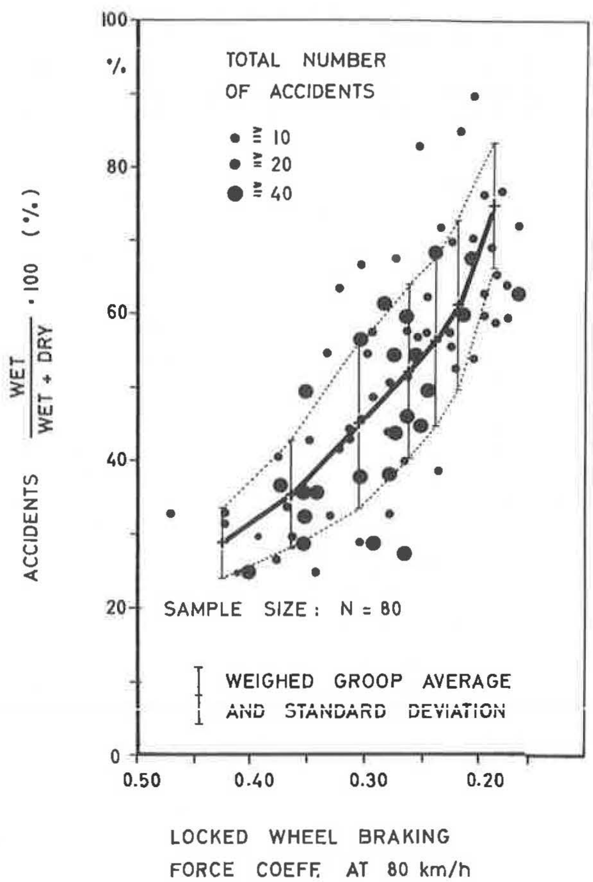
varies between zero per cent and approximately 50 per cent and averages about 33 per cent for the road network with slightly different figures from year to

Figure 2. Accident rate (mean and standard deviation) against friction level (dry levels for dry-road accidents, wet levels for wet-road accidents). The Netherlands, 1965 and 1966.



year. If on any particular section of road the proportion of wet-road accidents significantly exceeds this range of percentages, then this can be taken as an indication of reduced traffic safety under wet conditions (7). The survey (Figure 3)(8) covered 80 sections of motorways and main roads; the skid numbers (locked wheel braking force coefficients) were measured at a speed of 80 km/h (60 mph). Although there is a large scatter in the percentage of wet-road accidents for each friction level, the general trend of the increasing percentage of wet-road accidents with the decreasing friction level is unmistakable.

Figure 3. Percentage of wet-road accidents against friction number. F.R. of Germany, 80 sections of motorways and main roads, each over one or two years within 1964-1971.



In France, skid-prone sites are being detected by the following method (17):

1. The first step is black spot detection in a general sense (all accident causes mixed) using the nomogram given by Thedie and based on the binomial distribution.

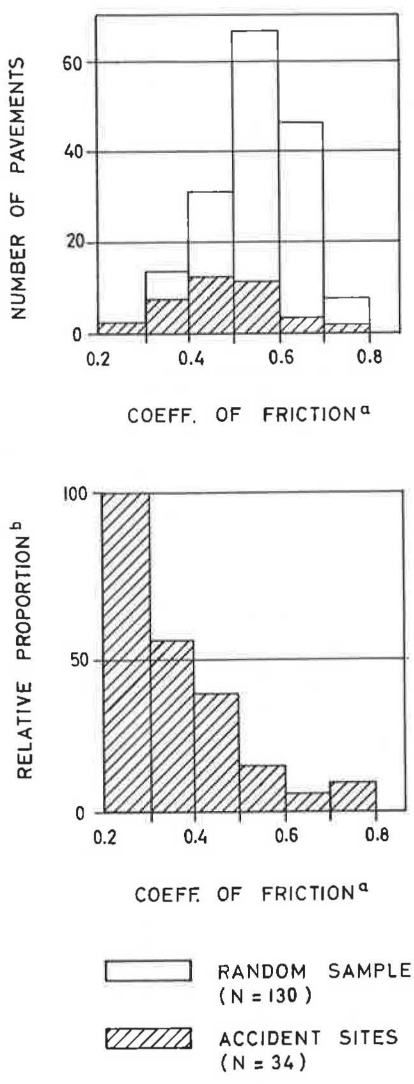
2. Then, for these sites or sections of road, the number of accidents that occurred under wet conditions (M) is compared with the total number of accidents (M + S), and the confidence interval for the ratio R = M/(M + S) is estimated for a certain level of significance. If the lower confidence limit determined in this way exceeds a certain value, say 25%, then the section of road in question is said to be

"skid-prone".

According to this investigation, the detected sections of road exhibited skid resisting properties in the medium range (Figure 4), but slipperiness was not the only major factor involved. Other factors intervened, such as:

- The horizontal alignment: 40% in straight sections, 54% in curves, 6% at junctions.
- The vertical alignment: 54% horizontal, 46% up-grades, 0% down-grades.
- The evenness of the road: 37% in good condition, 46% in bad condition, 17% intermediate.

Figure 4. Histograms of locked wheel braking force coefficients on accident sites and on randomly selected sites, France (16).



[a] LOCKED - WHEEL BRAKING FORCE (LPC - TRAILER, SMOOTH TIRE)

[b] OF ACCIDENT SITES FOR EACH LEVEL OF SKID RESISTANCE

Before-and-after Studies. Among the before-and-after studies carried out in recent years an Italian survey and a British investigation should be mentioned especially. In Italy a particular interest was taken in the British experience with epoxy resin/calcined bauxite surface dressing (9). Surfaces of this type give a sideway force coefficient of 0.78 - 0.88 at 50 km/h (30 mph) after one year and of still 0.67 -0.70 after eight years of exposure to intense traffic. At the same time a reduction in the total number of road accidents during one year has been reported (10).

In Great Britain, an instructive before-and-after study relates to the elevated section of M4 Motorway (11), where after some years of intense traffic the skidding resistance of the existing bituminous surfacing had fallen to a relatively low level. Afterwards the road was surface-dressed (calcined bauxite and/or Gilfach gritstone with PVC-tar binder). During the years following treatment the friction level of the surface remained well above that of the previous surfacing. The accident figures, including both injury and damage accidents, show that there were 28 per cent fewer dry-road accidents and 63 per cent fewer wet-road accidents of all kinds during the period following treatment than in the two years immediately preceding the work. In particular it can be seen that the reduction in wet-road accidents is primarily a reduction in wet road skidding accidents.

Establishing Guide or Minimum Friction Numbers

Examples of Current Practice

At the moment that highway administrations have knowledge of the importance of the skid-resisting properties of road surfaces in accident prevention they have the duty to use, in the interest of safety, the figures obtained. Consequently, attempts have been made in several countries to put forward standard, guide or minimum values of skidding resistance. Such values are aimed:

1. To support the highway authorities in taking decisions on maintenance or renewal work on existing roads, mainly based on sporadic measurements when and as the need arises.
2. To serve as an indicator for unsatisfying skid resistance in systematic road network investigations or black spot detection campaigns.
3. To serve as an acceptance criterion for road construction work if the specifications do include the skid-resisting properties explicitely (as it is the case in a few European countries only).

For all these purposes standard, guide or minimum values of skid resistance are used in a technical sense only and not in a legal sense (with the exception of their legal significance in the relationship between road work contractor and highway administration).

How standard, guide or minimum values of skid resistance are actually used in the different countries may be demonstrated by the following examples of current practice.

At first, the well known early British recommendations may be mentioned that date back to 1957 (4) and relate to the sideway-force method of test; different coefficient values are given for different categories of road according to the different frictional demands of traffic ("easy sites", "general requirements", "most difficult sites").

In a much more strict sense minimum values of skid resistance are in use in Belgium since 1962, where they have to ge guaranteed by the road contractor, forming a part of the contract conditions (19):

The skidding resistance of the pavement surfaces is verified by the Highway Administration by means of sideway-force coefficient measurements. Per pavement category a number of tests (n) given by the following formula is carried out by the Administration:

$$n = S/4000$$

where S is the surface area of the pavement in question, expressed in square metres. The number of tests n has a lower limit of 10 and a upper limit of 50. "A category" is understood to be any continuous pavement surface described in one contract item. However, in the case of motorways and other highways with at least two traffic lanes per carriageway, each traffic direction represents "a category". Anyhow, both parties may arrive at an agreement and subdivide the pavement of one contract item into several distinct conventional categories.

The tests are carried out at any time the Administration deems necessary and at locations pointed out by the Administration, and at any date at the time of the provisional acceptance and the final acceptance. When a result obtained during a test carried out in accordance with the standardized test conditions (20 °C, at 50 or 80 km/h according to the type of road) is lower than 0.45 for one of the two test wheels of the measuring apparatus, the Administration has a right to test any part of the pavement surface in order to delimit the defective areas.

At the time of the provisional acceptance, as well as at the final acceptance, the different pavement categories have to present over their whole length the characteristics in accordance with the clauses of the specifications, i.e. any change in the nature of the pavement surface is subject to approval by the Engineer.

As a rule the measurements are carried out at 80 km/h on motorways and other highways with four traffic lanes or more and at 50 km/h on all other roads. However, when local conditions (gradients, bends with small radii) do not allow to meet this condition, the tests are carried out at a speed considered possible by the Administration. In this case the measured sideway-force coefficient is affected by a speed correction factor.

Before undertaking any repair work the contractor submits the corrective measures he intends to perform in order to restore a sufficient sideway-force coefficient to the approval of the Administration. The fact that the Administration approves of the repairs proposed by the contractor does not diminish the responsibility of the latter to achieve a satisfying sideway-force coefficient.

Any point of the pavement not presenting during a 3-years period a minimum sideway-force coefficient of 0.45 measured at each test wheel (speed of 80 or 50 km/h according to the type of the road; temperature 20 °C) is rejected. These areas have to be repaired by and at the expense of the contractor over a length of at least 100 m and right across the carriageway. The repair methods are subject to approval by the Administration. An additional 2-years guarantee period, beginning on the day of the repair, is demanded for the sideway-force coefficient of repaired pavements or pavement sections.

The percentage of unsatisfactory results varies over the seasons from 5 to 8 per cent.

Another example for the use of friction numbers forming part of the contract conditions can be reported from the Netherlands. Here, minimum values of skidding resistance have generally been introduced into contracts for main roads (including resurfacings of existing roads) since 1967.

Examiniation of the friction coefficient is usually carried out before the opening of the new surface to traffic, but not later than four weeks after the opening. The minimum value prescribed in the contract was 0.51 during the period 1967-1974 and is 0.56 since 1975 (measured longitudinally, at a speed of 50 km/h, test wheel with constant brake slip of 86%, standard patterned tire).

During the period 1967-1974 in the average about 4% of the finished and examined surfaces (totalling 6700 km of lane, width about 3.50 m) did not meet the (old) specification (f = 0.51); this percentage was 5% in 1975 (examined length of lane 1000 km, lane width 3.50 m); in the average the percentage below the (new) specification (f = 0.56) was 20% before 1975 und 24% in 1975.

In the contracts for asphaltic concrete wearing courses the spreading of 2 kg/m² chippings 2-5 mm onto the hot surface during rolling is prescribed. This strongly contributes to achieving the specified minimum skid resistance value in a high percentage of road lengths. If friction coefficients below the specified values (now 0.56, and formerly 0.51) are found, payment reductions ("penalties") are applied. Moreover, surfaces with $f < 0.51$ had, and still have to be improved, mostly by means of a treatment with white spirit and crushed sand. This method is rather labour-intensive and costly. But if carried out carefully the method is generally effective. In some rare bad cases locally a 40 mm extra new top layer had to be applied. These improvements were made and paid for by the contractor.

All these regulations have been developed and introduced by the government authority in continuous deliberation with the contractors' organizations. As they are accepted by them, the specifications, as a rule, do not lead to big problems.

The third example of a country where friction numbers form part of the contract conditions, is Switzerland. First in 1964 Swiss Standards (20) defined acceptance values as follows, related to the British Portable Skid Resistance Tester (pendulum SRT) and depending on the design speed V_a of the road:

- for roads with $V_a < 80$ km/h: SRT $\geqq$ 50
- for roads with $V_a > 80$ km/h: SRT $\geqq$ 55
- for most difficult sites: SRT $\geqq$ 60

As far as it is known, these standards - that may be classified as "moderate" - have not been satisfied only in four cases during the last six years. In all these cases the problem was a problem of the initial skid resistance after the construction of a bituminous concrete surfacing, and traced back to excess rolling at high air temperatures with the result of excess binder accumulating at the top of the surfacing.

Only in one of these cases the excess binder was removed mechanically from the surface of the road. The method proved successful, and afterwards the acceptance values were easily attained. The other three cases related to minor roads where the posting of warning signs "danger of skidding" and the introduction of a speed limit (60 km/h) were considered sufficient care. Satisfying friction numbers have then been measured on all these sections after the first winter period has passed.

Generally spoken, there exist no serious problems with the initial skidding resistance of asphalt pavements in Switzerland, so that difficulties can only arise from "failure".

Apart from these examples, most of the European countries, however, are still hesitating to include minimum friction numbers into their contract conditions. Some prefer to prescribe specifications for highway constructions (e.g. texture depths and resistance to polishing of the aggregates as to ensure, from experience, acceptable friction values) rather than demand explicitely minimum values of coefficient. A particular example of this type of policy has been implemented in France (13). In addition to that, however, France has recently started periodic or systematic measurements within the road network by using the machine SCRIM (18). The results of the 1974 measuring campaign are given in Figure 5 and Table 1.

Figure 5. General results of the SCRIM measuring campaign in France in 1974.

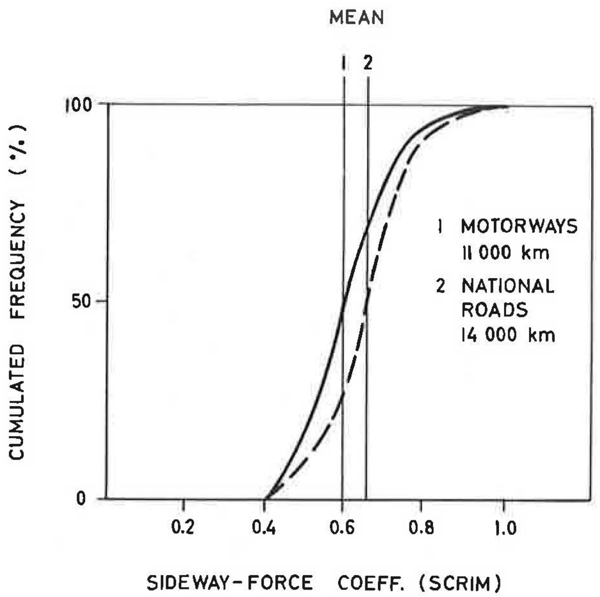


Table 1. Main results of the SCRIM measuring campaign in France in 1974 (18).

SFC = Sideway-force Coefficient	3000 km of Motorways	4000 km of National Roads[a]
Mean of SFC	0.60	0.64
Standard deviation	0.11	0.13
Percentage SFC below 0.50	16%	9%
Percentage SFC above 0.70	21%	32%

[a]Reinforced according to the directive scheme.

These few examples may suffice to indicate that friction standards if established, are quite different in character and significance as well as with regard to the practical consequences drawn, much depending on the particular conditions in each individual country. (For more details on the figures actually used in the various countries and their significance see the Committee's contribution to Session 1, "Pavement characteristics and skid resistance", chapter III, Analysis of regulations in European countries). There are two main reasons for this variety in policy, the one originating from the principal difficulty in defining safe minimum friction numbers, the other originating from the legal aspects referred to later in this contribution.

"Safe" Minimum Friction Numbers ?

The question of how minimum or guide values of the friction number should be formulated cannot be answered by means of single before-and-after studies. Regression analysis appears to be the only way to proceed but then the whole complexity of the skidding accident problem is under question, since, under the influence of the other factors involved (site parameters in particular), any relationship between friction numbers and accidents so far established shows a residual variance larger than desirable from the viewpoint of practical application for measures to prevent vehicles from skidding.

As a consequence of the large variance, only extremely low values of the skid resistance criterion used are definitely associated with an unusually high percentage of accidents (chiefly skidding accidents) in the wet; and only with rather high friction numbers can the influence of the road surface on accidents be excluded. Between high and low values, however, there is a large transition zone of friction levels around and below the average where an interrelation between frictional level and accidents can neither be excluded nor be assumed with certainty. Against this background it would be desirable, following the classic principles of materials testing, to select guide values of skidding resistance which are definitely "on the safe side". This would lead to guide values corresponding to the average friction level found in the road network. It would be unwise, however, to proceed without considering what friction level is possible to obtain and to maintain and, if need be, to restore under the conditions of intense and heavy traffic with the given natural materials in relation to the financial limitations.

Therefore, it is mainly for economic reasons that standard, minimum or guide values of skidding resistance have been chosen in the different countries which cannot be considered to be definitely "on the safe side". However, there is the practical way of adapting to different frictional demands of the traffic by applying different guide values according to a classification of sites as to their "difficulty". There is also the method of adjusting the guide values within prescribed limits from site to site in the light of accident records (14). In this case instead of providing surfacings of uniformly high resistance to skidding, a compromise situation seems possible to achieve in which the risk of the occurrence of skidding accidents would be uniform within the road network. This concept brings out the problem of defining the admissible risk of the occurrence of skidding accidents, or the "degree" of safety under wet conditions to achieve. The real dilemma the road engineer is exposed to, and to which no solution is in sight, is that from the standpoint of jurisdiction, "safe" and "unsafe" is the only distinction admitted (1).

Spot Detection and Remedial Measures

To detect road sections with insufficient friction levels there are, in principle, two approaches:
(1) Systematic routine skid resistance measurements,
(2) Evaluations of the accident statistics.

For systematic measurements to be used as a means of spot detection it is a pre-condition that minimum or guide values of skidding resistance have been formulated in relation to the standard method of test employed. Clear decisions can be taken in all cases where the test result falls definitely short of the minimum. A more complicated situation will arise from test results just exceeding the minimum. Then it is

Table 2. Reduction in accidents as the result of black spot treatments during the Safety Operation No. 6 in France (17). Relative figures related to 51 black spots in wet conditions improved during 1971 and 1972.

	Number of accidents[a]			Number of victims[a]			
	Total	On wet surface Total	Per cent	Total	Fatal	Seriously injured	Slightly injured
Before treatment (1969)	85.31	63.98	75	177.71	14.55	56.99	106.17
After treatment (1972)	34.98	6.64	19	59.43	4.10	21.40	33.93
Reduction following treatment, per cent	59	90	75	66	72	62	68

[a]Annual mean value.

necessary to take into account the particular situation of the spot with special attention to be drawn to the conditions of surface drainage, and also to the level of the frictional demands of the traffic.

The comparison of measured friction numbers with standards implies a certain degree of merely schematic application which not necessarily results in optimum utilization of funds unless the friction numbers found are extremely low. Therefore, there is a tendency to base decisions on remedial measures on more comprehensive considerations with the accident figures as the starting point.

Spot detection by the use of accident figures can be successfully based on two inputs for any section of road under consideration:

1. On the proportion of wet-road accidents involving skidding related to all wet-road accidents (skidding accident rate).
2. On the proportion of wet-road accidents related to the total number of accidents (wet and dry conditions).

The use of the first input is bound to the precondition that the question of whether a vehicle skidded during an accident is recorded in the accident report form filled-in by the police for each (injury) accident, as it is the case in Great Britain. If this information is not explicitely available, as in most other countries, then the use of the proportion of wet-road accidents is most recommendable. In this way successful campaigns of spot detection have been carried out in the F.R. of Germany (15) and in France.

Due to its comprehensive disposition the French "Safety Operation No. 6" (16, 17) provides guidance for developing skidding accident prevention strategies. Indeed, the method not only necessitates an analysis of the accident statistics and the detection of "black spots" in wet conditions, but also a thorough site investigation for decision making on how the section of road in question can be improved in order to prevent further accidents of the same type. These improvements possibly include road characteristics other than the resistance to skidding. As it is considered in France, it is this site investigation that guarantees the rentability of this type of safety operation: In general, the cost of the accidents prevented during one year is well superior to the cost of the site investigation work. More precise information on these different points is given in the sections to follow.

The following definitions have been used (16): A "black spot in wet conditions" is a section of road where, on the 0.05 level of significance, the proportion of wet-road accidents exceeds the value which would be obtained by using the Poisson distribution. In an other region, the first step was the selstion of road sections where the total number of accidents was abnormally high, and then, by using the binomial distribution, those of them were selected for further investigation where the proportion of wet-road accidents was abnormally high. The sections of road detected on the basis of these definitions did not necessarily prove to reveal low friction numbers when measured. Consequently, and in accordance with other investigations (15), even with medium friction numbers safety against an accumulation of accidents in the wet is - under some circumstances - not ensured.

Under these conditions where other characteristics of the road were involved, it has been concluded that an interdisciplinary working group (road engineers specialized on construction and maintenance work, on road alignment, on surface properties, as well as other specialists on vehicle dynamics, on driver psychology) in cooperation with the local authorities should analyse, by means of in situ studies, the situation of the spot and elaborate proposals for remedial treatments. Among a sample of 51 sections of road with totally 210 fatal accidents recorded during three years, the following types of remedies related to a summed-up length of 10 km (with a total surface area of 4000 m^2) have been proposed solely or in combination:

- Signalization and warnings to road users: 36 times.
- Improvement of the evenness of the surface: 21 times.
- Anti-skid surface treatment: 26 times.
- Widening of the road and other particular measures: 11 times.

From before-and-after studies of the accident figures remarkable reductions in the numbers of accidents and victims have been reported (Table 2). To assess the effectiveness of the treatments an estimate was made on the basis of the average cost of one accident (53.000 Francs) and the average cost of one black spot treatment (63.000 Francs), and under the following assumptions:

- That after treatment the proportion of wet-road accidents will render normal (about average) if compared with a reference section of road.
- That the total number of accidents will increase linearly with the growth in traffic flow.

According to the estimate, the annual advantage gained from the improvement of 51 "black spots in wet conditions" amounts to 3,800,000 Francs for a period of one year in the average after treatment.

Juridical Aspects in Skidding

The juridical aspects in skidding can be divided into three parts related to

- The contractor's liability.
- The liability of the administration.
- The liability of the civil servants.

The liability of the contractor depends largely on the specifications for road construction work given in each individual country. In general, there are three types of regulations in use.

The first type implies friction numbers to be achieved as part of the contract conditions (as in Belgium, the Netherlands, and Switzerland). In this case, the liability for non-compliance with the standards is, during the guarantee period, completely due to the contractor, and remedial measures (with laying a new surfacing as the extreme solution) have to be performed on its own cost.

In the second case the contract conditions as far as skidding resistance is concerned, are restricted to prescribing a minimum value for the polished stone coefficient (as for example in France). If nevertheless the finished surfacing reveals poor resistance to skidding, the road authority will be concerned with and finance remedial measures, unless the next case applies.

In the third type of regulations the contractor can be held responsible for any failure in the skid-resisting properties of the finished surfacing only when he can be convicted of not having observed "the generally accepted rules of the art". Otherwise, the administration will be concerned with and finance remedial measures that might be necessary to perform.

The liability of the highway administration is a much more complicated matter. It must be viewed in two stages: (1) Can the standards (what form and significance they ever have) be called into question during an accident and lead to a judgement against the highway administration ? (2) More general, can the highway administration be found liable for a wet road accident because of lack of maintenance or insufficient signalization ?

The answer to the first question depends, of course, on the legal conditions given in each individual country. In general, there is a tendency to acknowledge that the simple measurement of the friction number by the skid testing technique employed is not suitable for a judgement to be based on. It is realised that it is necessary to consider the problem of safety in terms of overall stresses and responses between the vehicle and the road. Therefore, in analysing the causes of any one wet-road skidding accident the local features of the road, the vehicle parameters, the mechanical condition of the vehicle, the environmental factors and the partilucar circumstances of the accident have to be taken into account. As a rule, courts will base their decisions preferably on expert evidence.

A particular situation, however, arises when it can be clearly shown that there was a case of "negligence or disregard". For instance, the highway authority has been previously informed of the inadequacy of the surface properties, and has not taken any suitable measures. Then the state will be held responsible for the lack in safety. In this context there is a tendency to regard the absence of clear signalization of dangerous spots more and more a failure in duty.

While, in certain cases as has been explained, the government can be held responsible with respect to an accident on a slippery road, it is exceptional for the road engineer himself to be liable personally. Theoretically, the case of personal legal liability is possible but exceedingly rare in practice. As a general rule, it must be clearly shown that a flagrant offense committed by the officer, or even a criminal action, was involved. Within these margins, however, different definitions, stronger or weaker, are possible.

Finally, it should be noted that the extent of problems raised by legal responsibilities with regard to skidding varies considerably from one country to another. At the present time only Belgium appears to be developing significant action aimed at incriminating, as often as possible, the public organisation, or even its agents, in the case of an accident on a wet road which is "abnormally" slippery.

Conclusions

Suitable techniques are available to determine the skid-resisting properties of road aurfaces. It is a question of management and implementation to use them in the most effective way.

It is, however, necessary to emphasize again and again that friction numbers measured under standardized conditions of test do cover only one aspect of the complex problem of skidding accidents, unless the friction number obtained is extremely low. Then remedial surface treatment is, in the long run, the only possible action to be taken.

The purpose of standard, guide or minimum values of skid resistance is

- To serve as an acceptance criterion if the road construction work specifications do include the skid-resisting properties (in a few countries only).
- To assist highway authorities in taking decisions on maintenance or renewal work.

The significance of the standard, guide or minimum values is technical and administrative and not legal (except for the relationship between road contractor and highway administration if and when they are used as an acceptance criterion).

The most promising approach to develop strategies for skid prevention is to combine systematic skid resistance measurements with the evaluation of the accident statistics as related to each individual section of road. Close contact and effective exchange of information between highway authority and highway police is of paramount importance for this purpose.

Black spots in wet conditions can be successfully detected by calculating for each section of road under consideration the "proportion of wet-road accidents" to be compared with what is to be regarded as "normal" from a statistical point of view.

In situ analyses of detected sites by a multidisciplinary working group of experts are necessary to elaborate proposals for remedial measures which can be multifold (e.g. improvements in skidding resistance and road evenness, improvements of the surface drainage, improvements in road alignment or geometric dimensions, augmentation of the sight distances, signalization).

The suppression of "black spots in wet conditions" belongs to the most effective actions ever thinkable in accident prevention.

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