TRANSPORTATION RESEARCH RECORD 622

Skidding Accidents

Pavement Characteristics

Proceedings of a conference conducted by the
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Preface

Wet-weather skidding on highways and runways is a major contributor to accidents. In the United States alone, deaths from highway accidents have averaged more than 50 000 each year for the past 5 years. A significant number of those accidents can be directly attributed to wet-weather conditions.

Wet-weather accidents result from the interaction of many factors: climate and environmental conditions, vehicle operator, pavement design and construction, maintenance of roadway, and materials properties. Because the responsibilities of both public agencies and private individuals are involved, the question of legel liability for injury and damage is raised.

The First International Skid Prevention Conference, held in 1958 at the University of Virginia, emphasized the definition of problems and identification of research needs. During the intervening years, numerous techniques have been developed for reducing wet-weather accidents. Most of the basic mechanisms and interactions involved are known, and numerous promising solutions have been identified and demonstrated.

The Second International Skid Prevention Conference was organized to facilitate an international exchange of information on all aspects of wet-weather skidding accidents on highways. Primary emphasis was placed on research results and their application, vehicle industry developments, and operating agency practices and programs known to have a significant influence on reducing wet-weather accidents. The interaction among the driver, the vehicle, and the pavement surface was of prime concern. The papers in Transportation Research Records 621, 622, 623, and 624 constitute the proceedings of the conference held May 2-6, 1977, in Columbus, Ohio.

All papers prepared in advance for the conference are included in the proceedings. Records 621, 622, and 623 contain all papers addressing one of the three major topics of the conference; Record 624 contains ancillary papers not included in the conference program but considered to be important contributions to the state of the art.

Organization and direction of the conference were responsibilities of the Conference and Program Committees and Subcommittee on Tires, Vehicles, and Vehicle Components; Subcommittee on Pavement Characteristics; Subcommittee on Wet-Weather Accident Experience, Human Factors, and Legal Aspects. Chairmen and members of these committees and subcommittees are listed on page ii of this Record.

The Second International Skid Prevention Conference was partially funded by the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation. The following organizations cooperated to make the conference possible:

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Papers

PAVEMENT CHARACTERISTICS AND SKID RESISTANCE

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Summary

Based upon recent information of its members, and the reports of the Technical Committee on Slipperiness and Evenness for the World Road Congress in Prague (1971) and Mexico (1975) the state of the art in member countries has been given. A comparison of recommendations and specifications relating to the skid resistance properties of new and existing pavements is made. A growing awareness of the need for standards for new and existing pavements is established. For new pavements specifications dealing with materials are of great importance, in particular the polished stone value.

The importance of systematic investigations of skid resistance of road networks is underlined, information on the practical approach in some countries and specifications of equipment is given. An overview of compositions and construction methods for both bituminous and cement concrete pavements with sufficient skid prevention properties is given. An economic choice out of the numerous techniques available for achieving sufficient skid resistance should be made with special regard to the possibility of the use of local materials, workmanship of contractors and experience of the highway engineer. For existing pavements techniques are discribed to restore the skidding properties. From the problems in skid prevention the item rolling noise has been selected as a compromise between skid resistance, thus safety, and noise generation, thus environment, has to be found.

In conclusion can be derived that from research and experience, techniques have been made available generally, to offer pavements to the road user with an adequate skid resistance. In education and permanent formation this knowledge should be implemented. At the same time an economic evaluation of skid resistant road surfaces is obvious. Special problems as rolling noise, tolerable water layer thickness and its relation with road geometry need attention in future.

Contents

Section I: PREFACE

In the course of the preparation of the Second International Skid Prevention Conference, several non-American experts were invited to submit a contribution. Most of these experts are also members of the P.I.A.R.C. (Permanent International Association of Road Congresses) Technical Committee on Slipperiness and Evenness. Consequently, the Committee decided at the Berlin meeting in November 1974 to submit a joint contribution for the Sub-Committee on Pavements and the Sub-Committee on Accidents and Human Factors of the International Skid Prevention Conference.

In order to place P.I.A.R.C. in its context, it should be pointed out that its main task is to organize a World Road Congress every four years in one of the member countries and to enable a number of Technical Committees to operate. P.I.A.R.C. (1) includes members from 59 countries, 47 of which are member countries, meaning that their governments are members of P.I.A.R.C. The financial resources of the association are confined to the contributions of members, whether individual members or bodies such as governments, administrations, etc. The Technical Committees of P.I.A.R.C. are concerned with the subjects of cement concrete pavements, road tunnels, flexible pavements, low-cost roads, testing of road materials, winter maitenance, road traffic and safety, economic questions, and slipperiness and evenness.

The Technical Committee on Slipperiness and Evenness was officially formed in August 1949 in order to enable the Permanent International Association of Road Congresses to present, at the 9th International World Congress in Lisbon in 1951, an exchange of views on the skid prevention properties of pavements. At the present time the Committee acts as a centre of exchanges and discussions between experts on problems of pavement skid resistance and evenness. At each world congress of P.I.A.R.C., the Committee submits a report reflecting the evolution of research, knowledge and know-how in its field. The Committee is in close contact with other organizations and experts working in the same fields of skid resistance and evenness. Since the latter aspect may not be of interest to this conference, the present report deals only with the problem of skid resistance. In accordance with the aims of the skid prevention conference, this report has been based on reports of the Committee to the Prague Congress in 1971 (2) and the Mexico City Congress in 1975 (3).

The specific questions dealt with are:

- Recommendations and specifications relating to the skid resistance of pavements.
- Systematic measurements of pavement skid resistance with a view to conforming with recommendations.
- The design and construction of skid resistance of bituminous and concrete pavements.
- The restoration of the skid resistance of existing pavements.
- The noise problem in relation to road surface characteristics.

This report takes into account information available on 1 June 1976, unless otherwise mentioned in the text.

Section II: RECOMMENDATIONS AND SPECIFICATIONS RELATING TO THE SKID RESISTANCE OF PAVEMENTS

2.1. Introduction

Road surfaces with a low skid resistance can increase the accident rate resulting from a loss of control of vehicles. This is clearly demonstrated on pavements covered with glazed ice. Furthermore, skidding may occur even on dry surfaces with a high skid resistance at all speeds. Hence the grip of the tyre on the pavement may be inadequate independently of the condition of the pavement. The important factor is the relative frequency of skidding under such conditions.

On a pavement covered with glazed ice, the road itself is no longer in contact with the tyre. On a dry pavement, the problem of grip is quite different, so much so that if pavements never got wet quite different surfaces would be used. However, the problem of slipperiness mainly arises on wet pavements, and the present report deals with this question.

The development of high-yield methods of non-destructive testing of roads necessarily implies the definition of standards of quality. On this point, the determination of the quality of a road is not an end in itself, and use can be made of it only if the degrees of quality measured can be compared with standards in order that maintenance may be undertaken if necessary. This naturally leads us to examine the regulations concerning skid resistance which are in force in various countries (2-3).

2.2. Definition of skid resistance requirements

The requirements can consist of specifications on materials (choice of aggregates, components, geometrical characterisitics) on skid resistance properties (evaluated by direct skid testing) or on both. Specifications on materials generally set forth minimum resistance values for aggregate polishing (15) and sometimes minimum macro-roughness values on the pavement in place. Direct measurements of skid resistance is normally carried out in accordance with one or more of the following methods: braking force coefficient, sideway force coefficient, pendulum measurement. In most countries, these specifications constitute recommendations rather than compulsory standards. In certain cases, the contractor is legally required to ensure a given level of pavement skid resistance checked during acceptance testing; in others, he is responsible for maintaining this level for a guaranteed period.

2.3. Analysis of recommendations and specifications

2.3.1. Belgium:

The contractor must conform to the specifications of the Ministry of Public Works for any new or existing roads. These specifications cover aggregate polishing resistance, ignition loss and the type of chip sealing or grooving. Certain skid resistance levels are required when the road goes into service as well as during the three following years. More precisely, specifications governing motorways and main highways are the following:

- Aggregates larger than 8 mm (0.314 in) used in wearing courses must have a polished stone value of at least 50 within a scale of 0 to 100; all aggregates - including sand - must have an ignition loss no greater than 10 percent.
- For cement concrete surfaces, surface treatment is compulsory and the absolute texture depth, measured with a depth meter, must be between 6 mm (0.236 in) and 10 mm (0.393 in) at the time of provisionnal acceptance.

Table 1. Recommended polished stone values

POLISHED STONE VALUE	EVALUATION	COMMENT
Lower than 0.35	Poor	In principle, such an aggregate must not be used for wearing courses.
Between 0.35 and 0.45	Passable	Such an aggregate is to be used only where alignment and traffic conditions are favourable.
Between 0.45 and 0.55	Good	
Higher than 0.55	Very good	The use of such an aggregate is recommended when alignment and traffic conditions are unfavourable (turns, intersections, high speeds, dense traffic).

- The minimum sideway force coefficient must be 0.45 at 80 km/h (50 mph) for pavements on motorways and highways with four lanes or more, and 0.45 at 50 km/h (31 mph) for other roads. These values are applicable for measurement at any point.

The polished stone value is measured with BS 812 (1976) (15) (the crushing of materials larger than 8 mm (0.314 in) is however authorized).

The sideway force coefficient is measured by means of the "odoliograph" and "Stradographe", at an angle respectively 20^{o} and 15^{o} under a load of 2500 N (550 lb), further details are given in table 6.

2.3.2. Czechoslovakia:

National standard recommending criteria CSN 736177 "Skid resistance measurement methods" has been issued on January 1976.

2.3.3. France:

Specifications cover only construction materials and methods in so far as these have an effect on skid resistance properties (4, 5). The definition of standards dealing with skid resistance properly so-called is in fact regarded as very complex. A circular of 11 June 1969 (Ministère de l'Equipement) establishes minimum polished stone values for aggregates used in wearing courses consisting of bituminous mixtures or surface dressings as well as minimum recommended levels of geometrical roughness evaluated by the sand patch test.

Table 1 gives the minimum recommended value for the polished stone test used in surface dressings and bituminous material for wearing courses.

Table 2. Recommended macro-texture

Pavement Class	Sand Patch Test TD mm (in)	Pavement Evaluation
A	HS ⩽ 0,2 (0.007)	Very fine-textured pavements; these pavements are to be prohibited.
B	0,2 < HS ⩽ 0,4 (0.007) (0.015)	Fine-textured pavements; these pavements are to be reserved for sections on which vehicle speeds are only occasionally capable of exceeding 80 km/h (50 mph), e.g. in urban areas.
C	0,4 < HS ⩽ 0,8 (0.015) (0.031)	Medium-textured pavements; these are normal pavements for sections on which moderate speeds are encountered, between 80 and 120 km/h (50 - 75 mph).
D	0,8 < HS ⩽ 1,2 (0,031) (0.047)	Coarse-textured pavements; these pavements are to be used for sections on which speeds are normally higher than 120 km/h (75 mph).
E	HS > 1,2 (0.047)	Very coarse-textured pavements; these pavements are to be used in special cases: danger zones following a straight line on which speeds are very high; zones where there is frequent and moderate frost (condensation when relative humidity is high and temperature near $0^{o}C$).

Table 2 defines five categories of all kinds of bituminous and concrete pavements from the point of view of their macro-texture characterized by the sand patch test.

In addition, directives covering the wearing courses, developped for the different pavement techniques, specify the precautions to be taken in particular with regard to formulation and placing in order to obtain suitable skid resistance levels.

2.3.4. Federal Republic of Germany:

The texts existing since 1966 are basically recommendations to the extend that it is considered to be impossible to constantly guarantee certain minimum values of skid resistance (6, 7).

The recommended values for existing pavements, measured with the Stuttgarter Reibungsmesser (braking force coefficient, locked wheel, patterned tyre) are the following:

Speed km/h	(mph)	BFC minimum
40	(25)	0.42
60	(37)	0.33
80	(50)	0.26

Since 1972, in order to quickly determine the initial friction level on newly laid pavements, increasingly greater use has been made of the British portable apparatus (SRT pendulum) in combination with a surface outflow meter. This instrument gives an indication on compliance with existing minimum macro-texture. This indication is combined with values found by means of the pendulum tester (which are related to low-speed conditions) for assessing higher speed skid resistance. In case of doubt, use can be made of the locked wheel braking force coefficient method.

2.3.5. Great Britain:

The texts on skid resistance constitute recommendations. Measurements are carried out with the S.C.R.I.M. vehicle which allows a continuous measurement, over long road stretches, of the sideway force coefficient. The test wheel is inclined 20 degrees and has a smooth tyre of 3.00 x 20 inflated to a pressure of 3.5 bars (3.5 10^5 Pa; 50 lb/sq.in). As the data recorded by the S.C.R.I.M. are processed by computer, a considerable length of road can be measured and analysed in a short time (8).

Table 3. Required polished stone value for sufficient skid resistance on a bituminous pavement as a function of traffic and the required aggregate abrasion value.

Sideway force coefficient at 50 km/h required in summer		Required polished stone value					
		Lorry traffic per lane and per day					
		250	1000	1750	2500	3250	4000
0,30				40	45	50	55
0,35			40	45	50	55	60
0,40		40	45	50	55	60	65
0,45		45	50	55	60	65	70
0,50		50	55	60	65	70	75
0,55		55	60	65	70	75	
0,60		60	65	70	75		
0,65		65	70	75			
0,70		70	75				
0,75		75					
aggregate abrasion value	chipped surfacings	< 14	< 12	< 12	< 10	< 10	< 10
	macadams	< 16	< 16	< 14	< 14	< 12	< 12

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

The TRRL has proposed the classification of sites into four categories ranging from the lowest, with little traffic and limited skidding risk, to the highest which includes the approach of intersections and pedestrian passageways in urban areas. For each category, a range of sideway force coefficient values is proposed, from 0.30 to 0.45 for the lowest and from 0.55 to 0.75 for the highest.

There is also a recommendation setting a minimum level of texture depth: 1.0 mm (0.039 in) for bituminous pavements and 0.5 mm (0.020 in) for cement concrete when transversely grooved. Under such macro-texture conditions, the drop in skid resistance between 50 (31 mph) and 130 (80 mph) km/h is 20% in both cases.

In order to comply with these standards, a specification covering the materials allows the highway engineer to choose the aggregate having the polishing resistance suitable for ensuring the desired skid resistance under given traffic conditions (see table 3) (9).

2.3.6. Netherlands:

Two standards, each setting a minimum skid resistance value, are in force.

1. The first is required by highway authorities in order to establish their maintenance criteria. This standard constitutes a recommendation and not an obligation.
2. The second is legally laid down by highway authorities and is aimed at contracting firms which may be penalized for noncompliance with the considered minimum value at the end of the work.

These values are based upon the braking force coefficient method, with 86 percent slipping and a patterned radial tyre. The thickness of the water film is 0.5 mm (0.019 in) and the standard test speed is 50 km/h (31 mph) (speeds of 70 (43 mph) and 90 km/h (56 mph) are also used for special requirements).

For existing roads measures are generally recommended when the skid resistance value is lower than 0.51, immediate measures are to be taken when this value is under 0.46.

For new pavements,a skid resistance value of 0.56 is the minimum value mentioned in the contract. This value should be measured within four weeks after construction.

2.3.7. Japan:

There are no compulsory standards, but two distinct drafts are being studied and are to be used as guides within the framework of new work and maintenance. These are:

1. Recommendations by the Public Works Research Institute of the Ministry of Construction: "Antiskid requirements". They establish minimum friction coefficient values measured with the Japanese heavy test vehicle (of the braking force coefficient test type) at 60 km/h (37 mph). These minimum values are 0.40 for normal roads and 0.45 for difficult sites such as poorly designed curves and intersections.
2. The "Antiskid requirements" of the Japanese Highway Department require that a recently-built road should have a coefficient higher than 0.60 (measured with the Skid Resistance Tester). In the case of values lower than 0.55 confirmed by repeated measurements, the considered section is tested with the heavy test vehicle by the Japanese Highway Department. If the braking force coefficient at 80 km/h (50 mph) is found to be higher than 0.35 no other action is undertaken. If it is lower than 0.28, the road may not be opened to traffic before adequate measures have been carried out for improving the skid resistance. Where values are between 0.28 and 0.35, the road may be opened to traffic but repairs must be considered in case of accidents.

2.3.8. Poland:

Values are recommended for skid resistance evaluated by the locked-wheel braking force coefficient measured with a Cobirtd trailer using a patterned tyre with a load of 400 kg (880 lb) at a speed of 60 km/h (37 mph). A coefficient higher than or equal to 0.35 is considered to be satisfactory in most cases, but those lower than 0.20 indicate a slippery road which requires treatment.

2.3.9. Spain:

There are compulsory national standards but these have been defined only in terms of the polishing characteristics of aggregates used for wearing courses. For bituminous pavements, the minimum values required for the polished stone test, measured with the NLT 174/72 (procedure which is very similar to BS 812.1967), is from 40 to 45 depending on the traffic volume and can be from 50 to 55 in certain special cases.

2.3.10. Switzerland:

Skid resistance is specified in the national standard SNV 640511 which places the sites in three categories and assigns minimum skid resistance values to each one on the basis to the SRT (British portable apparatus). The details of the standard are given in table 4: for roads on which speeds are lower than 80 km/h (50 mph), the value aimed at is 55; the minimum value upon the acceptance testing of the work is 50 and the tolerated minimum value in service is 45.

Lower values indicate the need for treatment. On roads where traffic speeds are higher than or equal to 80 km/h (50 mph) the corresponding values are given as well as for difficult sites such as turns with a radius of 150 m (492 feet), slopes greater than 8 percent, intersections, bridges and tunnel exits. The national standard SNV 640510 defines the manner in which the portable apparatus is to be used, in particular for checking compliance with specifications (standard SNV 640511) during the acceptance testing of the work.

Table 4. Relation between pendulum readings and type of road

type of road	aimed value	min.value in acceptance test	min.value for roads in service
speeds under 80 km/h (50 mph)	55	50	45
speeds over 80 km/h (50 mph)	60	55	50
difficult sites	65	60	55

Table 5. Types of specifications in some countries

Country	Formal specifications of recommandations	polished stone value (1)	macro tecture (2)	BFC	SFC	SRT or similar	minimum skid resistance guaranteed by contractor
Belgium	yes	S	S		S		yes
Czechoslovakia	yes			C			
France	yes	C	C				
Federal Republic of Germany	yes			C		C	
Great Britain	yes	S	S		C		
Netherlands	yes	S	C	S			yes
Japan	yes			C		C	
Spain	yes	S					
Switzerland	yes					S	yes

S = Contractual specification   C = Recommended or aimed level

(1) B.S. 812 or similar   (2) B.S. sand patch test or similar

2.4. CONCLUSION

There has been growing awareness of the need for standards covering skid resistance, testified to by the fact that the corresponding requirements are making up an increasingly greater part of the standards concerning new work and maintenance on existing roads.

These standards take on different forms. It is noted that great importance is attached to specifications dealing with materials, in particular with respect to the polished stone value used for wearing courses, as well as to minimum macrotexture requirements and, finally, to the direct measurement of friction.

A significant development is the clearer definition of the responsibility of the contractor to ensure given skid resistance levels. In three countries (Belgium, Netherlands and Switzerland), this is already defined in very precise terms. This aspect of standards governing skid resistance should become the decisive factor of their future development.

Table 5 allows a comparison of main types in effect in different countries.

Section III: SYSTEMATIC MEASUREMENTS OF PAVEMENT SKID RESISTANCE

3.1. Introduction

3.1.1. The skid resistance of pavements must be measured for the following reasons:

a. Predicting the safety on wet pavements
b. Choice of priorities for maintenance of road systems
c. Management of road systems and budgetary programming
d. Gathering information on pavement skid properties for the preparation of standards.

Assuming that it is possible to set thresholds concerning pavement skid resistance, it is possible to compare these objectives with existing values and to deduce recommendations for the future maintenance of roads.

3.1.2. Skid resistance measurement methods can be classified in many ways. In particular, it is possible to distinguish:

. the manual methods (SRT pendulum, macrotexture measurement by sand patch test, surface outflow-meter, etc.)

. methods involving the use of a vehicle and most often making it possible to measure the braking force coefficient or the sideway force coefficient.

The practical capacity can be significantly different depending in particular on utilization constraints (self-contained spray systems, insertion in traffic, recording and analysis of measurement data). In this respect, the following can be distinguished:

- Methods oriented towards research. These are, for example, the equipment of the braking force coefficient type (Remorque LPC and Stuttgarterreibungsmessgerät), of the braking force or sideway force coefficient type (the Stradographe of the CEBTP). These units offer excellent analysis possibilities and often allow further interpretation of assumptions by local studies in the field.

- Methods oriented towards systematic measurements. They are based upon the principle of a continuous measurement (wide-angle braking force coefficient, braking force coefficient with retarded wheels) in which the loss of flexibility is permissible for the benefit of efficiency (f.i. SCRIM).

3.2. Main characteristics of equipment in service

3.2.1. The distinction between high-efficiency equipment and research equipment is not very clear. The main specifications of these equipments are shown in table 6 indicating nevertheless the main utilization tendencies for the different types. In fact, the two types of equipment are complementary and are moreover highly utilized.

3.2.2. Characteristics required of high-efficiency equipment. When a significant relationship has been found between the number or rate of accidents on wet pavement and the skid resistance measured by a given apparatus, this apparatus may be used if it meets the following requirements:

a. It must be reliable, easy to calibrate and as simple as possible.
b. Results of tests must be reproducible and it should be possible to repeat the tests.
c. It should have a high measurement rate and must be economical.
d. Automatic recording or a digitizing system represents an advantage.
e. The equipment must be completely self-contained, with its own water reserve and spraying system, and must be able to carry out tests in traffic without any particular signalling precautions.
f. Its testing speed must make it compatible with traffic (i.e. 50 to 100 km/h (31 to 62 mph) on highway and 30 km/h (18 mph) in town).

All test sites must be determined and clearly identified by lateral marks easily seen from a moving vehicle. These measurements points must be identified by the number of the road, the tested lane and the length.

3.2.3. Specifications on tyres for skid resistance measurements. The P.I.A.R.C. Technical Committee on Slipperiness and Evenness has recommended three types of tyres since November 1974:

- In conjunction with the use of the SCRIM apparatus, a smooth diagonal tyre of dimensions 3" x 20", with a tread in natural rubber.
- For other measuring apparatusses (when mechanically possible) a radial tyre with dimensions 165 R x 15, smooth or grooved. The tread consists of a synthetic rubber, in composition and specifications identical with the ASTM E17 tyre. The external dimensions of the tyre are in the neighbourhood of 165 mm width (6,5 in) and 640 mm diameter (25 in). The machining of a special rim enables this tyre to be fitted to most equipment in service in Europe.
- For some apparatusses, the ASTM E17 tyre, dimensions G.78 x 15 (width 212 mm, external diameter 703 mm), treaded. The nominal load is 492 kg (1000 lb).

At the initiative of the P.I.A.R.C. Committee the P.I.A.R.C. type of tyre has been made commercially available, a series of 800 P.I.A.R.C. tyres were manufactured in 1975, which would be the need for about 4 or 5 years.

3.3. Use of equipment

Depending on the performance of the measurement equipment used, it is possible to choose one of following methods for the organization of systematic measurements:

3.3.1. Continuous nondestructive testing on all roads in order to obtain an average friction coefficient each 10 m or 100 m, over road section 10 to 20 kilometers long, in the most unfavourable wheel trace.

This is possible with the SCRIM (Sideway Force Coefficient Routine Investigation Machine) developed in Great Britain by the TRRL (Transport and Road Research Laboratory). (4).

3.3.2. Nondestructive testing of samples of the network determined at random. The measurement section must be representative for the type of pavement. This procedure assumes good knowledge of the composition of the wearing course and of the traffic on the network. It is this method which is used for mixture in Holland where skid resistance was measured on 3,300 sections of 100 m (320 ft) each which are representative of the 4,800 km (3,000 miles) of twolane roads in the national highway system. The choice of the test sections is associated with a visual inspection so that it is possible to also carry out measurements on doubtful sections.

3.3.3. Selection of accident-prone locations and doubtful sections on the basis of an accident study. This can be achieved by analysing the ratio:

$$\frac{\text{Number of wet-pavement accidents}}{\text{Total number of accidents on wet and dry pavements}}$$

By comparing this ratio for each road section with the overall average for all roads during the same period, and provided comparable weather and traffic conditions are considered, it is possible to pick out the doubtful pavements from the viewpoint of skid resistance (5). This method is used in many regions of Germany (6, 7).

3.4. Conclusions

The systematic measurement of skid resistance can be carried out at a moderate cost, in particular with high-efficiency equipment. It is of great interest for the highway engineer as it allows him to programme his maintenance work in order to obtain a predetermined skid resistance value on the network. Measurements can also be used for accident prevention after a relationship has been established between skid numbers and accidents.

Section IV: SKID RESISTANT PAVEMENTS

4.1. Introduction:

4.1.1. Surface texture of pavements. The skid prevention properties of the surface depend on its surface texture.

a. The coefficient of friction at low speed depends mainly on the angularity of the surface asperities (microtexture).
b. The decrease in the coefficient of friction with increase in speed depends on the dimensions of these asperities (macrotexture) and, more generally, on the extend to which the surface allows the water trapped under the tyre to escape. The less it does so, the more rapidly the coefficient of friction decreases.

Whatever the speed, satisfactory grip can therefore be obtained only on a surface possessing angular asperities. Figure 1 shows the four main types and the terms employed to describe texture (2).
The macrotexture is generally measured by the sand patch test (14).

Table 6. Main characteristics of skid measuring equipment

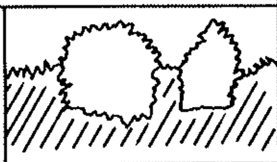
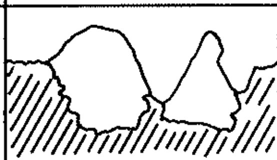
N	Name of the apparatus	SCRIM (GB)	Skiddometer B.V. 8 (S)	RWL Trailer (NL)	Stuttgarter Reibungs-messer (D)	Odoliographe (B)	Single-wheel trailer (USSR)	Remorque L.P.C. (F)	CEBTP-Strado-graphe (F)
1	Measurement method angle slip	SFC 20°	BFC, locked or 13% slip	BFC 86% slip	BFC locked	SFC 20°	BFC locked	SFC locked	BFC or SFC, any slip till locked any angle till 15°
2	Number and position of test wheel	1 - on side of lorry	1 - in axis of trailer	1 - in axis of trailer	1 axis at rear of vehicle	1 right side of car	1 in axis of vehicle	1 single wheel trailer	2 on each side of car
3	Nominal load per wheel	2000 N (440 lb)	4930 N (1090 lb)	2000 N (440 lb)	3500 N (770 lb)	2500 N (550 lb)	4000 N (880 lb)	2500 (550 lb) (1750 to 3000) (358 to 660)	2500 N (700 to 4000) 550 lb (154 to 880)
4	Tyre - size carcass Tread	300 x 20 diagonal smooth	7.5 x 14 diagonal-ribbed	5.60 x 13 diagonal-patterned (PIARC tyre)	6.40 x 13 diagonal-patterned or PIARC tyre	5.60 x 14 radial - smooth	6,70 x 15 diagonal - patterned	165 mm x 15 radial smooth or ribbed	165 mm x 15 radial smooth or ribbed (PIARC tyre)
5	Test wheel suspension	spiral spring shock absorber	spiral spring	oil-pneu-matic	no suspension, shock absorber	spiral spring schock absorber	spiral spring schock absor-ber	oil-pneu-matic	citroen hydraulic suspension
6	Load of un-sprung masses	580 N (123 lb)		900 N (200 lb)		600 N (130 lb)			600 N
7	Watering system	gravity-3000 l tank on lorry	pressure - tank in vehicle	speed pro-portioned pump, tank in vehicle	gravity plus speed proportioned pump	separate vehicle	Pressured tank by com-pressed CO_2	pressure-tank in vehicle	tank and auxiliar pressured tank in vehicle
8	Water film thickness	0.5 to 1 mm (0.02 to 0.04 in)	0.5 mm (0.02 in)	0.5 mm (0.02 in)	1 mm (0.04 in)	1 mm (0.04 in)	0,5 mm (0.02 in)	1 mm (0.5 to 4) (0.04 in(0.02/015)	1 mm (0.5 to 2) (0.04 in (0.02/ 0.08)

to be continued on the next page

Table 6. Main characteristics of skid measuring equipment (cont.)

N.	Name of the apparatus	SCRIM (GB)	Skiddometer B.V. 8 (S)	RWL Trailer (NL)	Stuttgarter Reibungs- messer (D)	Odiolographe (B)	Single-wheel trailer (USSR)	Remorque L.P.C. (F)	CEBTP-Strado- graphe (F)
9	Standard test speed	40 to 80 km/h (25 to 50 mph)	60 to 120 km/h (37 to 75 mph)	50 to 90 km/h (31 to 54 mph)	40-60-80-100 km/h (25-37-50-62 mph)	50 to 80 km/h (31 to 50 mph)	40 to 60 km/h (25 to 37 mph)	50 to 140 km/h (31 to 87 mph)	40 to 170 km/h (25 to 106 mph)
10	Sensor	hydraulic	strain gauge	strain gauge	dynamometer	hydraulic	strain gauge	dynamo- meter	mutual indica- tion
11	Records	digital printer or punched tape	digital printer	potentio- metric re- corder and digital printer	mechanical recorder	mechanical recorder	electronical recorder	U.V. re- corder or digital printer	U.V. recorder
12	Number of machines in service	12	10	3	5	4	1	4	model "65"...2 model "70"...1
13	Main uti- lizing countries	GB - Aus.- ZA.	S - CH - E - J - D	NL	D - A	B	USSR - PL - CZ	F - NL	F - B
	References	(2)-(8)- (9)	(2) - (12)	(2) - (12)	(2) - (13)	(2) - (12)	(2)	(2) - (11)	(2) - (10) - (12)

Figure 1: Terms used to describe the texture of a road surface

SURFACE		Scale of texture	
		Macro (large)	Micro (fine)
A		rough	harsh
B		rough	polished
C		smooth	harsh
D		smooth	polished

4.1.2. Aggregates. Various tests of mechanical strength (resistance to crushing strength and wear; resistance to fragmentation; static or dynamic compression tests; abrasion tests) are used in different countries. The correlation between the result of the test in the laboratory and the behaviour of aggregates on the road is not always clearly specified.

a. Mineralogical properties. Liability to polishing is generally determined by the British Standard 812 test performed on a clearly specified particle size (8/10 mm or 0.314-0.393 in) (15); this poses a problem for the reception of natural aggregates. In several countries notably Great Britain, France, Belgium and Germany special studies have been conducted. In particular, with a view to obtaining very hard aggregates which withstand abrasion and above all have a high polished stone value, an attempt has been made in Great Britain and France to use synthetic materials. Some of these materials are already on the market (calcined bauxite, corundum, etc.).

b. Angularities. The aggregates must have sharp edges. In order to eliminate rounded surfaces, they must be crushed in as angular a form as possible. The ideal solution would be to spread them in such a way that the edges come into contact with the tyre. But during spreading and subsequent compaction, the flat surfaces tend to become apparent, and this reduces the effect of the angularity obtained by crushing.

c. Particle size. Generally speaking, a large particle size favours the achievment of a satisfactory macrotexture.

4.1.3. Review of the functions of a pavement surface. Problems of slipperiness are involved in the choice of the type of pavement surface. But this problem of choice cannot be reduced to seeking a single characteristic, whatever it may be; it can only be the result of a compromise between different requirements, some of which are moreover contradictory:

- Evenness in order to provide acceptable riding comfort.
- Adequate grip in the light of traffic conditions (number of commercial vehicles, speed, geometrical conditions, etc.)
- Imperviousness (except in special cases).
- Mechanical strength (resistance to cracking, rutting, and wear; distribution of load).
- Resistance to studded tyres.
- Visibility or optical contrast (in liaison with markings).
- Evacuation of surface water.
- Satisfactory time of life.

The influences of the surface characteristics (microtexture and macrotexture) mean that the following conditions must be met to wearing courses:

- Avoid rounded aggregates and use crushed aggregates (possessing sufficient resistance to wear and polishing; suitable edges and harshness of surfaces).
- Ensure that the wearing course has an adequate roughness. This implies that:

a. The composition of the wearing course, the dimensions of the chips and the methods of laying must be such that the aggregates form sufficiently sharp projections.

b. The composition of the wearing course must be such that the asperities do not disappear as a result of the embedment of the aggregates into the wearing course.

c. The aggregate must be strong enough to withstand early fragmentation or wear from traffic. For a given aggregate, liability to fragmentation depends on the type of wearing course. It is less if the surface ensures laterally gripped aggregates.

4.2. Bituminous surfaces

The achievement of bituminous mixes of high quality implies that rapid non-destructive controls relating mainly to the temperatures of rolling and laying and to compactness during and after rolling be carried out regularly (16, 17).

The principal types of bituminous surfaces are described in 4.2.1. and 4.2.5.

4.2.1. Bituminous concrete without chippings. In these surfaces without chippings (by contrast with those described in 4.2.2.) aggregates intended to appreciably increase the macrotexture are not encrusted before compaction. This means that in the composition of the bituminous concrete without chippings there must be a sufficient percentage of fine aggregates (elements above 2 mm (00.78 in)); in general, more than 50% to 55%. The correlative result is an improvement in resistance to rutting if the formulation is properly chosen. The surface texture of these pavements is only moderately high and the skid resistance at high speed is generally no more than average, though adaquate in many cases.

There are three distinct categories of bituminous concretes without chippings:

a. Bituminous concrete (less than 5% of voids). These pavements generally possess excellent mechanical properties. They are impervious. These true bituminous concretes are used notably in Belgium, Great Britain, Holland (18), the Federal Republic of Germany, Switzerland and elsewhere. It is important to take care to choose a rational composition, (including the partial use of crushed stone sand, a 40/60 bitumen, and a good quality filler) and to conform to certain conditions of production, laying, and notably temperature of rolling (19). An example of the specifications of bituminous concrete commonly employed in Belgium for many years now is given below (20, 21).

Particle size composition (percentage by weight of the mixture of aggregate plus filler)	- Stones (round hole sieves) - 16/22 mm (0.629/0.866 in).... 5 ± 5 - 8/16 mm (0.314/0.629 in).... 30 ± 5 - 2/8 mm (0.078/0.314 in).... 20 ± 5 - sand ...36 ± 3.5 - filler.. 9 ± 1.5
nature of binder	- bitumen 50/60 tar with EVT/52-57
percentage of binder to be incorporated in the combined weight of aggregate plus filler	- justificatory note based on CRR method (21) - at least: bitumen ⩾ 6% tar ⩾ 7%

The skid resistance of these bituminous concretes is partly influenced by the polished stone value of the rock, but it is mainly influenced by the texture of the mortar and by the binder. A bitumen of high viscosity favours the achievement of a higher skid resistance. Furthermore certain physical-chemical properties of the asphalt (asphaltened content, for example) have been correlated with the skid resistance.

In some countries (Holland, and to a certain extend in Belgium and the Federal Republic of Germany) small stones are spread before compaction (for instance, in Holland 2 kg/m^2 (0.409 lb/sq.ft) of aggregates). This treatment has only a temporary effect: its purpose is to give the surface a sufucient coefficient of friction at the beginning and to counteract the possible undesirable presence of a film of binder on the surface of the wearing course. But this surface treatment does not make it possible to obtain a surface texture of type "A" (figure 1).

b. Semi-granular mixes. The percentage of voids in these mixes is between 5% and 10%; they are not completely impervious. They contain a higher percentage of elements larger than 2 mm (0.078 in) than the type described in the previous paragraph.

These types of surfaces are used in France and Holland. Their roughness is higher than that of bituminous concrete, and their coefficient of friction is generally more sensitive to speed than in the case of bituminous concrete. Semi-granular mixes 0/14 (0/0.551 in) give a macrotexture slightly superior to that of mixes 0/10 (0/0.397 in). But these mixes have a slightly less satisfactory resistance to fatigue than the concretes previously described in (a) above. Semi-granular mixes must be laid on a foundation which is not easily deformable. Table 7 gives the compositions used in France.

c. Gap graded concretes. In this category may be placed asphaltic concretes used experimentally in various countries. They need to be laid by skilled workers (22).

In the Federal Republic of Germany a special material has been developed and successfully used on urban roads and motorways, thanks to its satisfactory properties of resistance to wear and resistance to creep. It is called "Splitt Mastix Belage" and was developed with a view to reducing the destructive effect of studded tyres and to achieving and maintaining a coarse macrotexture (24). The principal characteristics of Splitt Mastix Belage are as follows:

- A high proportion (70 to 80% by weight) of aggregates of top quality and a gap graded (for a 0-8 (0-0.314 in) mixture for example, fraction 2-5 (0.078-0.314 in) 9s very scarce.
- High filler and mortar content.
- The use of very stable fillers.
- The use of a binder with a penetration of 80 or even better 65.
- Additives to increase the rigidity of the mortar, asbestos for example.
- Voids ratio 2% to 3%.

To combat the initial slipperiness with a high mortar content, finely crushed chips may be spread over the still hot surface of the bituminous mix prior to final compaction by heavy rolling (particle size 1/3 mm (0.039/0.118 in) for "Splitt Mastix Belage").

4.2.2. Bituminous concrete with pre-coated chippings. To improve the roughness while preserving the specific characteristics of the bituminous concrete (mechanical strength, imperviousness) some countries have developed on a large

Table 7. Example of a semi-granular mix in France

	particle dimensions in mm	particles larger than 6 mm	particles larger than 2 mm	filler content 80	binder content	nature and hardness of binder	voids ratio in situ(*)
Semi granular mixes	0/10 0/14	25 to 45% 40 to 50%	55 to 70% 60 to 75%	5 to 9%	5.5%	bitumen 40/50 60/70 80/100 depending on climate	5 to10%

(*) 5% to 6% in Northern France 8% to 9% in the South.

scale the roughening system which consists of spreading crushed pre-coated chippings on the bituminous concrete while it is still hot, and driving them in by compaction. Some countries, such as Belgium (25, 26) and Great Britain (27) have been using this form of surfacing commonly and on a very large scale for several years. In other countries, limited use is made of it (in Holland it is in the pilot stage, while it is in current use in the French Jura and in Northern France, as well as in Sweden). "Topeka" and sprinkled hot rolled asphalt are the initial formula of these bituminous concretes with chippings (3).

Bituminous concrete contains 35% to 45% (or in exceptional cases 25% to 53%) of elements larger than 2 mm (0.078 in). Its void ratio is less than 5%. The binder is a hard bitumen with a penetration of 40 to 60. An example of the specifications of bituminous concrete with chippings widely used in Belgium (20) for many years is given.

Particle size composition	- stones 2/12: 35 (± 5) round hole sieves
% by weight of aggregate + filler mixture	- sands : 53 (± 3.5) filler : 12 (± 1.5)
nature of binder	- bitumen 40/50 tar with EVT/52-57
percentage binder incorporated in the weight of aggregate plus filler	- special notice based on practical tests (in general 8% to 9%)

The sprinkled stones (which must be of excellent quality in respect of resistance to wear, polishing and fragmentation) are pre-coated with hard asphalt in the proportion of about 1% by weight of binder and spread in particle size 12/16 (0.472/0.629 in) in the proportion of 7 kg/m^2 (1.43 lg/sq.ft.) or in a particle size of 8/12 (0.314/0.472 in) 5 kg/m^2 (1.02 lb/sq.ft) by means of a chip spreader. Bituminous concretes with chippings possess not only a very high skid resistance at low speeds if suitable stones are used (crushed, with a high harshness and a high PSV), but also a high and durable skid resistance at high speed.

For this type of surface roughening stones should not be allowed to penetrate the bituminous concrete. This being so, an appropriate formulation of the concrete must be adopted, the aim being either to prevent the chippings from penetrating under the effect of traffic, or to compensate this penetration by wear of the mortar.

Bituminous concretes with chippings thus make it possible - by seperating the functions of mechanical strength and skid resistance - to use in the mass of bituminous concrete polishable stones which do not appear on the surface, harshness and roughness being obtained by the use of hard chippings which do not polish easily. This is therefore an economically advantageous solution for regions where there is a shortage of high-performance aggregates.

The laying of the concrete pavement with chippings calls for qualified personnel and favourable climatic conditions. It must be borne in mind that if the job is not done properly (that is to say if the chippings are not embedded) it will be necessary - as a result of the polishing by heavy traffic of the stones in the concrete mass which appear at the surface - to restore the skid resistance.

4.2.3. Gussasphalts and rolled gusasphalts. These surfaces have been used in Germany for several years. Because of their very special characteristics, based upon the behaviour of the very hot bitumenous mixture as a liquid, they cannot be classified under any of the types of surfaces described in the other paragraphs of 4.2.

a. Conventional gussasphalts. Originally this was a surface which was laid manually and used uniquely in urban streets. Subsequently it was decided to considerably increase the quantity of stones and to mechanize the process.

The material is poured on to the road at a very high temperature (220° to 240° C) and sets itself in place without having to be compacted. Its voids content is practically zero and it is totally impervious to water. The bitumen has an average penetration of 20/30. The percentage of stones in the mass is about 50%, and the percentage of filler 20% to 25%. On to the still hot surface are spread (in the proportion of 3 kg/m^2 or 0.61 lb/sq.ft.) small aggregates (1/3 or 2/5 mm, 0.039/0.011 or 0.078/0.196 in) which are pre-coated and embedded by means of light rolling; sometimes a corrugated texture is created.

This type of surface, laid to a depth of 3.5 to 4 cm (1.37 to 1.57 in) seems to have a good resistance to rutting. Its coefficient of friction at high speeds is fairly close to that of bituminous concrete without chippings (4.2.1., type a.). The surface texture is excellent at the beginning of the life of the gussasphalt, but in hot weather the macrotexture always diminishes, especially under heavy traffic.

b. Rolled gussasphalt. Mention should be made of a variant which is still in the experimental stage, rolled gussasphalt (28). 15 to 20 kg/m^2 3 to 4 lb/sq.ft.) of 5/8 mm (0.196/0.314 in) stones are spread on the layer of gussasphalt while it is still hot. Immediately afterwards the surface is rolled with pneumatic tyred rollers. In this way, the top centimetre of the surface constitutes a zone containing a high density of stones and an excellent macrotexture.

4.2.4. Tarmacadams and bitumacadams: pervious surfaces.

a. These surfaces contain 80% to 90% of crushed stones larger than 2 mm (0.078 in) with 3% to 6% of filler, 4.5% to 6.5% of tar (38° to 43° EVT), or 4% to 4.5% of asphalt (180/220 or even 80/100). After laying, these mixes have a void ratio of 10% to 15% or 15% to 20% depending on the particle size districution, the mineralogical nature and the shape of the aggregates. The particle size distribution curve is of the continuous type. This surface, which is essentially permeable, has a high roughness and if the stones have a high PSV, skid resistance will be high even at high speed. It is evolutive (its permeability diminishes slightly with the passage of time). The stones must have a satisfactory mechanical resistance to attrition. These tarmacadams and bitumacadams have less satisfactory mechanical properties under bending than bituminous concretes. Until a few years ago they were used on a large scale in several countries (Great Britain, Belgium (29) etc.). They must be laid on foundations and soils which are insensitive to water.

Table 8. Example of a pervious bituminous mix composition (30)

aggregate grading percent by weight passing (crushed aggregate	19 mm (0.074 in) size bitumen macadam	10 mm (0.379 in) nominal size bitumen macadam
1-in B.S. sieve	100	-
3/4-in	90 - 100	-
1/2-in	50 - 80	100
3/8-in	-	90 - 100
1/4-in	25 - 35	40 - 55
1/8-in	10 - 20	22 - 28
No. 200	3 - 6	3 - 5
Binder content	4.0 - 4.4	4.4 - 4.8
Thickness of the layer	30 mm (1.18 in)	20 mm (0.78 in)

b. In the light of their high permeability, interest in these surfaces has revived in certain countries just recently (Great Britain, Netherlands) as overlay wearing course. They have a good capacity for draining surface water, and they considerably reduce splash and spray by vehicles. These surfaces are particularly worthwhile on sections where geometrical conditions are such as to cause a very thick film of water (junction zones, transition zones, airport runways, etc.). Their use implies the existence of a drain outlet downstream of the cross section. Though their durability (resistance to rutting, the effect of salt, the effect of petroleum products) is questioned by some research workers, it is considered satisfactory by others. The length of life is estimated at 4 to 8 years.

Experimental sections have been built in Great Britain and in the Netherlands. In Great Britain experimental roads were built as long ago as 1967 (30). Table 8 gives the composition of the mixes employed. The voids ratio, which was 20% to 29% at the time of laying, fell to 14% to 20% after a few months of heavy traffic and then remained constant.

4.2.5. Surface dressings. This type of surface (2, 31) comprises a film of binder on which are spread one or two layers of aggregates (a single-layer dressing with single or double chip spreading). The single layer may undergo a second spreading of binder immediately, followed by a second chip spreading, giving a two-layer dressing.

Since the volume of binder spread is low in relation to that of the aggregates, the surface is very granular when new. There are wide channels through which water can run off. Insofar as the aggregate has sharp edges and harsh surfaces, such a surface is extremely skid resistant.These properties can be preserved for a long time only if the aggregates are not loosened by traffic ("plucking"); neither must they penetrate too deeply into the pavement ("tacking"). The aggregates must also be as resistant as possible to fragmentation and polishing.

Adhesion between the aggragates and the binder depends on the mineralogical nature of the aggregates and their cleanliness. Adhesion may be markedly improved by coating the aggregates and doping the binder.

On a bituminous backing, the phenomenon of tacking, due mainly to the puncturing of the backing by the aggregates under the effect of traffic, may be retarded by appropriately adapting the particle size of the aggregates to the hardness of the surface and the intensity of traffic, the largest particles being used on relatively soft surfaces and/or under substantial traffic. Furthermore, wear and polishing must not cause the edges of the aggregates to be blunted too soon.

These two phenomena impose a relatively frequent renewal of the dressings (about once every five years for traffic of any consequence). Nevertheless surface dressing is an economical technique of maintaining pavements. Surface dressings account for an appreciable share of the total area of pavements, particularly on roads carrying average or light traffic. Whereas in Spain this technique is used only for roads carrying light traffic, it is used in Germany, Belgium, France and Switzerland also on roads carrying average and sometimes substantial traffic. The technique is widely used in Great Britain, even on motorways (bituminous surface).

Research is being conducted in several countries with a view to retarding or even completely avoiding the deterioration of surface dressings (loss of aggregates, impaction of aggregates, bleedings, etc.). This research is being carried out on binders, aggregates, and the equipment employed for laying surface dressings. Where binders are concerned (other than those incorporating resin), the incorporation of conventional polymers of high molecular weight such as vinyl polychloride, a thioelastomer, makes it possible to very appreciably improve the mechanical characteristics (elasticity, cohesion) and hence the adhesion of the aggregates, allowing these surface dressings to be used even on cement concrete (e.g. France uses this technique on motorways carrying heavy traffic; it seems that the fragmentation of the aggregates is the principal factor influencing the length of life of surface dressings successfully laid on a cement concrete surface).

Where aggregates are concerned, great interest is being taken in the development of artificial aggregates, which have the advantage in particular of allowing of the choice of a suitable sharp such that the edges always remain pointing upwards. Results so far obtained reveal, however, that though the mechanical strength of such aggregates is excellent, the polished stone value of some of them may prove no more than average.

With regard to laying, the tendency is to have recourse to more accurate equipment which makes better allowance for the increasingly severe conditions to which surface dressings are subsequently subjected. This equipment includes notably medium or high pressure binder spreaders giving a more uniform binder content, self-propelled chip spreaders, and combination sweepers and aspirators to subsequently eliminate rejects.

4.3. Cement concrete surfaces

Cement concrete surfaces pose no problems of rutting as a result of plastic deformation; but in order to obtain satisfactory skid prevention characteristics, adequate surface treatment is necessary, together with effective protection against desiccation and rainfall while the concrete is still young.

In certain cases there may be difficulties in the restoration of the texture. As in the case of bituminous surfaces, choices must be made between different and even contrary technical imperatives, and the contingencies of durability and economy.

In several countries (Great Britain, Switzerland, etc.) the pavement is built in two layers of different concrete composition. This means that in the bottom two-thirds approximately it is possible to use aggregates of lesser quality (in respect of mechanical strength and resistance to polishing) than that of the aggregates on the surface. The result can be a reduction in the cost of transport of aggregates. Such a procedure facilitates the achievement of a satisfactory evenness of the surface. However, these advantages are offset by a complication in the concrete production plant and the concreting train.

Cement concrete pavements generally contain a wearing course whose upper layer incorporates a fairly high proportion of mortar, and in the absence of special surface treatment this leads to a smooth surface texture, incompatible with satisfactory skid resistance, particularly at high speeds. Finishing the fresh concrete with a burlap drag or by means of light brushing, does not give an adequate roughness; it gives a texture of type C (figure 1). Skid resistance at high speeds is often judged inadequate. After a certain length of time and an appreciable volume of traffic, the texture gradually changes into type D (figure 1). This is why the following surface treatments have been developed over the past few years:

1. Grooving of fresh cement concrete.
2. Sprinkling fresh cement concrete with chippings.
3. Stripping of fresh cement concrete.
4. Grooving of freshly set cement concrete.

4.3.1. Grooving of fresh cement concrete. After the concrete has been vibrated and prior to spreading the curing compound (the latter should moreover disappear after a few weeks under traffic) transverse grooves are made in the concrete, using a groover whose comb consists of a single row of metal or PVC bristles or a groover of the curved fork or roller type; or again a vibrating plate. These instruments make it possible to obtain a harsh microtexture superposed on the rough macrotexture of the grooves (absolute depth 5 to 7 mm, 0.196 to 0.275 in or more; spacing 15 to 30 mm, 0.59 to 1.18 in). This treatment gives a high and durable skid resistance, even under very heavy traffic for many years. This mechanized (and hence low cost) process is used in Belgium (32), Great Britain (33), Germany, Spain and France.

As a protection against vibratory noises which are perceptible (in particular with certain radial ply tyres) on cement concrete pavements grooved at a constant pitch or with a sinusoidal texture, it seems desirable to vary the spacing of the grooves.

Transverse grooving considerably facilitates the rapid evacuation of surface water; furthermore it results in an appreciable reduction in the fine spray thrown up by certain trucks in the accompanying noise. In addition reflection, which is particularly troublesome on wet pavements at night, due to the headlamps of oncoming vehicles, and during sunrise or sunset, is greatly reduced.

The achievement of high and durable skid resistance even at high speeds is however closely linked with conformance to various rules: the absence of polishable materials (e.g. PSV greater than 50), the use of coarse natural sand in good quality concrete with a high cement content, the choice of a suitable grooving implement, deep grooving, and effective protection of the fresh concrete.

4.3.2. Sprinkling fresh cement concrete with chippings. After the concrete has been vibrated and prior to spreading the curing compound, a chip spreader is used to spread, on the fresh cement concrete, crushed, hard, not easily polishable stones which have been washed at the time of loading: 4 km/m^2 (0.82 lb/sq.ft) in the case of 12/16 round hole sieves (0.47/0.62); or 6 kg/m^2 (1.22 lb/sq.ft.) in the case of 16/22 round hole sieves (0.62/0.86). Immediately after the chip spreading the stones are embedded. This process allows of the use of polishable crushed stones in the mass of concrete; the economic repercussions of such a procedure are obvious.

The sprinkling of fresh cement concrete with chippings was developed in Belgium a few years ago, between 1949 and 1955, and in 1969, with excellent results (34, 35). This process gives a high roughness, even after twenty years' traffic (texture of type A). The coefficient of friction at high speeds is high. The process of chip spreading and embedding has been fully mechanized (using a patented machine which can work over widths of 3 to 13.50 metres (10 to 15 feet) and operating on fixed framework) by the Belgian Road Research Centre (35). The concrete must be of consistent quality, and sufficiently plastic. Behind the finisher, and prior to chip spreading, the profile must be corrected with an orthogonal smoothing beam. The chip spreading machine has three functions:

- Even spreading of chips by means of a corrugated roller.
- Embedding of the chips in the fresh cement concrete by tamping, using a vibrating beam inclined at 2% to 3% (with a view to uniform embedding of the roughening chips down to two-thirds of their dimension).
- Projection of a curing compound immediately after embedding.

4.3.3. Stripping of fresh cement concrete.

a. This process, used in Belgium in 1959 on an important experimental road, consists of stripping the fresh cement concrete, (removing the laitance and the mortar by energetic brushing) and consequently laying bare the mosaic of stones as soon as the road is open to traffic (37). Some types of cement (blast furnace type) favour the disappearance of the mortar and the appearance of the mosaic of stones under the effect of traffic. The initial macromixture is satisfactory, but it is essential to use hard stones which do not polish easily, otherwise after several years there will be a polished microtexture and the coefficient of friction will be inadequate even at low speeds.

The process was recently mechanized and experimental sections have been built in Belgium.

b. Another process was employed experimentally in Denmark in 1976. It consists of spreading a solution of sugar on the fresh concrete. After twenty-four hours the surface is brushed to remove the laitance and the mortar. The future will show whether this process is worthwhile.

4.3.4. Grooving of freshly set concrete. Concrete roads which have been subjected to traffic and need to have their skid resistance restored may be subjected to various techniques which are described in Section V of this report. Among these techniques are longitudinal or transverse grooving (15).

We shall deal here only with grooving for hardened cement concretes, performed shortly after and before the road is opened to traffic, or after several months of service.

To the best of our knowledge this technique has been developed only on airport runways, notably in France and Switzerland. It is used transversely. It gives rapid drainage of water over a very wide pavement, and can avoid accidents due to aquaplaning. The grooves are 3 to 5 mm deep (0.118 to 0.196 in), 6 to 10 mm wide (0.236 to 0.393 in), and the interval between grooves is either 30 mm or 100 mm (1.18 or 3.93 in).

4.4. Conclusions

Generally speaking, numerous techniques are available for laying surfaces possessing skid resistance properties. Choices must be made between different and even contradictory technical imperatives.

Economic choices must also be made, notably with regard to the use of local materials. The technique adopted for the construction of a pavement greatly depends on local data, such as the practical experience of highway engineers, the competence of contractors, the climate, traffic, etc. The possibilities of restoring surface characteristics must also be taken into account.

Section V: RESTORATION OF THE SKID RESISTANCE PROPERTIES OF PAVEMENTS

5.1. Introduction

The engineer and contractor must be able to have at their disposal processes for restoring surfaces where the skid resistance is deficient either locally ("black spots") or systematically. With a view to taking stock of the situation, a survey by correspondence was carried out, on the one hand, among the members of three PIARC Technical Committees in nine European countries plus Japan and on the other hand with the collaboration of the "Transportation Research Board" in Washington, among the 50 states of the United States of America and the districts of Columbia and Porto Rico.

5.2. Applications

A study of applications emerges that:

a. applications of processes for restoration of the skid resistance are fairly widespread although some processes are fairly new;
b. these techniques are used, with some exceptions, both on bituminous and cement concrete;
c. these treatments are carried out both on old and new pavements;
d. with the exception of Japan, which uses these treatments only for "black spots", these processes are used both in high-accident areas ("black spots") and over the whole network.

Another aim of the survey was to determine the major causes justifying the need for restoring the skid resistance properties. These can be classed in five categories:

1. Causes indirectly connected with surfacings: serious defects in evenness, wear from studded tyres, increases in traffic;
2. Causes directly connected with surfacings: inadequate or non-existent macrotexture, polished microtexture (polishable surface aggregate);
3. Causes specific to cement concrete surfacings: slipperiness of surface mortar (formation of carbonates);
4. Causes specific to bituminous surfacings: binder bleeding from surface;
5. Other causes: an unusually high rate due, for example to the alignment of the road, may be corrected by a surface treatment giving an exceptionally high skid resistance (39).

5.3. Types of techniques

Not included in this study is the technique of laying a new layer of bituminous concrete when its thickness exceeds about 2 mm (0.8 in). The techniques used to obtain skid resistance surface at the time of construction (grooving or spreading chippings on fresh concrete, spreading chippings on bituminous concrete, etc.) have also been left out of this study. Fourteen categories of techniques for restoration of the skid resistance properties have been listed. They can be classified into two groups:

a. Techniques involving the removal of material

1. bush hammering: percussion scouring using percussion tools;
2. milling: grooving by means of hard steel discs (flials);
3. grooving: cutting grooves by means of diamond edged discs;
4. spreading of hydrochloric acid: causing a chemical reaction in the cement mortar;
5. sanding: scouring under the action of an abrasive jet under pressure;
6. flame scouring: spalling of the surface of a cement concrete by means of high temperature;
7. planing: removal of a film of material from the surface using planing or milling machines.

b. Techniques involving the addition of material

8. re-heating and impacting of chippings into bituminous concrete surfacing ;
9. application of a resinous layer with gritting;
10. bituminous bound surface dressing with gritting (traditional or modified binder);
11. slurry sealing, spreading of a bituminous grout;
12. spreading and rolling of granular materials (possibly pre-heated) on the bituminous concrete surface or tack coat;
13. spreading of white spirit: removal of an excess of bitumen from the surface, followed by spreading and rolling granular materials;

Table 9.: Noise increase (dB (A)) related to grooving

Pavement	Surface	Summer tyre			Winter tyre (without studs)			Noise increase versus type of tyre			Noise increase versus speed ✱	
Speed (km/h)		80	100	120	80	100	120	80	100	120	100/80	130/100
normal (texture depth 0.4 mm)	dry	73	78	80	72	78	82	-1	+1	+2	+5	+2
		80	84	86	78	82	84	-2	-2	-2	+4	+2
noise increase		+7	+6	+6	+6	+3	+2	-1	-3	-4	-1	0
normal grooved	wet	78	80		78	81		~0	~1		+2	
		79	82		79	83		~0	1		+3	
noise increase		+1	+2		+1	+2		~0	~0		+1	
✱ for Summertyre	Noise increase versus pavement condition (wet or dry)											
normal	dry	73	72		72	79		-1	+1		+5	
	wet	80	80		78	81		~0	+1		+2	
noise increase		+5	+2		+6	+2		+1	~0		-3	
grooved	dry	80	84		78	82		-2	-2		+4	
	wet	79	82		79	83		~0	+1		+3	
noise increase		-1	-2		+1	+1		+2	+3		-1	

14. re-surfacing with open-textured bituminous concrete up to a maximum thickness of 2 centimetres (0.8 in).

A complete description of the techniques is given in the Conference-Debate on restoration of the skid resistance properties of pavements (38)

This study describes each process, and analyses its limitations and nuisance during the operation and for the environment, its cost, output and durability.

5.4. Choice of the best suited methods

As far as we know, it seems that depending on the types of surfacings to be treated and according to the result to be obtained, the following techniques can be adopted:

a. Techniques yielding a lasting effect

Bituminous concrete.

When the bulk of the surfacing contains polishable stones, three solutions may be comtemplated whatever the origin of the slipperiness:

- re-heating and impacting chippings,
- surface dressing with a bituminous binder, the binder being improved in case of heavy traffic,
- thin open-textured bituminous surfacing.

When the bulk of the surfacing contains polishing resistant stones, two cases should be considered:

- if the slipperiness is imputable to too fine a macrotexture, the three solutions hereabove are applicable,
- if the slipperiness is imputable to bleeding or to surface dirtying, the same three solutions still apply but two more solutions are valid: bush hammering and milling.

Cement concrete. When the bulk of the surfacing contains polishable stones, there is presently no satisfactory solution, but grooving reduces the thickness of the water film and may thereby help to improve skid resistance. It may be hoped that the recent applications of surface dressings with improved binders turn out to be successfull.

When the bulk of the surfacing contains polishing-resistant stones, two groups of solutions are possible:

- against mortar smoothing, or dirtying: bush hammering, hydrochloric acid spreading or planing,
- against too fine a macrotexture: milling or grooving.

b. Emergency treatments. Certain kinds of treatment, in spite of their poor durability, may be extremely useful because of their low cost and possible application in circumstances where other treatments are not applicable for various reasons (time of year, lack of funds, non-availability of large machines, etc.).:

- light bush hammering and planing, spreading of hydrochloric acid, sanding: during winter, a light scouring of the surface and an attack on the aggregates is carried out while awaiting spring;
- spreading and impaction of chips of granular material: during a period of heat, a temporary remedy can quickly be applied to the serious phenomenon of the bleeding of bituminous surfaces or surface dressings.

c. Alignment of the macrotexture. When the macrotexture is unaligned, as by chipping, only a reduction of the water film thickness may be expected, whence an appreciable gain in skid resistance at high speed. In this case, the noise nuisances seem tolerable.

In the case of aligned macrotexture, if obtained as by grooving, the controversy remains open:

- Transverse grooving entails a lower output at execution, an optimal transverse drainage, a sometimes high noise (especially in case of equally spaced grooves), an appreciable gain of skid resistance at high speed.
- In the case of longitudinal grooving, highest output at execution, no transverse drainage, sometimes water accumulation, no noise, but rail effect affecting motorcycles, limited gain in skid resistance at high speed, but better guidance in the curves.

Let us hope that valid accident statistics will permit to settle the dispute between the fierce tenants of the two opposite solutions.

Section VI: ROLLING NOISE

6.1. Context of the problem

6.1.1. Traffic noise has become gradually more perceptible, to the point where it constitutes a nuisance for people who live alongside roads carrying heavy traffic in urban zones and sometimes in rural zones. The solution to the problem is not simple, because the relative level of rolling noise varies with the type of vehicle and the conditions under which it is being driven (speed, engine revolution, etc.). From this point of view, we make a distinction between two categories of vehicles: "heavy" and "light". For the former, rolling noise is generally negligible under all conditions, especially when climbing gradients. For the latter, rolling noise tends to equal or even exceed other sources of noise, at least at speeds above 60 km/h (37.3 mph), though, driving in urban surroundings, engine noise comes to the fore because of frequent acceleration and deceleration.

However, independently of the very liberal existing regulations concerning engine noise (intake, engine, exhaust), rolling noise is nowadays a matter of concern to highway engineers (41).

6.1.2. The phenomena generating rolling noise are:

- Aerodynamic effects.
- Compression and expansion of cavity air.
- Tyre vibrations.
- Vibration of the vehicle.

The relative importance of these different phenomena has been only very partially established (42, 43); it may be noted however that the last three of them are unquestionably linked with the dimensions of the asperities of the surface.

6.2. Examples of studies carried out

6.2.1. Studies carried out in Switzerland (44). In accordance with the standardized method, studies have been carried out with vehicles with their engines switched off, the microphone being placed at 7.5 metres (24.6 ft).

Figure 2: Coefficient of longitudinal friction: envelope for all surfaces.

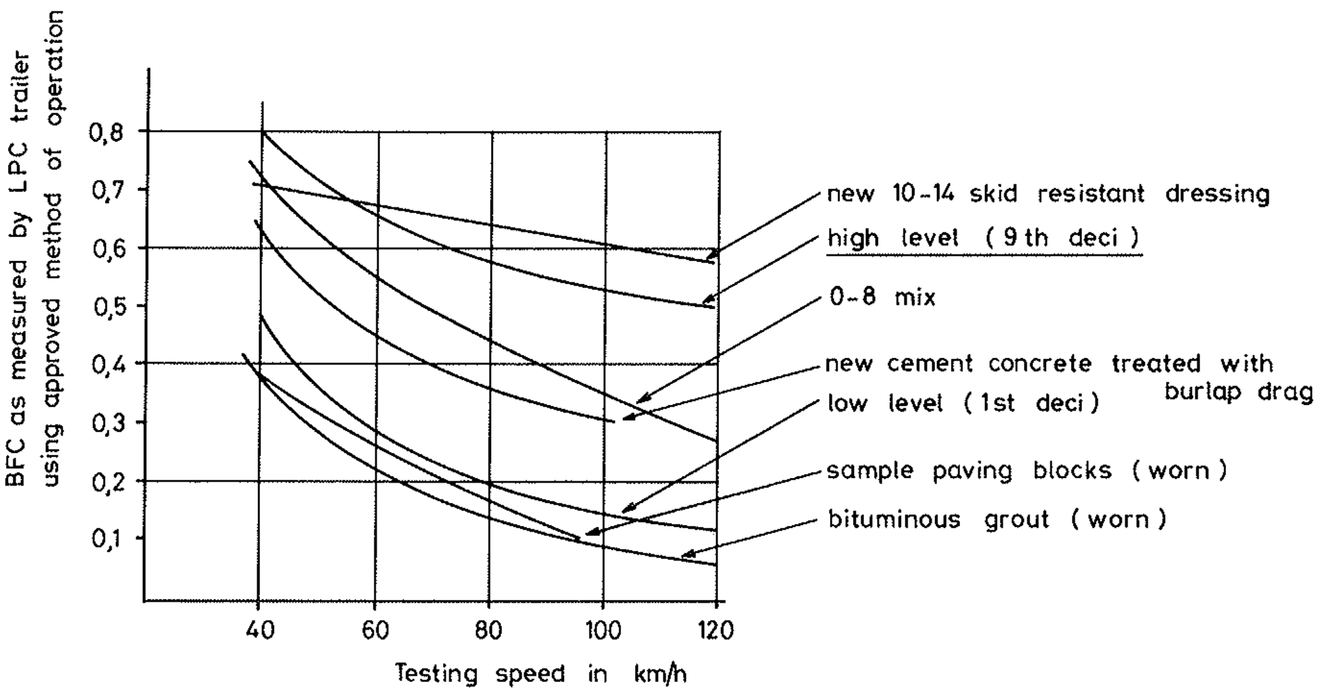


Figure 3.: Relation between noise and roughness

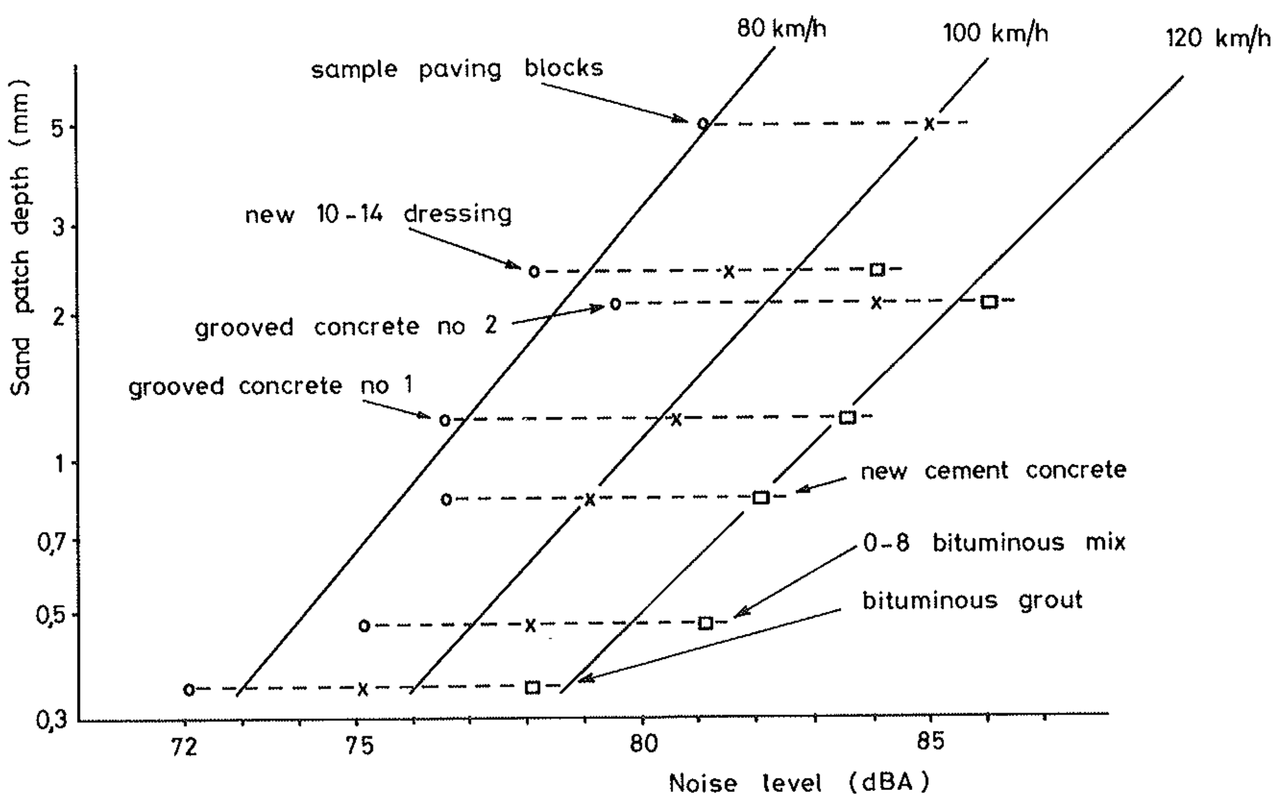
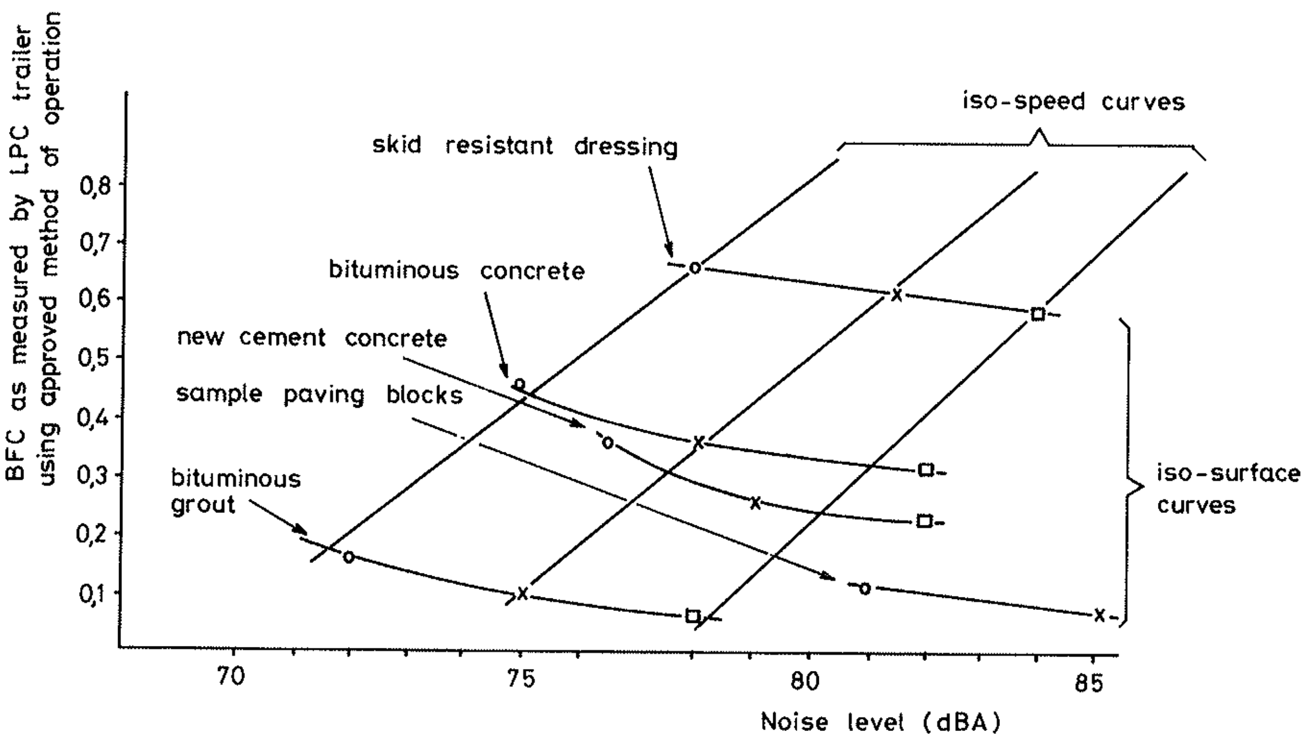


Figure 4.: Test of relation between noise and skid resistance



Note: The texture of the paving blocks is quite different from that of the other types of surface.

Table 10: Noise level (dBA) - outside the vehicle
- engine switched off
- dry surface

Surface	speed 80 km/h	speed 100 km/h	speed 120 km/h
Smooth dressing	72	75	78
Fine mix	75	78	81
ungrooved concrete	76.5	79	82
Skid resistant dressing	78	81,5	84
Paving blocks	81	85	-

Figure 5.: Rolling noise produced by a vehicle on dry surface

Figure 6.: Rolling noise produced by a vehicle on wet surface

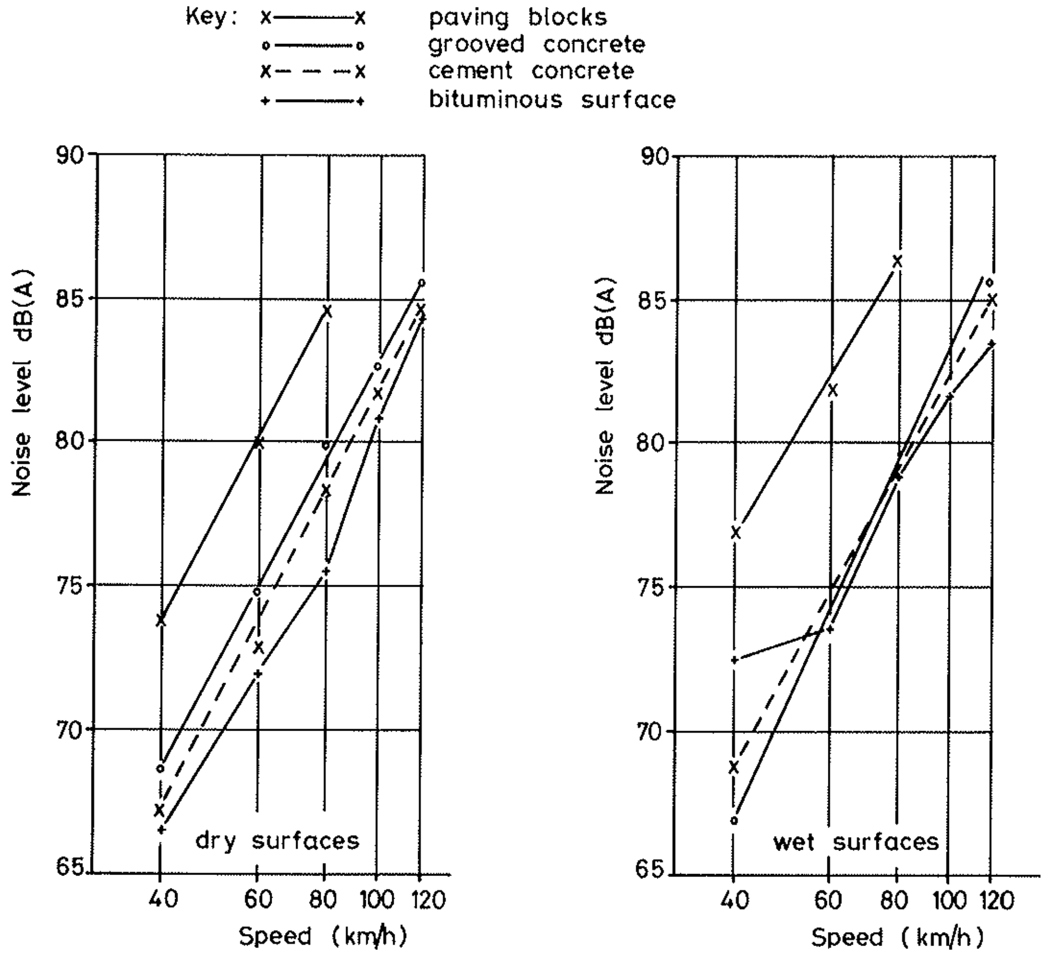
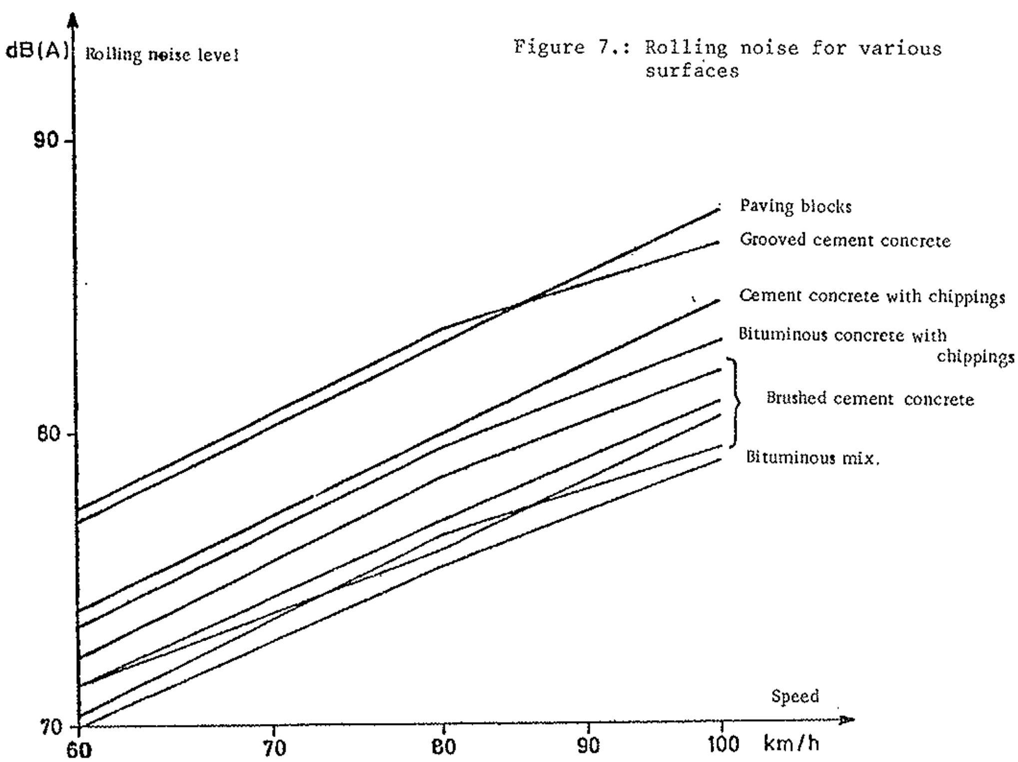


Figure 7.: Rolling noise for various surfaces



Tests were performed on normal cement concrete (texture depth 0.4 mm, 0.015 in) and on grooved cement concrete (texture depth 1.0 mm, 0.039 in), dry and wet, with normal tyres and with unstudded winter tyres.

Results are given in table 9. Analysis of these results shows that:

- The difference between the two types of tyres is less than the accuracy of measurement.
- Wetting of the pavement produces a considerable increase in rolling noise, though this increase is less on a grooved pavement.
- Speed increases rolling noise on dry and grooved pavements; the effect is much less marked on wet pavements.
- Transverse grooving of the pavement very appreciably increases rolling noise; this effect is however less marked on wet pavements.

6.2.2. Studies carried out in France (45). Tests performed under similar conditions (engine switched off, dry pavement, microphone at 15 metres, 49.2 ft) gave analogous results for a wide range of surfaces (table 10). Analysis of the results shows that:

- The noise level increases with speed; the order of classification of the different surfaces is not modified.
- The noise level is generally related to the roughness.
- There is a very marked relationship between the noise level and the skid resistance properties:

  a. for a given surface, noise increases with speed, while skid resistance diminishes;
  b. at a given speed, noise increases with skid resistance.

These relationships are valid for the surfaces studied; we note in particular that bricks are one of the noisiest surfaces, and one of the most slippery. These relationships are shown in figures 2, 3 and 4.

6.3. Summing up

6.3.1. Depending on the nature of the surface, we know that the rolling noise level of a vehicle may, all factors being equal, vary by about 10 dB (A) at most. But results relating to individual vehicles cannot be immediately transposed to traffic in general; the influence of the surface on the overall noise level will depend on the composition of the traffic, the average speed per category, the gradient of the pavement and numerous other factors. Up to the present, no systematic study has been carried out in this field.

Only figures 5 to 7 express the results of measurements made in Belgium (46, 54) with a light vehicle with its engine running, and table 11 gives an example of the influence of the surface on the noise level in the case of a motorway in service.The increase in rolling noise with roughness is still appreciable, but greatly attenuated (averaging 3.5 dB instead of 6 to 10 dB).

6.3.2. The NCHRP Guide (47) and the SETRA (48) recommend, with regard to traffic noise, applying a corrective term of -5 or 0 or +5 db (A), depending on whether the surface is smooth, normal or rough. Since no quantitative criterium is available, the classification of a pavement in one or other of these three catagories is left to the judgement of the user, who might, a priori be tempted to fall back upon the notion of skid resistance. But data concerning the relationship between the noise level and skid resistance are still very imprecise.

Characterizing the surfaces studied in terms of their "profile ratio", Waters (49) obtains no correlation with their noisiness. Looking at the problem from the point of view of tyres, Sakagami (50) has found a relationship between surface noisiness and the profile ratio. Gachignard and Sardin have attempted to use a similar parameter to characterize surfaces, but unsuccessfully (51). These same authors obtain an apparently better correlation on the basis of the sand patch depth (52). However, the pertinence of this parameter remains to be verified in the case of surfaces with a special texture, such as grooved concrete pavements, a feature of which is that the increase in noise level with speed is greater than average, and subjectively, the noise spectrum itself is peculiar to such pavements.

Furthermore, according to Leasure, cited by Favre and Pachiaudi (42), the influence of subjectively assessed roughness may be either positive or negative depending on the type of tyre.

More recently, the initial results of a study carried out by the TRRL (53) suggest that the relationship between texture depth and noise level may differ depending on whether the pavement is cement or bituminous. However, it may be noted that all the cement concrete pavements examined were grooved in one way or another, which makes it possible to attribute the difference in noise level just as much to the binder as to the type of texture.

Some of the results obtained by the CRR in Belgium (54) are such as to support this second interpretation; cement concrete pavements with chippings may, for an equal average sand patch depth, present noise levels markedly lower than grooved concrete pavements, and comparable to those obtained with asphaltic concrete incorporating chippings (figure 7).

6.3.3. In conclusion, it can be said that at the present time a descriptive parameter of texture which is linked with the noise produced remains to be determined, and that in principle the demands of safety and acceptable noise level are not incompatible.

Section VII: CONCLUSIONS

7.1. Minimum values of skid resistance

In many non-American countries, the minimum values of skid resistance are laid down for the road system as a whole. These values have been established on the basis of analyses of accidents or of the properties of materials. In some countries, minimum values are also laid down in contracts for the construction of new roads.

7.2. Construction of pavements possessing a satisfactory skid resistance

In general, we know how to construct a satisfactory skid resistant pavement. The use of rocks resistant to polishing is very important. In addition, an adequate macrotexture must be obtained by means of a proper mix formulation.

7.3. Skid resistance levels

It is desirable to establish national rules relating to skid resistance levels. These levels should be laid down in the light of the volume of traffic, the availability of materials, questions of safety, and economic and legal questions.

7.4. Restoration of skid resistance

When skid resistance is inadequate, a new surface can be laid or one of the numerous treatments described can be applied.

7.5. Informing engineers of the formulation of surfaces

Very appreciable progress has been made as a result of the publication of directives or recommendations, and following the establishment of acceptance conditions for new pavements. Usages in various countries are summed up in the report.

7.6. Systematic treatment of deficiencies in the road system

These deficiencies, which are not necessarily related directly to skid resistance, may however be a contributory cause of accidents on wet pavements. The report does not deal with this aspect, but in certain countries (notably France) studies of this type are in progress, in particular regarding motorways.

7.7. Thickness of the water film and geometry of the pavement

Research is necessary to establish criteria for the acceptable depth of rutting. Studies have been carried out on the relationships between the geometry of the surface, skid resistance, and water film thickness; but little information is available concerning safety and the real thickness of water films.

7.8. Development of surfaces possessing high skid resistance

A considerable effort has been made in certain countries to develop and employ special surfaces, (particularly in the United Kingdom). But existing solutions are costly, their application is tricky, and research is proceeding in this field.

7.9. Relation between skid resistance and rolling noise

At present time a descriptive parameter of texture which is linked with the noise produced remains to be determined.

Table 11. Noise levels (L_x) measured on French motorway in service with different surfaces.

Test	time	L_{99}	L_{95}	L_{90}	L_{50}	L_{10}	L_5	L_1	L_{eq}	T.N.I.	veh./h	% P.L.
					Transversely grooved concrete							
1	11h00	58	61	63	74	83	85	87	79	113	637	14
2	11h06	61	64	76	76	84	85	87	80	108	886	13
3	11h13	62	65	66	75	83	85	88	79	104	713	17
					Bituminous surface							
1	11h26	54	58	59	69	80	82	86	76	111	724	16
2	11h33	57	59	61	71	79	81	84	75	103	767	17
3	11h40	58	60	62	71	80	82	86	76	102	724	16

L_x = in Db (A) T.N.I. = traffic raise index in dB (A) % P.L. = % heavy vehicles

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RESEARCH ON SKID-RESISTANCE AT THE TRANSPORT AND ROAD RESEARCH LABORATORY (1927-1977)

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Research on skid-resistance of roads started in Britain in 1927 at the National Physical Laboratory at Teddington but the work was transferred to the newly formed Road Research Laboratory at Harmondsworth in the early 1930's. It has continued there (now the Transport and Road Research Laboratory, Crowthorne) to the present time and a considerable fund of knowledge now exists on the subject. The paper reviews this work, starting with the development of apparatus to measure skid-resistance reliably. An early machine was an adapted motorcycle and sidecar, the sidecar wheel being mounted at an angle to generate a sideway-force. This was later superseded by in-board systems in front-wheel drive cars and has led to the present-day commercial production of a sideway-force routine investigation machine (SCRIM) which is available for general use and which produces an automated output suitable for computer processing. The paper goes on to discuss the evolution of standards of skidding resistance which are necessary to minimise numbers of skidding accidents and describes work which has enabled materials to be specified to give levels of micro-texture necessary for the nominated low-speed skidding values to be maintained. High-speed skid-resistance and its dependence on macro-texture is then discussed together with side-effect problems (eg noise and spray) connected with the creation of surface texture; the paper concludes with 25 references to major publications in the field. An indication is given of the probable form of a comprehensive specification scheme which may be adopted soon in Britain.

1. Early Research at the National Physical Laboratory

By the middle 1920's the dominance of motor transport was becoming very apparent in Britain with the total numbers of both commercial and private vehicles showing spectacular rates of increase. But with the increased number of vehicles came an increased number of accidents, many of which were directly attributable to lack of adhesion between tyre and road, especially in the wet. It became clear that here was a potentially important field of research because the problem would become more severe as the years went by.

In 1927, Batson started work at the National Physical Laboratory at Teddington, with the aim of understanding the phenomena involved in the process of a vehicle skidding, his first experiments consisting of drawing rubber sliders over the surfaces and measuring the tractive effort required. This work soon indicated that there was a speed effect involved and that an apparatus was needed to carry out tests over a range of road speeds.

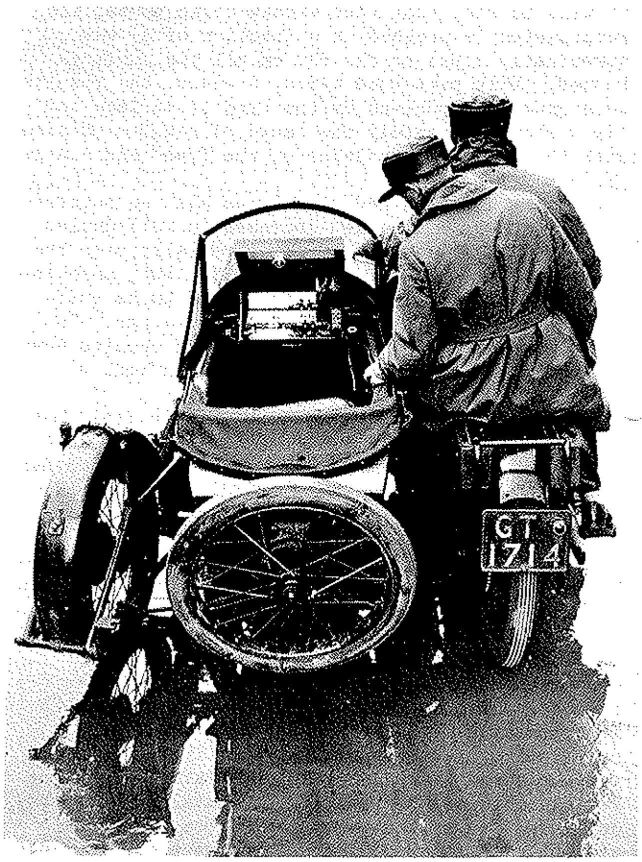
1.1 Skid-resistance Measurements - 1929

The apparatus took the form of a specially designed motor cycle and sidecar with the sidecar wheel mounted at an angle to the direction of travel (Plate 1). The side thrust on this wheel and the vertical reaction between the tyre and the road were measured and transmitted by a link-mechanism to a pen which gave a single track on a moving paper chart. The ordinate of the record was proportional to the ratio of sideway-force to load and was, therefore, proportional to a form of the coefficient of friction which was called Sideway-Force Coefficient (SFC). The tread of the tyre employed had to be of a standard form and it was decided to use smooth tyres for the work to eliminate problems which would arise as a patterned tyre wore during use. The modern apparatus is a development of this early machine but the principles involved are identical and the SFC is the same as that measured in the work of nearly fifty years ago.

1.2 Road Experiment - 1930

An early road experiment on the skidding resistance of a range of bituminous materials (using this method of measurement) was laid in 1930 on the Kingston By-Pass, about 16 km to the south-west of Central London. Eleven materials were laid in sections, eight of which were treated with chippings to provide resistance to skidding. In the remaining three sections the claim was put forward that the porosity of the materials was such as to give adequate wheel-grip. Skidding measurements were

Plate 1. Early motorcycle and sidecar for measurement of SFC.



carried out using the motorcycle and sidecar at speeds up to 50 km/h and the results showed that the eight sections that were treated with chippings showed good resistance to skidding throughout the speed range. The other three materials, however, exhibited a marked falling off in the value of the coefficient at speeds above 25 km/h.

The value of texture and the influence of speed on skidding resistance were thus starting to be recognised by the year 1931, but it was to take many years for these interactions between tyre and stone to be fully quantified and put into contractually implementable form.

2. Development of Test Methods

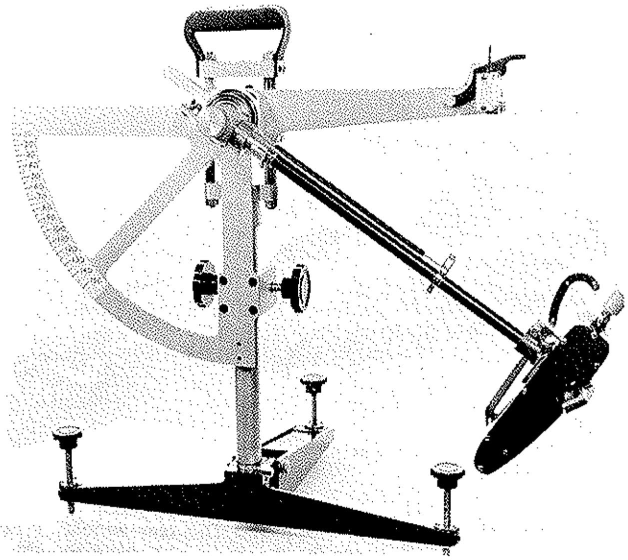
Further changes in the techniques and apparatus of skid-resistance measurements between that period and the 1950's[1,2,3] were more of detail than of fundamental concept but the work of the next few years led to rapid advances in the field.

Three forms of apparatus had come into use in Britain, the portable skid-resistance tester, braking force machines (in the form of either trailer or vehicle decelerometer) and a more advanced version of the sideway-force machine. Each of these still has a role to play although it will be seen that SFC has now been adopted in Britain as the basic measure of skid-resistance.

2.1 Portable Tester

This apparatus, shown in Plate 2, is now well

Plate 2. Portable skid-resistance tester.



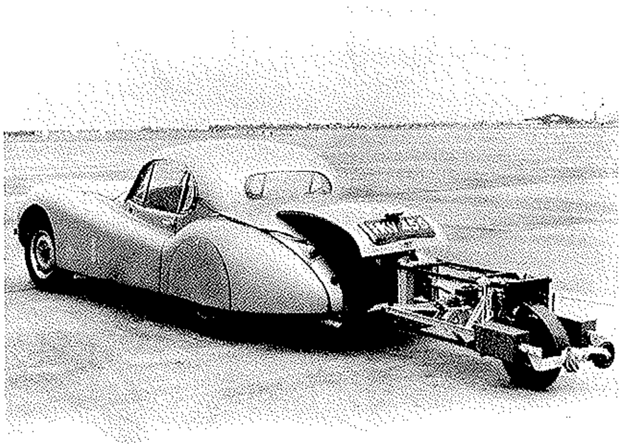
known in many parts of the world. It was designed to provide a simple and rapid method for checking skid-resistance in local areas and entails measuring the frictional resistance between a rubber slider (mounted on the end of a pendulum arm) and the wetted road surface. There is some link here with Batson's early work, but in this case the loss in energy of the pendulum arm, after the slider has traversed the surface, is equated to the work done during the sliding process, and it has thus been possible to calibrate the instrument directly in terms of a form of the coefficient of friction termed the Skid-Resistance Value (SRV). Full details of the apparatus and of its method of operation are given elsewhere[4]; it is sufficient to say here that useful as the apparatus sometimes is to give a quick local guide to skidding resistance, it suffers from two major disadvantages. One is that on coarse textured surfacings (ie with chippings larger than 12 mm) results can be misleading, even in skilled hands, and the other is that it provides only partial and slow coverage if routine monitoring of road networks is planned. Other forms of measurement are clearly needed for this purpose.

2.2 Braking-Force Machines

2.2.1 Braking-Force Trailer. A small trailer apparatus, built by the Laboratory, has been used for some years for studying braking-force coefficients (BFCs) at high speeds on roads and runways (Plate 3). The skidding resistance of the surface is determined by measuring the torque acting on the trailer brake when the wheel is locked for about 2 seconds on a wet surface. This apparatus has been particularly valuable in investigating the skid-resistance of airfield runway surfaces on which tests are carried out at speeds of up to 130 km/h and also in studies of the effect of texture depth on the high-speed skid-resistance of roads (see Chapter 4).

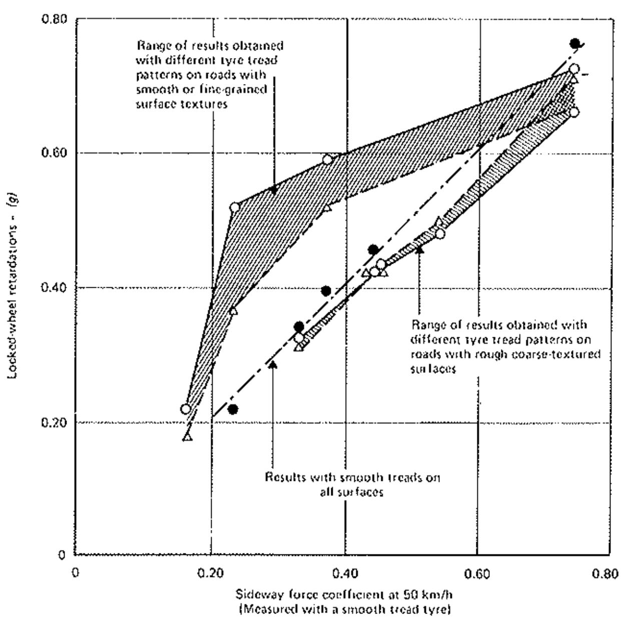
2.2.2 Road Vehicle with Decelerometer. A simple locked-wheel braking method was found to be of particular value in making rapid comparisons of the non-skid properties of tyre tread patterns. A brake-testing meter is used to record the decelera-

Plate 3. Trailer for measurement of BFC.



tion when the brakes are applied for one second from an intial speed of 50 km/h, locking all four wheels and making them skid. The method showed good correlation with the sideway-force method when the vehicle used was equipped with smooth-tread tyres (see Fig.1) but is not easy to standardise if different tyres are used on the different vehicles employed. It cannot, of course, be used for tests on bends or curves and care has to be taken that all four wheels are fully locked.

Figure 1. Vehicle retardations from 50 km/h obtained with a variety of tyre tread patterns and road surface textures under wet conditions.



2.2.3 <u>Effect of Tyre Tread Patterns on Skidding</u>. The decelerometer method was used by the Laboratory in the early 1960s to investigate the effect of tread patterns on tyres by fitting the different sets of tyres to be compared, in turn, to the same vehicle. The deceleration from 50 km/h was obtained both on fine-grained surfacings with SFCs ranging from 0.17 to 0.75 and on coarse-textured surfacings with SFCs from 0.33 to 0.75. The main features of the results obtained are given in Fig.1, from which it will be seen that with smooth-tread tyres, the retardation (expressed as a fraction of g) was numerically equal to the SFC on all the surfaces tested. With patterned tyres, however, the results were greatly dependent on the type of surface and Fig.1 shows separately the range of results obtained with the different patterns on the fine- and coarse-grained surfacings.

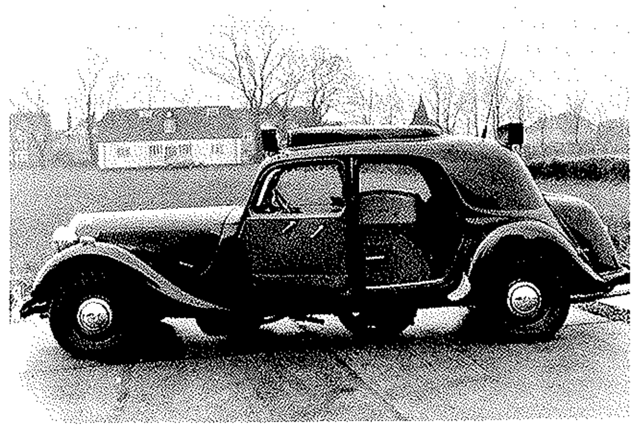
On the fine-grained surfacings all the patterned tyre treads gave a marked increase in retardation over that of the smooth tyres, especially over the important range of SFCs (0.3 to 0.5), but, perhaps surprisingly, the situation was found to be quite different on the coarse-textured surfacings. In this case the smooth tyres gave better results than the patterned ones when braking from 50 km/h with locked wheels in the wet.

A great deal of further work in this field has since been carried out be the major tyre manufacturers and modern tread patterns have become increasingly effective in improving skidding resistance, especially when braking from high speeds.

2.3 Sideway-Force Coefficient Routine Investigation Machine (SCRIM).

The development of machines to measure SFC passed through several phases following the use of the early motorcycles. The first of these was the incorporation of a fifth wheel in a front-wheel drive car. A Citroen car was the first production vehicle found to be suitable and Plate 4 shows the vehicle with the test equipment installed. In the early 1960s a suitable British saloon car became available (Austin 1800) and three of these were converted in a similar way to the Citroen.

Plate 4. Citroen car for measurement of SFC.

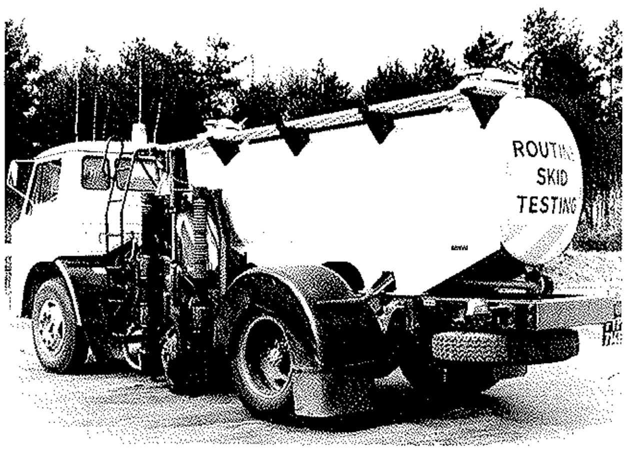


In each of these cases, the test cars were designed specifically for research work and not for routine use by highway authorities. They required separate water tankers to wet the road in front of them (although they did carry small water tanks for local use) and the processing of the pen-recorded paper charts was time consuming and suitable only for comparatively short stretches of road. A machine suitable for routine use was clearly necessary with the following basic requirements:-

(a) To be robust enough for field use.
(b) To be operable within the normal traffic stream.
(c) To be capable of testing an average of 100 km/day.
(d) To produce test results meaningful over the range of normal traffic speeds.
(e) To produce the results in a form readily processable by computer.

The first prototype of the Sideway-force coefficient routine investigation machine (SCRIM - Plate 5) manufactured to Transport and Road Research Laboratory specifications was delivered in 1968, and 15 are now in use throughout the world. Commercial production is in the hands of a manufacturing company in Bristol and the machine is available for sale, complete with electronic recording apparatus.

Plate 5. Sideway-force coefficient routine investigation machine (SCRIM).



The sideway-force is generated by a test-wheel running at an angle of 20° to the direction of travel of the vehicle and carrying a smooth tyre similar to that used on the original sidecar. The vehicle is mounted on a production commercial vehicle chassis and its essential feature is a 2,700 litre water tank to wet the road in front of the test wheel. This quantity is sufficient for some 50 km of testing (ie half of one day's work).

The test wheel has its own deadweight, spring and shock absorber, to give a known static reaction between tyre and road, and in the hub there is an electrical load cell to provide the sideway-force input to the recording system. A speed input is provided from the vehicle transmission system.

Output, on magnetic or punched paper tape, consists of a record at 5 m, 10 m or 20 m intervals of SFC, speed and data to indicate location of the test. The recorder is fitted with facilities for calibration of the system, and the unit is mounted in the vehicle cab for operation by a technician accompanying the driver.

It is intended that in the near future a number of SCRIMS should be available to provide a standardised monitoring system for the national network under the control either of Central Government or of Local Government. In either case the operation of the machines may be direct (ie the vehicle purchased outright and manned by the authority's own staff) or on an indirect hire basis, an auxiliary service already being provided on an introductory basis by the manufacturing company.

2.4 Tests for Roadstone Quality

During the era covered by development of these skid-resistance test methods, parallel work was going on in another sector of the Road Research Laboratory on the polishing and wear properties of roadstones. It was by then being appreciated that stones from different geological sources varied greatly in their resistance to polish by the tyres of vehicles, limestones being notoriously bad in this respect while quartzites and gritstones were good. The gritstone group, however, suffered in some cases from rapid abrasion under traffic, and so, although the stones did not polish, the road lost macrotexture by wear. Two standardised tests were, therefore, developed, the Polished Stone Value test and the Aggregate Abrasion Value test, both of which are now fully documented in a British Standard[5].

The first of these tests gives Polished Stone Values (PSVs) ranging from about 30 for some limestones to up to 75 for some gritstones, and the second gives Aggregate Abrasion Values (AAVs) ranging from 1 or 2 for very hard flints to values above 20 for soft aggregates. Modern specifications nominate each of these properties for given levels of traffic flow and skidding accident potential.

2.5 Summary of Terms Used

The terms used in the remainder of this paper are as follows:-

(a) SRV - Skid-resistance value, measured by portable tester (pendulum) on the road surface.
(b) BFC - Braking-force coefficient, measured by locked-wheel trailer on trafficked roads and airfields.
(c) SFC - Sideway-force coefficient, measured (now) by SCRIM on trafficked roads.
(d) PSV - Polished stone value, measured on a laboratory-polished sample using an adapted portable tester (different scale from SRV).
(e) AAV - Aggregate abrasion value, measured in the laboratory by loss of weight of a sample under accelerated wear.

3. Correlation of Skid-Resistance with Accidents, Materials and Traffic Flow

By the late 1930's the restoration of a rough texture to a smooth road surface was widely achieved by means of surface dressings and macadam carpets, but there was no recognised quantitative method of establishing when such treatment had become necessary.

The first proposal for a method of doing this was to study accident reports in detail and to plot on large-scale plans the locations of those accidents in which wet-road skidding was a predominant factor. From this work at the (then) Road Research Laboratory, it gradually became clear that in many areas these accidents occurred in clusters and that a common factor between many of them was that a high degree of polish existed on the roadstones in the surfacings. Following from this it was also shown that if these areas were then given maintenance treatment, accidents could be reduced in numbers significantly.

This procedure has an appealing simplicity about it for use as a maintenance indication as it encompasses all the factors which combine to cause skidding accidents ie alignment, topography, surfacing regularity and surfacing smoothness. Unfortunately, it also suffers from the overwhelming disadvantage that it is necessary to wait until accidents have occurred before any information is obtained. Obviously a method was required of spotting danger areas before any harm had been done.

3.1 SFC and Accidents

The next major requirement, therefore, was to establish values of SFC which were required in order to minimise the number of skidding accidents at given categories of site so that routine monitoring could detect potential danger areas in advance. This was a very large task indeed and entailed the collection of data, both on SFC and on numbers of skidding accidents that had occurred, from a wide ranging variety of sites.

The work culminated in 1957 in a paper to the Institution of Civil Engineers[6] by Giles in which he related SFC at 50 km/h to the relative liability of a site to become the scene of repeated skidding accidents in wet weather. He concluded that, whilst a surface with a coefficient of 0.60 and above may by chance sometimes be a scene of an accident in which a vehicle skids in wet weather, the risk that it will be the scene of repeated skidding accidents is extremely small. This risk first becomes measurable with a coefficient of 0.55 to 0.60 and increases sharply by more than 20 times as the coefficient falls to values of 0.40 to 0.45 and by about 300 times when the coefficient is 0.30 to 0.35. These data clearly provided the basis of a set of skidding standards (see Chapter 5) but knowledge of the type of stone needed to give a nominated SFC was also necessary before a full national roads policy could be implemented.

3.2 SFC, Materials and Traffic Flow

3.2.1 Bituminous Surfacings. During the years up to 1970, a large number of measurements of skidding resistance had been made on road experiments in which a range of different road aggregates had been used in the surfacing. In order to study the relationship between the PSV of the stone and the low-speed SFC of the surfacing, regression analyses were made of the data from 13 of these experimental sites, 20 analyses being possible because of division into different traffic lanes or types of surfacing at some sites. Details of the results of this work have been published[7] and a synopsis of the findings is that a change of 1 unit of PSV corresponds to a change of 0.01 units of SFC at 50 km/h (SFC_{50}).

The effect of traffic was not so simple to establish but a close study of the measurements taken on one site over a period of years showed that despite variation in skidding resistance during a given year, if a 'mean summer SFC' was taken, the high value of SFC obtained on a newly laid bituminous surfacing rapidly decreased, and within about one year settled to a constant value. It remained at that value provided that no significant change in traffic volume occurred in that time. Examples of results from a few sites are shown in Figs.2 and 3.

If identical surfacing materials were compared on different sites, the level of SFC was found to be inversely related to the volume of traffic.

One conclusion which was apparent from these observations concerns the manner in which SFC and traffic are inter-related. The effect of traffic on SFC is not cumulative from year to year and, therefore, the concepts used, for example, in fatigue studies do not apply to skidding resistance. Instead SFC is simply related to traffic volume for any aggregate of given PSV.

Figure 2. Effect of traffic on skidding resistance of a typical motorway standard surfacing (rolled asphalt with precoated chippings of PSV 58-60)

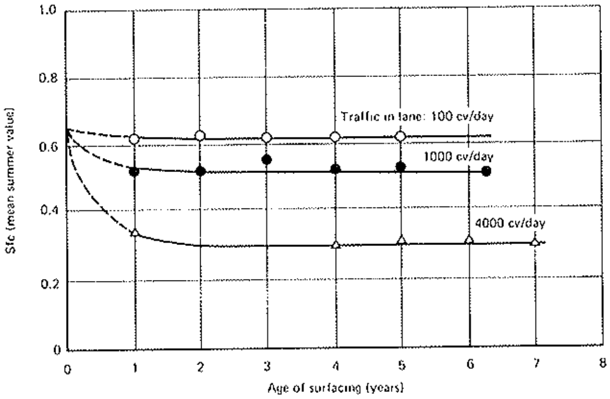
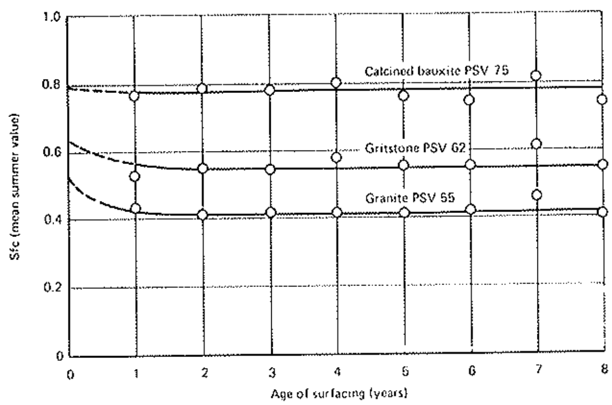


Figure 3. Levels of skidding resistance recorded on different sections of road (surface dressing using 13 mm chippings. Traffic in lane: 2100 commercial vehicles per day)



A possible explanation of these observations and one that is generally accepted, is that at the same time as traffic is tending to polish the surface, other factors, usually identified as complex physico-chemical phenomena described as 'weathering', are acting in the opposite way, restoring micro-texture of the exposed aggregate. Thus the resultant resistance to skidding represents an equilibrium between the effects of certain naturally occurring conditions on the one hand and those of traffic on the other.

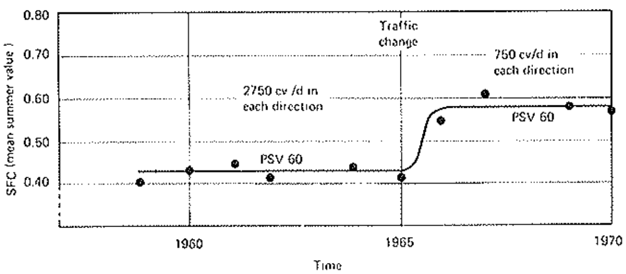
If, on any particular site, traffic flow changed (as a result, for instance, of road development in the area), a corresponding change in SFC would result. Fig.4 shows this phenomenon (as an increase in SFC) as measured on Trunk Road A4 at Colnbrook, Middlesex, when traffic decreased after a nearby section of Motorway M4 had been opened.

When it had been established that the three variables SFC, PSV and traffic were inter-related, a regression analysis was carried out to correlate the three simultaneously. One hundred and thirty nine different sections of road with traffic densities up to 4000 commercial vehicles per day were examined to provide data and the following highly significant correlation (correlation coefficient 0.91) was obtained:-

$$SFC_{50} = 0.024 - 0.663 \times 10^{-4} \cdot q_{cv} + 1 \times 10^{-2} \cdot PSV$$

where q_{cv} = flow of commercial vehicles per lane per day (in one direction). The relationship applies to straight roads only.

Figure 4. An increase in the level of skidding resistance recorded on trunk road A4, Colnbrook by-pass when traffic decreased due to the opening of a motorway.



The publication of this work[7] is regarded as a major advancement in the field of skid-resistance as it provides a method of nominating at the design stage the properties of the stone required to provide a given ultimate skidding resistance provided that the commercial traffic flow can be estimated.

3.2.2 Concrete Surfacings. Research to quantify the materials effect on low-speed skidding resistance in a concrete pavement is complicated by the greater number of variables involved. Here the polishing and wear characteristics of both the fine and coarse aggregates have an influence on the result, as does the strength of the concrete.

This field has been researched in Britain as a joint venture between the (Transport and) Road Research Laboratory and the Cement and Concrete Association, work starting in 1964 and still being active in 1977. The first major report[8] from this work appeared in 1970 and it concluded that the most important constituent in the mix was the fine aggregate. The use of high-silica-content natural sands always yielded higher skid-resistance values than did relatively soft sands or crushed fine materials.

The polishing characteristics of the coarse aggregate had only a very slight effect on the skid-resistance of concrete, an increase in PSV from 35 to 72 producing an increase in SRV of less than 5 units. Normally not more than 12 per cent of the surface of a concrete road consists of exposed coarse aggregate.

As a result of this and other work, the Department of the Environment Specification[9] introduced two aggregate restrictions for concrete surfacings on Trunk Roads and Motorways. Firstly the fine aggregate used in the top 2 inches of the carriageway was limited to a 25 per cent calcium carbonate content (that being the polishable constituent of the sand) and if the coarse aggregate was limestone it was required to satisfy an accelerated wear test. This latter test is carried out on concrete samples incorporating the aggregate in question and thus occupies a period of several weeks because of curing time. It would be more practicable to be able to forecast the ultimate low-speed skid-resistance of the finished concrete from laboratory tests on the constituents, so that delays could be avoided at the tendering stage of a contract.

To this end, a first study[10,11] has been made of a limited amount of data with the object of correlating the skidding resistance with the properties of the constituents. The aggregate properties and the strength characteristics have been subjected to multiple regression analysis and the equation derived from Motorway M4 (3400 commercial vehicles/day) was:-

$$SRV = 47.1 + 0.210 \times PSV_f - 1.11\ AAV_f + 0.335\ AAV_c - 0.204\ (\text{strength}) + 0.189\ (\text{fines content})$$

(Suffices 'f' and 'c' refer to fine and coarse aggregate respectively, 'strength' is compressive strength of concrete at 28 days (MPa) and 'fines content' is per cent by weight passing a 4.76 mm BS test sieve. The correlation coefficient was 0.84.)

This work is still in progress and it is hoped that it will soon be possible to specify materials to give a nominated SFC_{50} as accurately for concrete surfacings as for bituminous.

3.2.3 Factors other than Resistance to Polishing. Although resistance to polishing is the most important single characteristic of an aggregate in determining the resistance to skidding of a bituminous surfacing, a study[12] has been made of other characteristics of aggregates that have been thought to influence resistance to skidding. The most important of these were:-

(a) Geological group
(b) Particle size
(c) Differential wear of mixtures of two or more roadstones.

Briefly the findings of the work were:-

(a) Some aggregates, notably quartzites and blast-furnace slags, gave a resistance to skidding equivalent to that given by other roadstones which are 3 units higher in PSV. All the other types of roadstones tested performed as would be expected from their PSVs.

(b) Provided that adequate road surface texture is maintained, reducing the nominal size of an aggregate raises the low-speed resistance to skidding of a surfacing made with it. In the case of macadams this increase can be up to 0.10 units of SFC for a 3 mm maximum size material when compared with one containing 19 mm particles. This relative effect is even greater in the case of chipped surfacings, but it is difficult to prevent embedment of small chippings.

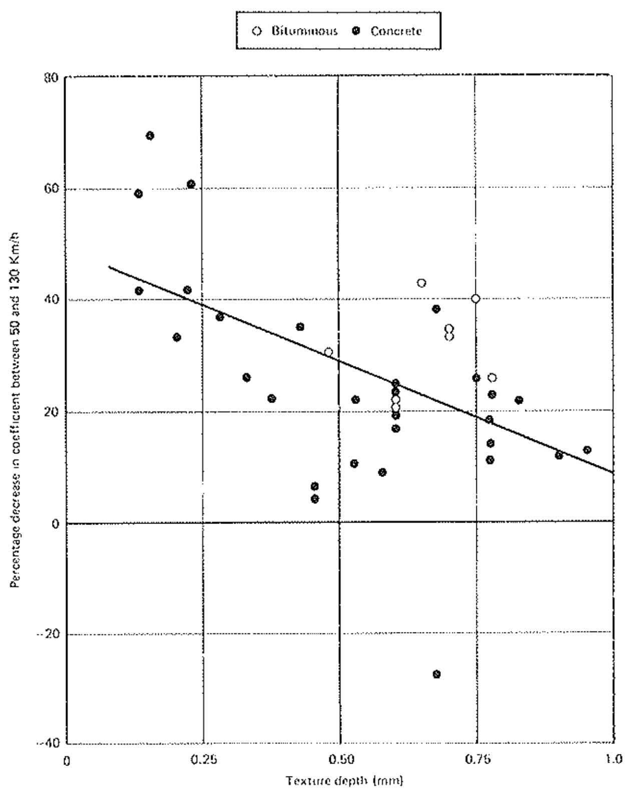
(c) The use of mixtures of two or more aggregates of normal surfacing quality yields a resistance to skidding and a depth of surface texture that is approximately equal to the means of those given by the constituents on their own.

4. Effect of Texture on High-Speed Skid-Resistance

The work discussed in Chapter 3.2 has made it clear that low-speed (50 km/h) SFC is provided by the micro-texture of the surfacing and is quantified in terms of the resistance to polishing of the aggregates used. The next question is that of the macro-texture and what its contribution is to the skidding resistance of the road.

It has been mentioned previously in Chapter 1 that various researchers had reported a 'speed effect' on the measured skid-resistance and that the small braking-force trailer (2.2.1) had been used to investigate change in skidding resistance from low to high speeds. The first attempt to quantify this effect and to correlate it with road surface texture came in 1966[13]. The texture used was that measured by a sand-patch method[4] and one measure of change in skidding resistance that was tested for correlation against texture was the percentage decrease in BFC between 50 km/h and 130 km/h. The relationship is plotted in Fig.5 and is seen to be linear, with a correlation coefficient of -0.52. A first attempt at nominating a mandatory texture requirement was made on this evidence and this was that a texture depth of 0.025 in. (0.64 mm) should be provided in order to restrict the decrease in skid-resistance to 25 per cent. This figure of 0.025 in. was subsequently included in the specification[9] for concrete roads but it has been used only as a guide in bituminous specifications. Consideration is now being given to new texture requirements based on the latest work in the field.

Figure 5. Effect of texture depth on percentage decrease in coefficient between 50 and 130 km/h.



Further evaluation of BFC measurements on a wider range of surfacings has shown that the random texture of bituminous surfacings has a different effect from that of the predominantly transverse texture applied to most concrete surfacings in the UK. Figs.6 and 7 show the effects of texture depth on change in BFC from low to high speed on bituminous and concrete surfacings respectively. These are plotted in a slightly different way from that chosen for Fig.5 because the later survey included a number of deep-textured surfacings which have the effect of actually increasing the skidding resistance at high-speed compared with that at low speed; as will be discussed later, this advantage brings with it a penalty of noise.

Figure 6. Bituminous surfacings: effect of texture depth on the change in BFC from 50 to 130 km/h.

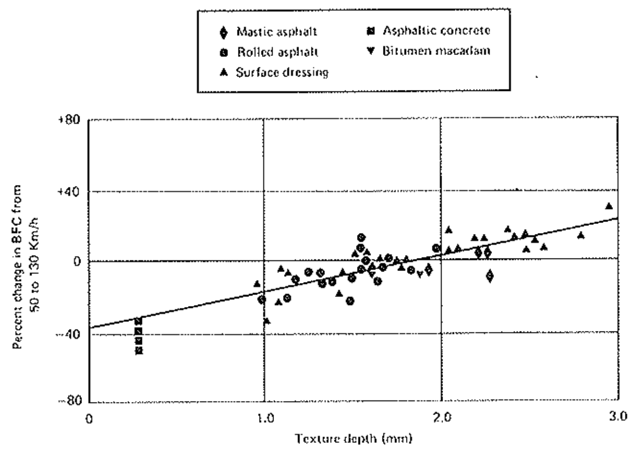
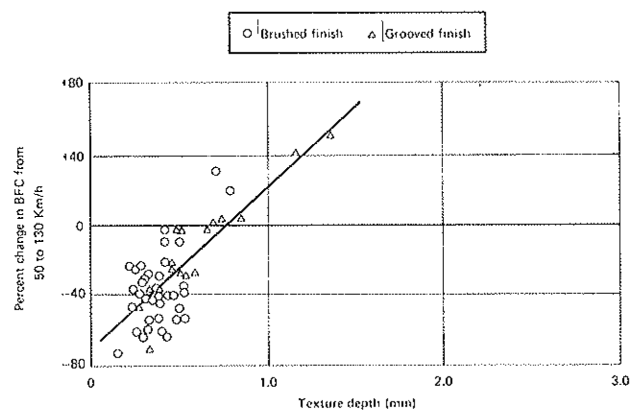


Figure 7. Concrete surfacings: effect of texture depth on the change in BFC from 50 to 130 km/h.



A comparison of Figs.6 and 7 shows that, for equivalent performance, the transverse texture of a concrete surfacing can have a lower average value than the random texture of a bituminous one. For example, for zero drop-off in BFC (ie the maintenance of the same skidding resistance at high speed as at low) a randomly textured surfacing requires 2.0 mm of texture whilst with a transverse texture only 0.8 mm is needed. This important finding is discussed again in Chapters 5 and 7 in connection with standards of texture required on roads and the noise that such textures will generate.

5. Standards of Skid-Resistance

5.1 First Standards Proposed (1957)

Mention has been made in Chapter 3.1 of Giles' work in the 1950's and of the relationship he obtained between SFC and numbers of wet skidding accidents. In the same paper[6] he suggested levels of SFC for different categories of site, which were intended as a very tentative guide and as a basis for further study. These figures are given in Table 1.

Table 1. Giles' suggested sideway-force coefficients (1957).

Category	Type of site	SFC at 30 mile/h on wet surface
A	'Most difficult sites' such as: 1. roundabouts 2. bends with radius less than 500 ft on fast derestricted roads 3. gradients 1 in 20 or steeper of length greater than 100 yds 4. approaches to traffic lights on derestricted roads	above 0.6
B	'General requirements' ie: roads and conditions not covered by categories A and C	above 0.5
C	'Easy sites' eg: mainly straight roads with easy gradients and curves and without junctions and free from any features such as mixed traffic especially liable to create conditions of emergency	above 0.4
D	'Proved sites' eg: roads with coefficients below 0.4 which because of factors such as very slow or infrequent traffic cannot be shown by accident studies to be above normal danger	-

With minor amendments (eg the substitution of 0.55 for 0.60 for Category A), these proposals were included in the suggested target values of SFC adopted by the Marshall Committee[14] on Highway Maintenance, whose report was submitted to the Minister of Transport in 1970. These values have never achieved a status higher than of proposals in Britain, aimed at providing guidance for the maintenance engineer but, in order to have maximum effect in improving road surfaces, it is essential that any standards should eventually have mandatory backing. One major deterrent to the adoption of such mandatory standards is common throughout the world, and that is the legal consequences of such action. In 1970 the Transport and Road Research Laboratory set out to try to produce a scheme which would be acceptable from all points of view.

5.2 1972 TRRL Proposals

5.2.1 SFC. The starting point of this study was a consideration of the limitations of the existing proposals. The recommendations of minimum values of SFC for three or four broadly defined categories of site has the advantage of simplicity but it does not fully reflect the fact that a slippery surface is just one of many factors contributing to the incidence of skidding. Two sites fitting into the same category may show widely different skidding accident records, because their liabilities to become a scene of such accidents will be influenced by factors such as traffic speed, road geometry, superelevation on bends, visibility and others.

Another problem with the old proposals was that since their introduction a considerable increase in traffic had occurred (59 per cent increase in commercial vehicles between 1956 and 1969) and the polishing effect of this traffic had reached such proportions that it had become impracticable to maintain the target values on many heavily trafficked lanes of motorways using any available natural aggregate.

The new proposals which were prepared[15] were based on a site classification system broadly similar to the existing one but including a new super class of high risk site. The main feature of the scheme was that in place of a rigid system, the minimum value of SFC required on any site should be additionally dependent on a 'Risk Rating' which would be determined locally by the accident potential of that site. If the mean summer SFC falls below the minimum value the maintenance authority should initiate remedial action by including the length of road in question in the programme for future maintenance work provided the accident record gives no grounds for re-coding with a lower risk number. The proposals are given in Table 2.

The ultimate aim to be achived after the scheme has been in operation for some time, is that every site should be rated at the correct risk level. This condition would be indicated by the disappearance of sites having a skidding accident record substantially different from an average value.

5.2.2 PSV Required. The materials requirements to achieve the nominated SFCs have been discussed in Chapter 3.2 and a summarised version of the PSV requirements for use in bituminous surfacings has been produced for a range of traffic conditions. These are given in Table 3.

5.2.3 Surface Texture. The effect of macro-texture on the change in skidding resistance with speed has been discussed in Chapter 4. The TRRL proposals for an all-embracing policy on surfacings include texture requirements and a summary of the effects mentioned previously is given in Table 4.

It is proposed that new surfacings, bituminous or concrete, should have sufficient texture to give the same skidding resistance at high speed as at low (ie zero drop in Table 4) and that maintenance intervention should take place when texture is reduced to the point where a 20 per cent drop occurs. These conditions require 2.0 mm for new bituminous

Table 2. Minimum values of skidding resistance for different sites.

SITE	DEFINITION	SFC (at 50 km/h) Risk Rating 1	2	3	4	5	6	7	8	9	10
A1 (very difficult)	(i) Approaches to traffic signals on roads with a speed limit greater than 40 mile/h (64 km/h) (ii) Approach to traffic signals, pedestrian crossings and similar hazards on main urban roads						0.55	0.60	0.65	0.70	0.75
A2 (difficult)	(i) Approaches to major junctions on roads carrying more than 250 commercial vehicles per lane per day (ii) Roundabouts and their approaches (iii) Bends with radius less than 150 m on roads with a speed limit greater than 40 mile/h (64 km/h) (iv) Gradients of 5% or steeper, longer than 100 m				0.45	0.50	0.55	0.60	0.65		
B (average)	Generally straight sections of and large radius curves on: (i) Motorways (ii) Trunk and principal roads (iii) Other roads carrying more than 250 commercial vehicles per lane per day	0.30	0.35	0.40	0.45	0.50	0.55				
C (easy)	(i) Generally straight sections of lightly trafficked roads (ii) Other roads where wet accidents are unlikely to be a problem	0.30	0.35	0.40	0.45						

Table 3. PSV of aggregate necessary to achieve the required skidding resistance in bituminous surfacings under different traffic conditions.

Required mean summer SFC at 50 km/h		PSV of aggregate necessary — Traffic (in commercial vehicle per lane per day): 250 or under	1000	1750	2500	3250	4000
0.30		30	35	40	45	50	55
0.35		35	40	45	50	55	60
0.40		40	45	50	55	60	65
0.45		45	50	55	60	65	70
0.50		50	55	60	65	70	75
0.55		55	60	65	70	75	
0.60		60	65	70	75		
0.65		65	70	75			
0.70		70	75				
0.75		75					
AAV	Chipped surfacings	not greater than 14	not greater than 12		not greater than 10		
	Macadams	not greater than 16		not greater than 14		not greater than 12	

surfacings, and 0.8 for new concrete surfacings with maintenance coming into play at 1.0 mm and 0.5 mm respectively.

Table 4. The effect of macrotexture on the change in skidding resistance with speed.

Drop in skidding resistance with speed change from 50 to 130 km/h %	Texture Depth (mm)	
	Flexible	Concrete*
0	2.0	0.8
10	1.5	0.7
20	1.0	0.5
30	0.5	0.4

* when textured predominantly transversely

6. Surfacings with High Resistance to Skidding

It is, of course, pointless to nominate surfacings with given properties unless the materials required for them are economically available in the required quantities, and much research effort has been expended at the Laboratory in identifying or developing materials with resistances to skidding to suit all categories of road. It is convenient to consider these in reverse order of the categories listed in Table 2.

6.1 Category C Sites

Roughly 80 per cent of the roads of the country are covered by Category C, and as the geology of Britain covers the complete range of rock types, there is no shortage of roadstone suitable for these roads.

6.2 Category B Sites

When we move up the scale to Category B, which includes about 15 per cent of the road network, difficulties start to emerge. It can be seen from Table 3 that with traffic of 4,000 commercial vehicles/day/lane, the maintenance of an SFC of 0.45 requires the use of a stone with PSV of 70. Very few sources of such stone exist in Britain and those which are available are all in the gritstone group and may not be suitably resistant to abrasion (eg soft sandstones). In 1972, a survey of the arenaceous rocks existing in Britain was conducted in conjunction with the Institute of Geological Sciences, and the findings published[16]. Rocks were classified as to their suitability for making skid-resistant surfacings, the range being from those with a PSV greater than 70 and AAV better than 10 (Class 1) to the poorest materials (Class 6). Five sources were identified in Class 1 and eighteen in Class 2 (PSV 65-69, AAV 10). A number of the sources listed were from disused quarries or were unworked, and the intention was that, as demand grew, some of these exposures would be commercially exploited. Considerable interest has already been shown in a number of these.

A commercial development of the use of high-PSV aggregates is based on work at Birmingham University[18] in the late 1960s concerning the packing properties of graded aggregates. The development concerned the use of two aggregates with different wear properties and with good PSVs, and has led to a Patent being filed[19] in 1971 to cover the production of a proprietary surfacing material. The material is under observation by the Laboratory on a number of sites.

6.3 Category A2 and A1 Sites

When roads in Categories A2 and A1 (Table 2) are brought into the problem, the use of artificial aggregates has to be considered, together with the development of improved binders to attach them to the road. Calcined bauxite was first proposed for such use by the Laboratory in the late 1950s and trials which included this material were carried out on Trunk Road A4 (Colnbrook By-Pass). An epoxy-resin binder was used and although the treatment appeared prohibitively expensive to the traditionalists, it was soon taken up by the Greater London Council for use in high-risk situations (Plate 6) and has proved to be highly cost-effective at certain sites[17]. The treatment is now marketed commercially in Britain and the producing companies are in active collaboration with the Laboratory, with a view to future improvements and widening the scope by producing cheaper binders for use on Category A2 sites.

Plate 6. The use of calcined bauxite/epoxy resin treatment in London

Work is also in progress at the Laboratory to identify other improved binders for up-graded surface dressing work, and good results have been obtained with thermoplastic polymer additives to bitumen and tar.

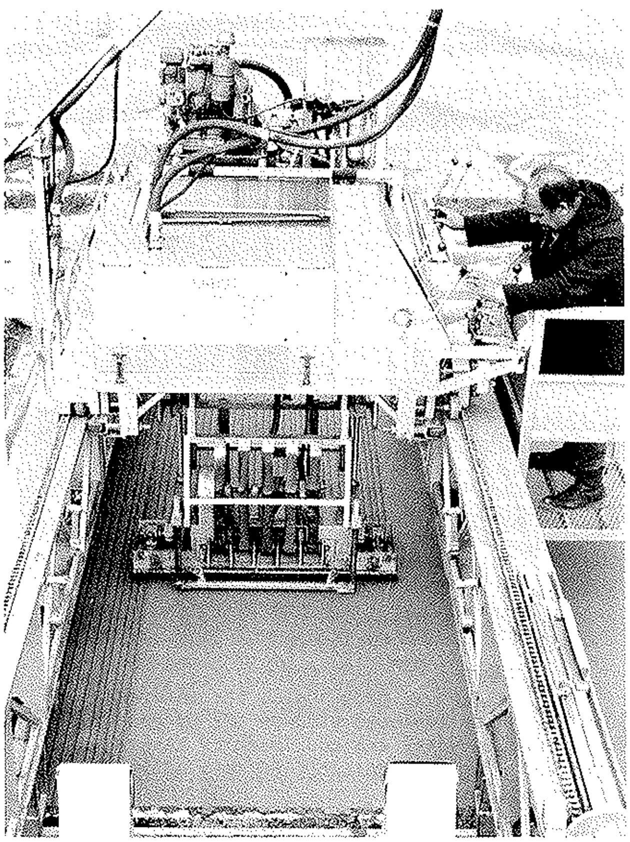
A summary of the work on high-PSV aggregates at the Laboratory and elsewhere was published in 1976[20]. It covers both natural rock aggregates and those manufactured from synthetic materials and contains a list of references on the subject. It concludes that few other artificial materials are as good as calcined bauxite, but a number exist which would fill the demand for an aggregate which is better than the natural rocks (either in polishing or abrasion resistance) and is less expensive than calcined bauxite.

7. Problems Associated with Texture

7.1 Noise

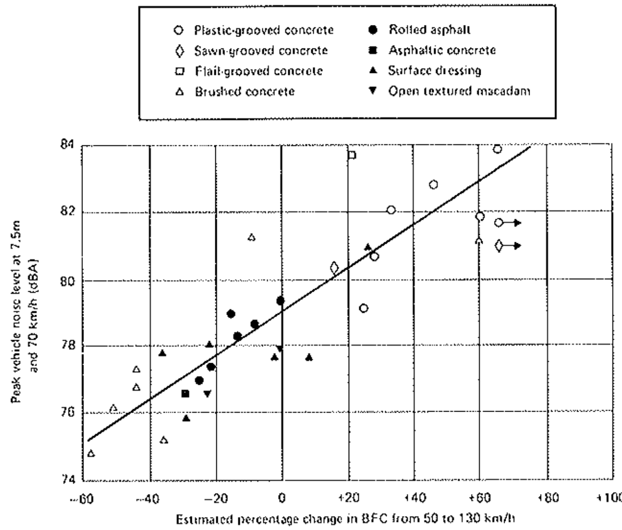
The problem of tyre noise generated on deep-textured surfacings was mentioned in Chapter 4 and this has been one of the subjects of recent close study at the Transport and Road Research Laboratory. The problem came to the fore because of the suitability of a concrete surfacing for accepting (and retaining) a deep texture while it is in the plastic state during construction. This advantage has, of course, been appreciated for many years throughout the world and in Britain a specialist machine was developed[21] for constructing 6 mm x 6 mm grooves rapidly and precisely (Plate 7). These are arranged at random centres to avoid the single-tone whistling noise which results from spacing the grooves uniformly, but when a major road scheme was built using the system, adverse criticism was received from local residents due to the total traffic noise generated. It was claimed that this was greater than that from a typical bituminous surfacing.

Plate 7. Plastic grooving machine for concrete.



A detailed study of the problem led to the conclusion that although the deep-grooved concrete did indeed create more noise than a typical bituminous surfacing, it was also providing greater benefit in terms of high-speed skidding resistance. Measurements from a large number of roads were then analysed and a summary of the results is plotted in Fig.8; this shows that the tyre/road noise emitted from a surfacing is linearly related to the effectiveness of that surfacing from the point of view of high-speed skidding resistance. For example, a bituminous surfacing with 2.0 mm of texture emits the same noise as transversely textured concrete surfacing with 0.8 mm of texture (see Chapter 5.2.3).

Figure 8. Relationship between estimated BFC of various surfaces and noise from light vehicles.



This finding dispels the previously widely held belief that concrete surfacings are noisier than bituminous ones and is important in the formulation of a specification policy which can cover all forms of construction in a general and equitable manner.

7.2 Spray

The problem of spray thrown up from the wheels of fast moving vehicles especially heavy commercial ones, has grown in importance as traffic intensities have increased. It is difficult to be precise about the numbers of accidents caused by poor visibility in periods of heavy rain but an estimate has been made[22] that 10 per cent of wet-road injury accidents may be in this category.

Research was undertaken at the Laboratory[23] in the 1960s to measure the depth of water on rolled asphalt and brushed concrete surfaces, using a 11 m x 5.5 m tilting platform and a 30 m rainfall simulator. The primary conclusions were that the distributions of water on the surface of rolled asphalt and brushed concrete during rainfall are very similar, indicating that, as far as the hydraulics of rain water flow is concerned, the surfaces can be considered to have similar roughnesses. Increasing the crossfall of the road pavement from 1 in 60 to 1 in 30 had a relatively small effect on the depth of water flowing across the road. Clearly any major improvements in this field are to come from surface texture improvements, but as these will in most cases involve increased noise, a compromise will have to be evolved.

In order that this compromise can be properly quantified, an apparatus is being developed which will measure the severity of spray thrown up from a surfacing. This operates on a reflected light technique, measuring the intensity of light scattered back from the spray particles. This work is currently in progress and will be reported when completed.

Considerable interest is being shown in many parts of the world in pervious surfacings of various forms and Great Britain is no exception. After early experience on airfields in the early 1960s, experimental surfacings were laid on roads in 1967 by TRRL and, independently, by Warwickshire County Council. In 1970 further experimental sections were laid by the Laboratory on Trunk Road A45 in Warwickshire[24], which at that time carried 4,500 commercial vehicles per day (in one direction) in the nearside lane. After 6 years, 4 of the 6 materials used are considerably reduced in perviousness but the 2 best formulations are still reasonably effective. One of these materials has been laid in a trial on Motorway M1 under the most severe traffic conditions (7,000 commercial vehicles/lane/day) and Plates 8,9 show the effect in heavy rain. Other trials are also taking place on some 10 sites in various parts of the country, and noise measurements are being made at some of these in addition to spray assessment.

Plate 8. Spray from standard surfacing on Motorway M1.

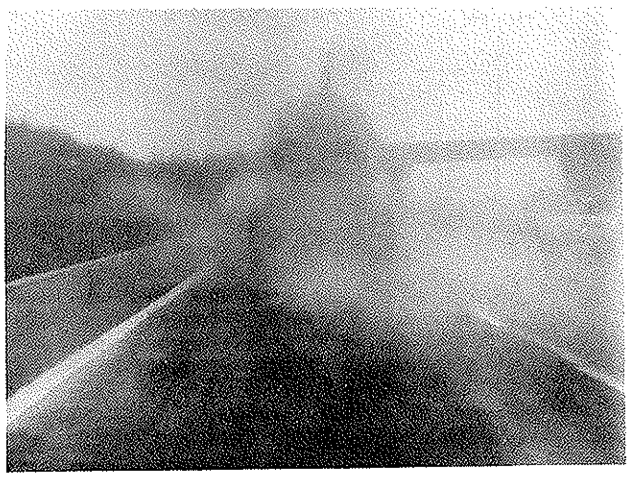
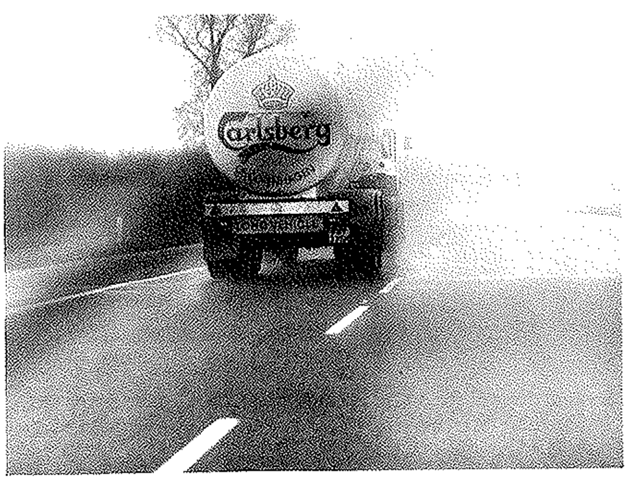


Plate 9. Spray from pervious surfacing on Motorway M1.



8. Specification of Materials and Texture in Practice

Most of the physical factors that have to be considered in writing specifications for skid-resistant roads have been discussed in the preceding chapters. The final problem is that of implementation in practice.

In Britain, the specifying authority for Trunk Roads and Motorways, ie those which receive their financing solely from Central Government, is the Directorate General of Highways of the Department of Transport. They receive recommendations from the TRRL, consider them in the context of the current economic, commercial and political situations, and issue specifications to suit. The subject of skid-resistance is a particularly delicate one, because the final decisions require a balance between cost and safety, with legal issues influencing matters.

The policy to be adopted is under consideration by the Directorate General of Highways but a decision has not been reached at the time of writing on the precise use of the proposals outlined in this paper.

A summary of these proposals is as follows:-

New construction:

1. The PSV of stone to be used would be nominated for the design traffic flow to maintain a given SFC. (Table 3 Chapter 5.)
2. The initial texture would be specified with the aim of giving zero drop-off in skid-resistance from low to high-speed (Table 4 Chapter 5). This would be backed up by a maximum AAV requirement (Table 3 Chapter 5).

Maintenance:

The inclusion of a road in a maintenance programme would depend on its mean summer SFC as measured by SCRIM, and on its texture depth as measured with a laser-based system at present under development[25]. The intervention level for texture would be aimed at 20 per cent 'drop-off' (Table 4 Chapter 5) but a national survey of existing road textures will be carried out to confirm the feasibility of this figure.

When this stage is reached, there will exist a complete package to enable British highway engineers to construct and maintain their roads to an optimum standard with the aim of keeping wet-skidding accidents to the minimum practicable level.

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PROVIDING SKID RESISTANT PAVEMENTS

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Abstract: Pavement skid resistance information and data is comprehensive but scattered throughout the literature. Here the state of the art and the state of the practice involving various methods of providing pavement surfaces (roads and runways) that reduce wet weather skidding and hydroplaning are summarized and reviewed; also identified are those areas where the practice lags behind the state of the art. Source information is also furnished for the serious student and researcher of the subject. Field and laboratory tests and specifications of skid measurement and predictability are discussed. Polish resistance of various aggregate types are listed as is the skid resistance of various pavement surfaces. The effect of characteristics of the materials and surfaces of pavement construction are presented in relationship to the design, construction and maintenance of road and airport pavements. Details of design, construction and maintenance for effective skid resistance are covered. Of special significance is the section on "The Future". The paper was contributed to by a group of experts in the field.

One of the most important factors in the safe operation of the modern motor vehicle is the development of necessary tire-pavement friction (skid resistance). It is well-known that during an emergency stop, the last chance for avoiding an accident resides with the level of skid resistance developed between the tire and pavement during braking. In most cases, emergency situations lead to over-reaction on the part of the driver, which often results in a locked-wheel skid.

There is a substantial drop in skid resistance of pavements during wet weather. This creates a serious situation since experience has shown that the average driver does not reduce driving speed under wet conditions.

It is also unfortunate that most tire manufacturers' advertisements vividly display the remarkable stopping ability of their tires. This can lead to overconfidence on the part of the driver, especially since no one explains that such stopping ability depends on many factors besides the advertised claims for the tire, such as the significant changes that occur due to tire wear. A "bald" tire on a wet pavement presents a very hazardous condition. Perhaps this is best stated from a quotation by R. W. Yeager (1) in his paper on "Tire Hydroplaning: Testing, Analysis and Design": "The road surface is a relatively lasting, stable, rigid platform and is conducive to resisting tire hydroplaning if properly designed. These qualities are absent in the tire. The improvement that a tire tread potentially offers is governed by the level of drainage and friction capability of the surface."

On the basis of the above statement and assuming the driver and the tires are competent, then one could conclude that the responsibility for the attainment of necessary tire-pavement friction under the variable environmental and vehicle operating conditions mainly rests with the paving engineer. This also appears to be the thoughts of the writers of NCHRP Synthesis 14 on Skid Resistance (2) wherein we find, "Next to congestion, pavement slipperiness is the greatest sin a public agency can, in the eyes of the public, permit to befall highways and streets. Indeed, when skidding accidents occur, the public is more likely to blame the pavement than anything else." We should add that although the public is not directly involved in terms of operations, the same feelings are of as great importance in the takeoffs and landings of commercial and military airplanes.

The problem of providing economical pavements which generate the proper tire-pavement friction would be difficult enough, but when the constraints of noise, excessive tire wear, pavement roughness, and road geometry must also be considered, one begins to understand the magnitude of the problem.

During the interval between the First International Skid Resistance Conference and this one, numerous studies on tire-pavement friction have been published and a number of outstanding papers have been made available to the paving engineer (2)(3)(4)(5)(6). The purpose of this report is to review the state of the art and the state of the practice involving various methods of providing pavement surfaces (highways and runways) that reduce wet weather skidding and hydroplaning, and identify where the state of the practice lags behind the state of the art.

In order to fulfill the preceding objectives we will consider:

. What are the basic requirements for a satisfactory skid resistance surface?

. What is being done to provide and maintain skid resistance surfaces?

. What remains to be done?

. What is our future plan of approach to the ultimate solution of our problem?

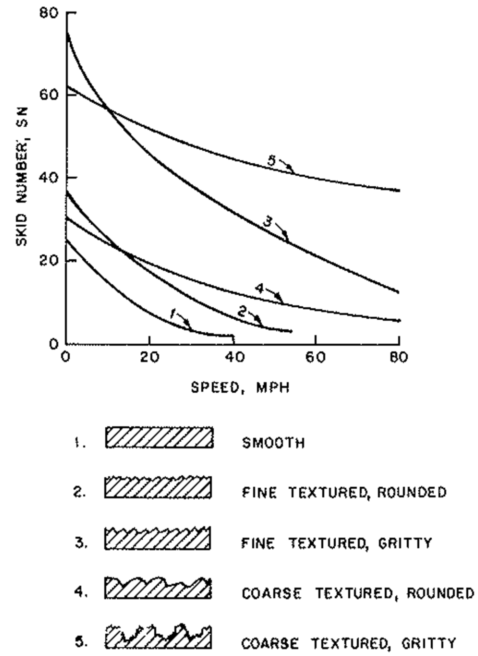
Fortunately at this stage of development, we appear to have reasonable agreement on the basic requirements for a satisfactory skid resistance surface. Among the many factors which affect pavement friction, the most important are the microscopic and macroscopic roughness of the pavement surface as well as the polish-wear characteristics of mineral aggregates. The recognition of these two texture scales which affect the friction and surface drainage properties of either a road or airport pavement allows one to classify various pavement surfaces in terms of skid resistance.

Figure I (3) and Figure II (7) show the influence of micro- and macrotexture and, of greater importance, the necessity of having both of these characteristics available at high operational speeds. As an example, Figure I shows the excellent skid numbers that may be attained by a fine-textured gritty surface below 30 mph (13.4 m/s) and the loss in skid resistance above this speed. This pavement surface may be a very acceptable surface for city streets, but would be inadequate for high speed highways and certainly not for airport runways. The paving engineer must be fully cognizant of the variation in tire-pavement friction with speed.

Figures I and II also indicate the beneficial effect of texture in the generation of skid resistance. The important function of texture is to provide drainage channels so water can escape from under the tire at faster vehicle speeds. This allows the tire tread elements to make positive contact with the pavement surface.

Having identified the pavement surface characteristics required for adequate skid resistance, the paving engineer is also concerned with maintaining such a texture during the service life of the pavement. This is done by obtaining materials which will have a high resistance to polish-wear action of traffic. The balance of this paper will be devoted to the study of materials, and the design and construction methods used to provide adequate tire-pavement friction during the operational life of airport and road. Also considered will be the maintenance operations required when surfaces fall below the desired skid resistant levels.

Figure I. Classification of pavement surfaces according to their wet friction and drainage properties.



REFERENCE:
NCHRP # 37 "TENTATIVE SKID-RESISTANCE REQUIREMENTS FOR MAIN RURAL HIGHWAYS" PAGE 24, FIG. 24

Figure II. Pavement Surface Characteristics.

PAVEMENT	TEXTURE		FLUID PRESSURE ALLEVIATION	
	MICRO	MACRO	VISCOUS	DYNAMIC
SMOOTH	LOW	LOW	POOR	POOR
SMOOTH STONES	LOW	MEDIUM	POOR	GOOD
SANDPAPERY	HIGH	LOW	EXCELLENT	POOR
FRACTURED STONES	HIGH	MEDIUM	EXCELLENT	GOOD
GROOVES	LOW	HIGH	FAIR	EXCELLENT
GROOVES	HIGH	HIGH	EXCELLENT	EXCELLENT
POROUS	MEDIUM	HIGH	GOOD	EXCELLENT

REFERENCE:
"ELEMENTS AFFECTING RUNWAY TRACTION" W. B. HORNE
SAE PAPER - NO 740496, MAY 1974 TABLE II

Materials

Assuming that proper design systems and construction methods are available for producing adequate skid resistant surfaces, then the most important consideration is the choice of suitable aggregate for bituminous pavements and the mechanical texturing of portland cement concrete pavements.

Excluding those bituminous pavements produced mainly from fine aggregates, the skid resistant properties of asphalt pavements depend primarily on the coarse aggregates, whereas in portland cement concrete pavements, the fine aggregate characteristics are considered the more important, at least until the surface has worn sufficiently to expose the coarse aggregates.

Four characteristics should be evaluated in the selection of aggregates for skid resistant surfaces. These are: texture, shape, size, and resistance to wear and polish.

It should be noted that characteristics such as texture, mineral constituents, chemical composition, and certain physical properties are controllable by the paving engineer through aggregate source selection. Once the source is selected, further characteristics such as shape (angularity), particle size and range of sizes (gradation), may be produced by processing. Microtexture or roughness of aggregates is a very important characteristic in terms of skid resistance of the pavement. For a portland cement concrete pavement, microtexture refers to fine-scale roughness contributed by individual small asperities of the fine aggregate particles in the mortar. This would also be the case for surface treatments with fine aggregate asphalt seal coats (sand seals and screenings) and asphalt slurry seals. On the other hand, in asphalt concrete and larger aggregate seal coats, the microtexture of the larger aggregate sizes is the most important.

Microtexture of an aggregate particle must be specified or determined at the time of its incorporation into the pavement, but of greater importance is the change in such texture during service life. Minerals of varying hardness in the aggregate matrix may wear differentially under traffic resulting in a continually renewed non-polished surface. This also happens when the individual aggregates have sand size particles composed of hard grains which are weakly cemented. On the other hand, if the cementing matrix is strong, the individual grains will be tightly held and polished by traffic. The rate of polish depends on the hardness of the grains, frequency of contact with traffic and the type of polishing media or abrasive material on the roadway surface.

Shape and Size

Shape and size of the individual aggregates are other important variables controlling skid resistance. The angularity of coarse aggregates contributes to tire-pavement friction in the case of asphalt concrete and screening (aggregate) seal coats by establishing points of contact, that protrude above the water level, with the tire rubber. Angularity is most readily attained by rock crushing operations. However, aggregates of different mineral composition with the same angularity may wear-polish at very different rates. A potentially slippery situation may develop if rapid wear and polish reduces the angularity of the points in contact with the tire rubber. Such characteristics should be determined by laboratory testing as discussed later.

Aggregate size is controlled by the grading requirements. In the case of screenings for seal coats, the sizes of the aggregate are a very important consideration in the final surface in terms of angular projections to different heights so as to provide rubber envelopment and drainage patterns. In the case of asphalt concrete, size is important in creating the character of surface exposed. Variance in maximum aggregate size even from the same aggregate source may result in different changes in tire pavement friction under equivalent traffic exposure.

Wear Resistance

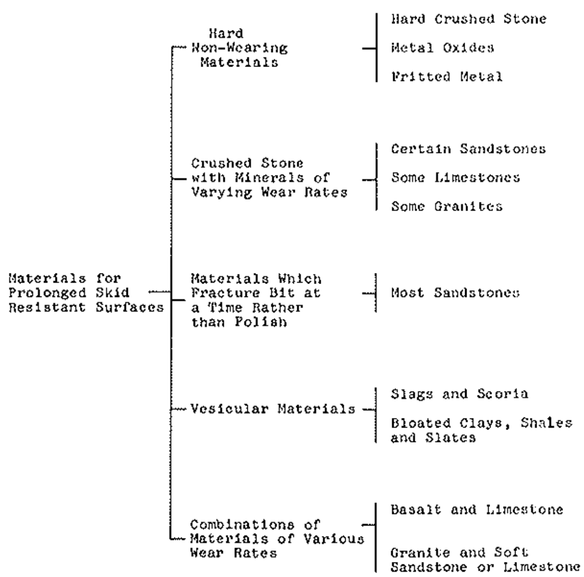
Having chosen an aggregate of appropriate microtexture and angularity and a proper maximum size and gradation, the paving engineer must determine if such a combination will produce the desired tire-pavement friction and maintain such skid resistance during the service life of the pavement. As mentioned previously, aggregates may exhibit different systems of wear and polish depending on their mineralogical composition. There is also the possibility of using aggregates composed of several minerals of various hardness that will result in differential rates of wear in a pavement.

An excellent summary on systems for maintaining high skid resistance under conditions conducive to wear and polish is given by B. B. Gallaway (6). Quoting from portions of this paper, "Surface microtexture renewal processes may be aided by proper selection of aggregates forming the structural skeleton of the mix. The choices that may be available include granulating materials such as sandstone; conglomerates which contain rock flagments that possess great resistance to disintegration and wear, like a quartz conglomerate; certain limestones with uniformly dispersed small sharp particles (Quartz in a limestone matrix); certain iron ore gravels and vesicular materials such as selected slags; scoria; and manufactured aggregate of the lighweight type such as expanded clays, shales and slates.

"Another mechanism that has met with moderate success utilizes the concept of differential rates of wear of at least two aggregates of distinctly different wear rates in the mix. In service such a mixture is worn and eroded by traffic and to some extent by environmental factors at such a rate as to create a continuous and effective skid resistant pavement surface. The soft particles wear in advance of the harder particles leaving the latter in relief.

As this relief is accentuated, the hard particles are removed by the shearing action of traffic. The process repeats itself to maintain a particle exposure which contains a preponderance of particles that never remain exposed to the action of traffic long enough to polish to low level. The Highway Departments of New York, Virginia, Kentucky, Tennessee, Louisiana and Texas, among others have utilized this approach with varying degrees of success for a period of several years." Figure III from this paper presents this information in outline form.

Figure III. Materials



(B.M. Gallaway - AAPT-42-401-1973)

One of the difficult problems in proper selection of aggregates in the United States is the enormous amount of limestone available as aggregate. Some limestone aggregates polish rapidly and lead to low tire-pavement friction values in a relatively short period. Numerous studies by the individual states and the National Crushed Stone Association have shown that it is possible through proper combinations of aggregates of different wear rates to use most sources of limestone aggregates. Studies indicate that blending is effective in proportion to the amount blended in the proper size range (coarse for asphalt concrete and fine for portland cement concrete) and the polish resistance of the blending aggregate. However, blending requires careful testing and evaluation (described later) during preliminary studies leading to mix design.

As mentioned previously, good skid resistance requires a satisfactory microtexture on the aggregate particles for both low and high speeds and the retention of this texture during the service life of pavements. The action of the tire rubber plus the available abrasive material causes a continuing wear of the pavement surface. Also through a polishing action, aggregate microtexture is reduced. All of this action in most cases leads to a reduction in pavement skid resistance. However, as noted in Figure II, careful use of different aggregates may provide differential wear and a continuing renewal of surface texture.

Tests and Specifications

One of the most difficult problems presently facing the paving engineer is the development of tests and specifications to enable him to characterize the microtexture of aggregates and the degree of retention of such microtexture during service life of the pavement.

There is a necessity for continuing field evaluation of the wear-polish characteristics of various aggregates and combinations of aggregates having different mineralogical compositions. Although continuing field efforts are important it is even more essential that the paving engineer have laboratory tests to provide him with answers for decisions on the suitability of aggregate sources. The importance of such tests should be stressed since the proper choice of an aggregate is not only based on its angularity, microtexture properties, and its susceptibility to polish-wear but also on the availability and cost as well as numerous other required properties. As is well appreciated the design of a pavement is a balancing act and tests that do not provide significant answers and guidance may result in costly mistakes.

Tests of significance in characterizing the resistance to wear-polish are the various petrographic tests which describe the aggregate and its mineralogical composition. This analysis may prove very useful in selection of aggregates if such tests or combinations of test results are correlated with field performance. In addition, special cases require special tests. In the case of limestones and dolomites which sometimes polish very rapidly, the acid insoluble residue test is being explored and has been used in some specifications. As with many tests of this type there is controversy on the interpretation and use of the results.

Recent guidelines (8) comment on the acid insoluble residue test as follows: "It is recommended that this test be used as a laboratory evaluation test, but not be considered as a principal means of predicting resistance to change in tire-pavement friction as governed by polishing action of traffic. The test should be considered as a very useful tool when used in conjunction with the results of field performance of a given aggregate or combination, or when combined with other laboratory tests such as a polishing test and petrographic analysis."

Perhaps the most significant test for predicting the resistance to change during service life is some type of wear-polish test. Although numerous studies have been performed in this connection a fully acceptable test is not presently available. However, the well-known British Wheel Polishing Machine is being studied by ASTM together with other devices for wear and polish determinations. Texas uses this machine for an accelerated polish test for coarse aggregate (Texas H.D. Test Method 438-A, January 1, 1974).

There are two approaches in the attempts to provide design information on aggregate wear and polish resistance, other than experience from field testing. The first involves a laboratory system which determines the change in microtexture of selected aggregate particles. The second involves laboratory simulation of field conditions.

The British Wheel Polishing Machine is an example of the first system. The quantitative measure of microtexture is a very difficult problem and it is best presently done with a low speed friction tester such as the British Portable Tester. This instrument provides friction readings which are relatable to the lower speed range (below 30 mph [13.4 m/s]) in which the dominant factor is microtexture of the aggregate particles. Through the use of this system one may obtain information on coarse aggregates for use in asphalt concrete and aggregate (screening) seal coats such as 1/2-3/8 and 1/4 inch. However, it is not possible to study fine materials with this method.

It is apparent that the second approach is the most logical development for characterizing the total effect of traffic on various pavements or surface treatments. Laboratory systems that simulate field conditions are under active study throughout the world with the use of some form of circular track as the most popular device. Other systems include a stationary spinning wheel wearing and polishing on a fixed area of the specimen and smaller instruments that employ small rotating rubber devices scrubbing on circular specimens. In any case, one of the most difficult problems with such simulation systems is the forming of a test specimen that represents the pavement surface. As an example, the preparation of portland cement concrete test surfaces must provide the same finish and strength as found in the field and with the mortar, water and aggregates in the same proportion relative to field conditions. This may or may not be possible during preliminary design. The use of additional water, for example, during construction finishing operations may result in a weak mortar. A strong mortar is necessary since a mortar weak in strength may wear at a rapid rate and lose good microtexture aggregate. In this case, rapid wear is the dominant factor in the future field condition, but may not show in laboratory studies.

It appears possible to produce realistic test specimens for the various forms of asphalt surfaces although sufficient results are not available to provide firm recommendations.

A problem with a circular track-type machine is the possible displacement of the surface because of the scrubbing motion of the wheel rotating on a short radius. A further problem is the difficulty of tracking in the same area. Most units presently under study, therefore, have a variable radius feature.

A wear and polish machine must produce accelerated results so most test methods employ some additional form of abrasive. There is a definite need for standardization of the abrasive to be used, the grain size or sizes and the time periods for testing with the same or different combinations of the abrasive.

As has been mentioned previously, both microtexture and macrotexture are involved in providing proper skid resistance over the range of speeds encountered in pavement and runway operations. Although microtexture comes into play at all speeds, macrotexture is essential at speeds above 30 mph (13.4 m/s). Therefore, it seems necessary that the full friction curve over a range of speeds be obtained from the wear-polish efforts with the circular or linear track. The British Portable Tester will provide readings that indicate the change in microtexture and represent the friction curve up to about 30 mph (13.4 m/s). Beyond this point macrotexture is of importance. The measurement of changes in macrotexture may be accomplished by use of either the Schonfeld method (33), the sand patch test or the outflow meter. However, these measurements must be correlated with friction readings from field studies.

Another system is actual field studies of trafficked surfaces. Skid resistance measurements are taken at frequent intervals with standardized (ASTM) equipment. There is a need for frequent measurements since there can be significant variations caused by relatively minor changes in environmental conditions. The Pennsylvania DOT studies indicate that this system will provide information of value within one to three years under heavy traffic. There is growing indication that practical equilibrium conditions are reached during this period. If we are to obtain useful data, it is essential that everyone place as many field sections as possible together with duplicate test surfaces in the laboratory. This effort will firm up our future efforts to standardize a method of determining the effect of aggregate wear and polish on tire-pavement friction values over the entire range of speed.

Summary

The development of a standardized laboratory device for wear and polish studies including methods of friction measurements over the entire range of operational speeds is presently of great importance in the many areas of the United States especially where limestone aggregates are the main source of supply. In these areas it may be necessary to avoid such materials or blend them with varying percentages of properly sized aggregates known to have superior wear-polish resistance. A suitable laboratory test would provide vital information for making the most economical selection. Although extensive studies have been performed (9) using a circular track, the only method of measurement of friction change was the British Portable Tester. This does not provide all of the information needed.

At the present time, tire-pavement friction values depend on experience with different aggregate types (noted in Figure II). This experience gained from field and laboratory studies makes possible the selection of aggregate combinations to overcome the problem of rapid polishing aggregates. There is an essential and immediate need for a standardized laboratory test method for producing test specimens, wear and polishing techniques, and proper methods of measuring friction which will predict changes in tire-pavement friction over the entire vehicle speed range. It is necessary that such methods be applicable to all pavement types. To be successful the system must also account for the action of weathering of the aggregate.

Design

A primary factor in achieving a skid resistant roadway or runway is the design of the pavement wearing course. The necessity of achieving a skid resistant surface is just one of a number of factors that must be considered by the designer. Some of the others are:

- Smooth riding qualities.
- Limit excessive tire wear and noise. (Noise is not a factor for runway pavement design.)
- Structural stability in order to withstand forces imposed by maneuvers of vehicles, environment, etc.
- Exhibit desirable qualities for day and night driving under changing environmental conditions.

The attainment of these properties is dependent on the careful selection of the properties of the aggregates and the choice of the cementing agent. The design of the several listed types of surfaces follows:

1. Portland Cement Concrete
2. Asphalt Concrete
   a. Continuous Grading
   b. Gap-Graded or Continuous Grading Mixture with Special Aggregate Additions to Surface
   c. Open-Graded
   d. Sand Asphalt
3. Slurry Seal Coats
4. Aggregate Seal Coats

Portland Cement Concrete

Guidelines for Skid Resistant Concrete Pavement Construction have been recently drafted by joint AASHTO-ARBA-AGC Task Force Number 15. These Guidelines (10) present the latest practical state of the art as follows:

Many factors affect the skid resistance of concrete pavement (28). Among the most important factors are the fine texture (grittiness) of the surface, contributed by the fine aggregate, and the coarse texture formed by the method of finishing. The durability of the surface texture is a function of the wear-resistant qualities of the concrete and the character and volume of the traffic.

Mix Design

Mix design formulation for concrete pavements should consider the quality and durability required to produce and retain good textures, during and following construction. The design of quality concrete mixes is adequately covered in current publications, bulletins, and specifications as issued by the Portland Cement Association, Federal Highway Administration, Federal Aviation Administration, American Concrete Institute and American Association of State Highway and Transportation Officials, as well as many other trade associations and state and federal agencies. Research previously referred to, (28) has shown that, to obtain better wear resistance in the pavement surface, special consideration must be given to the following factors:

- Wear resistance of concrete increases as the cement factor is increased.
- Wear resistance of concrete increases as the water-cement ratio is decreased.

A review and study of this information will indicate that, when designing a concrete mix for a pavement which will carry high traffic volumes or involve conditions that will subject the surface to highly abrasive action, the water-cement ratio should be lower (0.50 or less) than normally required for adequate durability under less severe conditions.

To provide good skid resistance, the proportion of fine aggregate in the concrete mix should be near the upper limit of the range that permits proper placing, finishing, and texturing. The sand content should provide an adequate amount of mortar for proper surface texturing without the addition of water or excessive manipulation.

Air Entrainment

Entrained air should be used in all concrete pavements because of the beneficial effects to both plastic and hardened concrete. An important benefit is to protect the textured surface of the pavement from the effect of alternate cycles of freezing and thawing and the application of deicing salts. Air entrainment also improves concrete in the plastic state by:

- Reducing segregation when hauling in nonagitating conveyances and during placing operations.
- Increasing workability.
- Reducing bleeding.
- Reducing the amount of water required for satisfactory workability.

Each of these factors contributes to the production of an adequate and durable surface texture.

The amount of entrained air needed to produce durable concrete varies with the maximum size coarse aggregate. The Joint Task Force (8) recommends the grading be within the following ranges:

Maximum Size of Coarse Aggregate, In.	Air Content, Percent by Volume
1-1/2, 2, or 2-1/2	5 ± 1
3/4 or 1	6 ± 1
3/8 or 1/2	7-1/2 ± 1

When entrained air is not required for protection against freeze-thaw or deicers, these air contents may be reduced by about one-third, while still obtaining the other benefits of air entrainment.

Aggregates

Where abrasion-resistant aggregates are not economically available, locally available aggregates with relatively low resistance to polishing may be used in the bottom layer of pavement. More expensive, hard and angular polish resistant aggregates would be required in a relatively thin surface course placed while the lower course concrete is still plastic. While this is not yet a common practice in this country, it is expected to be used more often as high quality aggregates become more scarce. The practice is in wide use in Europe.

Fine Aggregate

Research to date indicates that the siliceous particle content of the fine aggregate as determined by the acid insoluble residue test should not be less than 25 percent (28). The siliceous particle content is very important, and where economically feasible, a higher percentage should be required. Where suitable materials conforming to these requirements are not economically available, alternate methods of achieving a skid-resistant surface should be investigated. These might include blending of fine (natural) aggregates with synthetic aggregates or applying wear-resistant particles to the surface of the fresh concrete.

Coarse Aggregate

Coarse aggregate will not affect the initial skid resistance of concrete pavement, but will have an effect if it becomes exposed due to surface wear. The performance record of the coarse aggregate under consideration should be evaluated in terms of skid resistance.

Asphalt Concrete

After consideration of local material availability and environmental conditions, the designer must establish the tire-pavement friction need primarily on the traffic speed. As previously mentioned, a certain degree of microtexture is always needed for both low and high speed traffic; however, high speed traffic requires, in addition, an adequate macrotexture for rapid drainage.

There are a number of different types of asphalt concrete and surface treatments involving asphalt as a binder. Therefore, the designer has much flexibility when working with surface types containing asphalt as a binder. However, the designer must keep in mind that the choice of a surface type in terms of skid resistance must be balanced with other important factors such as availability and characteristics of local materials, climate, traffic and other factors.

The designer must select his aggregates to provide sufficient microtexture as well as a proper choice of crushed particles and gradation to insure adequate macrotexture. Generally aggregates fitting the selected requirements, if exhibiting resistance to wear and polish, will also aid in providing sufficient stability to the pavement. Presently used mix designs such as the Hveem and Marshall methods may be used to obtain the desired asphalt content. The determination of the optimum asphalt content is a very critical design decision, not only for pavement skid resistance but also for structural adequacy. An excess of asphalt cement in any pavement type or surface treatment may rapidly lead to "bleeding" or a "flushed" surface, one of the most serious wet weather skid hazards and a very difficult maintenance problem.

As discussed previously polish resistant aggregates may be scarce in some areas. Under these circumstances, skid resistant mixes may be designed by blending imported coarse polish resistant aggregate with polish susceptible fines. At the present there is rather limited knowledge on the percentages to be used in the blend.

Another method that may be used in this situation is a sprinkle treatment (10). In this case, one may design a continuously graded mix containing a polish susceptible coarse aggregate and, following laydown and prior to rolling, sprinkle the surface with 3-7 pounds/sq. yd. of a polish resistant precoated coarse aggregate. This method has also been used for a number of years in England where very dense mixes, gap-graded, high in sand are laid. These mixes have a very smooth surface, so they are finished with a sprinkle treatment. The designer should be aware that the two designs relative to the application of surface aggregates are for meeting the same criteria, but should be selected on a different basis. In the first system, the surface aggregate is for the purpose of preventing rapid polish of the coarse aggregate in the mixture. In the second case, the purpose is not only to provide resistance against polish, but also to provide a drainage system since the underlying mix within itself will produce a smooth rolled surface.

Another excellent anti-skid pavement is now known as an open-graded friction course. This mix contains about 30-40% voids and has a high film thickness. The voids and heavy texture created by a coarse grading provide an excellent nonskid surface. Both surface drainage and sub-surface porosity are provided so as to drain surface water away rapidly. If the aggregate properties, gradation and asphalt content are properly selected, the resulting mix will not only provide microtexture but, of great importance, outstanding macrotexture. This mix has been found to be a highly satisfactory asphalt concrete surface course for runways (11, 12). Its performance for high speed highways has been excellent.

The designer must be aware of certain overall requirements for open-graded pavement mixtures. Since this type of pavement permits very rapid downward movement of water, the underlying pavement must be impermeable to prevent entrance of free water into the structural section. Cross-slope must be sufficient to allow rapid movement of water through the open-graded surface onto the adjacent shoulder. This is of special importance in hilly country where rapid longitudinal flow of water through an open graded surface may build up water to above the surface in swales, creating a severe hydroplaning situation at these locations.

The most recent design procedure together with gradations and other aggregate properties are found in references 11, 12, 13, and 14.

Another form of surface is sand asphalt mixes. Kentucky Bureau of Highways has proposed four types of sand asphalt surfaces (15) as follows:

Type 1 - dense-graded; for general use.
Type 2 - dense-graded; skid resistant; for moderate speed traffic.
Type 3 - open-graded; skid resistant; intended for moderate traffic.
Type 4 - open-graded; skid resistant; intended for high speed, heavy traffic.

Reference 15 contains proposed specifications for these different types as well as a paper by J. H. Havens on porous sand-asphalt mixtures. This paper describes the development of Type 3 and Type 4 mixtures wherein modification of a sand asphalt paving mixture leads to adequate microtexture and also to direct removal of surface water by downward drainage in the same manner as the previously described open-graded friction course. This would then provide the necessary drainage for high speed traffic.

The recommendations put forward for open-graded sand asphalt (15) have been partially implemented by the Kentucky DOT and the continual development of the state of the art should soon permit the full use of sand asphalt mixtures for the full range of highway speeds. They recommend that sands be selected in terms of mineral composition, gradation and particle shape. The need for excellent wear-polish characteristics of the aggregate, even for lower speed sand asphalt surfaces, is clearly indicated. The dense-graded, moderate speed surface, requires the sand to be either crushed slag or a select angular high-silica material containing at least 75% SiO_2. This requirement must be met on the portion of sand retained on all sieves down to and including the 100 mesh sieve. Field studies by Kentucky clearly indicate the need for controlled wear or attrition under traffic and the accompanying continuous renewal of the all-important microtexture.

Slurry Seals

Slurry seals in most specifications are a form of sand asphalt mixture. The main difference is in the method of preparation and construction. An asphalt emulsion is used in the slurry seal mixture and the percentage of material passing No. 200 sieve is higher than normal. Unless a larger size aggregate is used, most slurry gradations lead to a microtextured surface with little macrotexture for drainage under high speed traffic. Therefore, the material should be considered for use mainly on moderate speed roads unless the designer uses gradations involving larger sized aggregates. As with sand asphalt mixtures, the problem of wear-polish must be carefully considered. Of great importance is the use of proper design tests for asphalt content since these seals are critical in terms of "bleeding."

Aggregate Seal Coats

Aggregate or screening seal coats involving different maximum sized aggregates have been used on pavement surfaces for many years. The designer has flexibility with this type of surface since he is able to provide microtexture and a choice of a maximum size aggregate allows development of gradations that will produce different amounts of macrotexture depending on the volume and speed of traffic.

Design methods are available (16, 17, 18). This state of the art is being used in most States and other agencies for determining the amount of required asphalt. A continuing problem to the designer is the selection of satisfactory aggregates, especially in terms of resistance to wear and polish. Presently, most specifications require a crushed aggregate and many define the geologic type of aggregate. A special problem to the airfield engineer is the selection of aggregate quantities so as to eliminate loose aggregate.

At the present time, methods of design are following the most recent state of the art for the various asphalt surface systems. Once again the problem that must be solved is the development of laboratory methods for preparing test specimens of the different surface types that will simulate the final texture found in the field after completion of construction. Following this, one must standardize a method for wear and polish and a procedure for measurement that will provide measures of change in micro and macrotextures and the significance of such change in the wet tire-pavement friction values for various operating speeds.

Construction

One of the most important requirements for attaining satisfactory initial skid resistance as well as minimum change during the service life is the use of proper construction methods. Methods provided by the specifications must be rigidly followed since such methods are an integral part of the designer's overall procedure for providing a satisfactory surface.

Portland Cement Concrete

One of the surfaces whose tire-pavement friction is heavily influenced by variables in construction techniques is portland cement concrete pavement. The creation of a satisfactory macrotexture or surface dtainage system for this type of pavement is primarily dependent on the construction procedure followed during surface finishing operations.

The state of the art for concrete pavement finishing shows many recent improvements. The old traditional method of forming striations by burlap dragging does not consistently furnish surface sufficiently textured. Other methods are under intensive investigation. Numerous field trials are underway on both highways and runways. Recent proposed guidelines (8) recommend burlap finishing only where low speed limits are in effect. Instructions for burlap finishing in combination with plastic grooving are available (30). According to reference (19), 46 states in 1969 were approving a burlap-drag finish of highways; however, in most cases the burlap drag finish resulted in less texture depth than recommended by leading organizations involved with concrete pavement technology.

It is interesting to consider the possible reasons for failure of the normal burlap drag system to provide adequate resistance to wear and polish. According to Reference 19, research on actual pavements under traffic disclosed that for texturing methods using burlap drags, brooms, and belts, generally the wear rate increased with texture depth. "Probably this rapid rate of wear is due to the fact that most of the texture above the general plane of the surface has less strength and abrasion resistance than the mass of the slab." Experience indicates that the situation presented above may not be due to the inadequacy of the burlap method as specified by the designer, but the actual nature of the finishing operation. For instance, the use of excessive water during the final finishing operation.

After problems occurred with the burlap drag, the use of brooms for finishing was instituted. This treatment produces a deeper texture with better drainage, and several States now approve the use of this method. However, according to Reference 19 most engineers preferred a fairly light brooming to minimize noise from roadways (noise is no problem for runways).

The development of sawed grooves in the hardened concrete of highways and airport runways as a system for increasing drainage and thereby reducing the danger of hydroplaning is well known (20, 21, 25, 26). The high reduction in accidents clearly indicated that grooving might be very effective for the original concrete surface. Research continues on methods for texturing plastic concrete. An excellent survey of the status of these methods is available (19). A continuing problem is the direction of sawed grooving. All grooving on airport runways has been in the transverse direction which, based on cross slope and water movement, etc., is the most efficient direction (29). The British have demonstrated that transverse grooving for highways is effective (4). On the other hand, extensive wet weather accident studies in California (22, 24) have clearly indicated excellent results with longitudinal grooving, especially on curves.

On the basis of the results from presently available studies (19), the state of the art is to groove both highways and runways employing combs with steel tines while the concrete is in the plastic state condition. The depth and width of the grooves is still a subject for further field studies. However, a tentative guideline has been suggested by the American Concrete Paving Association (30).

Methods for forming plastic grooves are still in a stage of development. A factor of great importance, as with other forms of finishing operations, is timing for texturing. The optimum time to texture depends on such variables as consistency of the surface mortar, temperature, humidity, and wind velocity. In other words, correct timing must be determined on the job as the job progresses. Presently, experience must be the final judge. There is little doubt that research into texturing of portland cement concrete pavements should be given the highest priority in the immediate future by paving engineers. As stated in a number of places in this paper, it does little good to form an adequate texture in a portland cement concrete pavement if the texture virtually disappears within a few years. In fact, skid-prone surfaces due to such wear was the reason for the development of grooving of existing highways. If the surface mortar strength is properly maintained during construction operations, then the primary construction factor influencing durability and wear resistance of the concrete surface is the effectiveness of curing. Curing compounds have been developed and machines built for uniform application. The use of presently available knowledge result in a durable ourface. However, in future field trials involving plastic grooving, careful observations should be made of the coating of the sides and bottom of the grooves. Effective coating of these areas is of great importance, especially at the groove-surface edges where spalling could occur. Another concern is that the grooves be of sufficient width and depth so that the curing compound coating does not materially decrease the area of the groove. It should be noted that this could effectively reduce the drainage capacity of the groove and defeat the purpose of the operation since compound in this area will not be removed by wear of traffic.

Another possible method for preventing wear of the surface is the use of hardening agents such as polymers. This type of treatment is in the experimental state (23). Because of high cost, laboratory and field studies are necessary prior to use.

Asphalt Surfaces

As previously stated in the section on Design, there are two major ingredients in providing skid resistance in asphalt concrete mixtures: large-scale texture, and fine, gritty texture, each is controlled by the aggregate size gradation and mix design. Therefore, a proper design involving a continuous grading, if rigidly followed during construction, should lead to a satisfactory tire-pavement friction.

When special aggregate additions (sprinkle treatments) are made to the surface during construction, certain difficulties may be encountered. This is probably caused by the newness of the system and the need for special equipment. Such equipment has been designed and built by the Virginia Department of Highways and used successfully to apply a precoated aggregate. Such a system is used to provide a skid resistant layer over a mix containing locally available polish-susceptible aggregates. This type of construction requires carefully-controlled construction practices or serious problems may occur with bleeding or rapid polish of the susceptible aggregates. Open graded friction courses require careful construction control (11, 13, 14, 29). Control of mixing temperatures, limitations during adverse ambient periods, proper preparation of existing surface including cleaning and tack coating are some of the important variables that should be under strict control. Many miles of roads and, recently, airport runway areas have been successfully constructed with such porous friction courses. The state of the art is being followed with some well-defined methods for proper construction practices.

Sand asphalt mixes also have well-defined and recommended construction practices (15).

All forms of seal coats, sand, slurry and aggregate require the use of proven construction methods, satisfactory environmental conditions, careful quality control of materials and adequate traffic control. Improper construction has resulted in aggregate loss from seal coats, while the prevention of such losses from roadways is important, it is critical to runways. Construction equipment for seal coat operations has been developed to a very satisfactory state.

Distributors, when kept in proper condition, are capable of spreading an accurate desired amount of binder in a uniform transverse and longitudinal direction. The spreading of aggregates (screenings) in a rapid and uniform manner can now be accomplished by available equipment. Rolling with both pneumatic and steel-wheeled rollers is easily accomplished. However, the state of the art still requires a great deal of experience. Weather conditions at the time of sealing, and traffic control in the first hours after construction, are very critical to the future performance of the seal coat. References 17, 18, and 29 should be carefully studied.

In summary, we can now say with assurance that our present construction procedures can build surfaces for either roadways or runways that provide satisfactory skid resistance. As pointed out previously, the production of a "durable" texture for portland cement concrete pavement is still under investigation and the necessary machines to perform what appears to be a satisfactory solution are still under development.

Even with adequate design, asphalt surfaces may present future problems in maintaining proper tire-pavement friction values because of poor construction procedures. Hankins writes, private communication from Texas Highway Department) "We feel future work is needed on the effects of construction on skid resistance. When we study the polish rates of different construction jobs even using exactly the same mix, large variations in skid resistance are noted as traffic applications cumulate. Some of this variance is due to 'weathering' or seasonal effects, but there is also variance resulting from construction differences."

Probably the most serious skid problem encountered with asphalt pavements is bleeding or failure of surface treatments. This can be prevented by known mix design procedures and proper construction control.

A very important objective for the future should be the continuing effort to improve construction procedures so that a uniform pavement texture is attained that complies in all respects with the design of that surface in terms of original and service life skid resistance requirements.

Maintenance

The present state of the art of design and construction of skid resistant pavements can provide an anticipated service life. However, construction problems, materials variations and increases in traffic beyond that assumed during design may cause an accelerated service wear and polish to occur, leading to an unsatisfactory skid resistance short of the calculated service life of the facility. Therefore, to be assured that a satisfactory roadway or runway is maintained throughout the service life, the continued use of the pavement will require some form of rehabilitation in order to insure a reliable skid resistance, rideability and structural adequacy. It may even be necessary to cover the existing surface which will require a new design and adequate skid resistance.

Portland Cement Concrete

A method of maintaining skid resistance of portland cement concrete pavements is the sawing of grooves in large areas of concrete surfaces. This technique is outlined in the chapter on Construction. The present state of the art is summarized in reference 26.

Methods for modifying existing concrete surfaces to increase skid resistance are acid treatment, different forms of mechanical abrading and sawed grooving (previously mentioned). References 2 and 27 provides information on the use of such methods. According to reference 2 the benefits from acid etching are rather short lived; usually such treatment will be effective for less than a six-month period. There are a number of different methods for mechanical abrading of existing concrete surfaces. One method employs a machine with hardened cutters rotating on a drum. Another machine uses several percussive hammers mounted side by side. These strike the pavement at a rapid rate and each impact removes a small amount of the existing surface material. These methods improve the tire pavement friction and increase drainage; however, the degree of improvement and the duration of such an improvement is difficult to assess since the nature of the existing surface will govern the amount of change in texture.

Asphalt Concrete

Asphalt concrete pavements and seal coats may suffer a loss in skid resistance in a number of ways. The existing surface may become worn or polished or, because of an excess of asphalt or loss of surface aggregates, a "bleeding" condition may occur.

In the case of isolated "bleeding" a heater planer treatment may be used for removal of the excess surface asphalt and, coupled with an immediate application of screenings or sand, the tire-pavement friction may be definitely increased. However, this treatment should, in most cases, be considered as temporary since excess asphalt throughout the pavement may again cause a "bleeding" condition.

Depending on the surface condition, grooving may be performed on asphalt concrete pavements. Such pavements should be those with a high aggregate content and of such age that the asphalt binder is relatively hard. At the present time, insufficient information is available on the state of the surface that will insure the grooving to be "durable".

Probably the best system for improving the tire pavement friction value is the application of a new asphalt concrete surface. All of the previously discussed surfaces (seal coats, blankets, etc.) may be used for this work. The thickness will depend on whether such an overlay is to correct only skid resistance or is also being used for improving structural adequacy. In any case, the same care in design and construction must be used for resurfacing as used on the original pavement.

A serious problem encountered on runways of any material is the buildup of rubber from tires of aircraft. This markedly reduces the tire-pavement friction. A number of methods are available for removing the rubber, including chemicals, high pressure water blasting, sand blasting, and shot peening, to improve friction.

The Future

The paving engineer has the responsibility to provide adequate tire-pavement friction for contemplated operating conditions and for a satisfactory period of service. At the present time he does not have the required tools to fulfill these requirements with the necessary degree of confidence, especially when one considers the economic aspects of pavement design and construction. The following areas are recommended for high priority attention by researchers and paving engineers. A most important objective for the future is the development of laboratory methods, properly correlated with field studies, that will provide test specimens which represent all forms of pavement surfaces, a wear and polish system that simulates the action of traffic and, finally, methods of friction measurement that will recognize micro and macrotexture effects through the operating range of vehicle speeds. The accomplishment of these tasks is far from complete. Their importance cannot be overstressed since an increasing amount of effort is being expended on determining minimum standards for skid resistance. Once such standards are adopted, the designer must have the tools to design a surface to meet the standards.

Another immediate need is for intensive study of construction practices for both asphalt and portland cement concrete. Design of equipment to produce an adequate surface texture for portland cement concrete pavement is needed. Such a surface to provide the desired initial requirements for micro and macrotexture and prevent such values from falling below a minimum value during the assumed service life.

Studies should also be initiated on construction control parameters that influence the uniformity of pavement friction values and surface undulations (this latter is of special importance to runways).

Acknowledgements

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PAVEMENT CONTRIBUTIONS TO WET-WEATHER SKIDDING ACCIDENT REDUCTION

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This paper reviews the state of the art in the United States of the contributions of pavement surface characteristics to the reduction of wet-weather skidding accidents. Although primary emphasis is on road and street pavements, the surface characteristics and wet-weather performance of airfield pavements are also discussed. With regard to roadway pavements, the scope of the paper includes surface characteristics needs in relation to geometrics and traffic, types of surfaces currently being used, and methods for measuring surface characteristics. Current practices and research findings that are considered suitable for implementation are covered. Skid resistance, described as the skid number (SN) measured in accordance with ASTM Method E-274, is the most generally used method to characterize roadway pavements. Texture and surface drainage are becoming increasingly recognized as characteristics to be considered. The method of skid-resistance measurement in widest use in the U.S. uses properly calibrated locked-wheel skid trailers conforming to ASTM Method E-274. No nationally accepted pavement surface characteristics requirements have been established. A SN of 37 measured at 65 km/hr (40 mph) is the most generally recognized surface requirement for main rural highways with a mean traffic speed of 80 km/hr (50 mph.)

Although motor vehicle accidents have decreased in the United States during the past two years, the unpleasant 1975 statistics show that motor vehicle accidents for that year cost $21.2 billion and resulted in 1,800,000 disabling injuries and 46,000 deaths (1). Wet-weather traffic accidents are estimated to be responsible for about 15% of motor-vehicle injuries and fatalities (2). Wet-weather traffic exposure (that percentage of total vehicle-miles exposed to wet pavements) is very difficult to determine on a national scale. One study (3) indicates that wet pavements exist about 6% of the driving time in Central Texas. Another study (4) has found that a rainfall intensity of 0.25 mm/hr (0.01 in./hr) or greater occurs only about 3.5% of the time over the state of Illinois. Use of such figures indicates that wet-weather accident rates are several times dry-pavement rates. At certain high accident sites, the wet-weather accident rate may be 10 to 20 times the dry-pavement rate. For example, 55 accidents were recorded on one curve of the Ohio Turnpike during a 4 1/2-year period. Of these, 37 (67%) were reported as involving skidding on a wet pavement.

With the intent of zeroing in on this important aspect of highway safety, Project 1-H, "Skid Accident Reduction," has been included in the Federally Coordinated Program of Research and Development in Highway Transportation in the U.S. During the past 10 years almost $20 million has been spent or programmed in this area, with the over-all objective of reducing the frequency and severity of accidents associated with skidding and loss of control on wet pavements. The project includes Federal Highway Administration (FHWA) staff studies, direct FHWA contracts, National Cooperative Highway Research Program (NCHRP) projects, and many individual state highway agency studies.

This paper deals with the state of the art in the U.S. of the contributions of pavement surface characteristics to the reduction of wet-weather skidding accidents. It describes current practices and the findings of research considered suitable for implementation. The paper is divided into the specific areas of (a) highway geometrics and the needs of traffic, (b) surface characteristics, (c) measurement of surface characteristics, and (d) airfield pavements.

Highway Geometrics and Traffic Needs

Skidding of a rubber-tired vehicle occurs when the forces developed at the tire-pavement interface exceed the ability of the particular tire and pavement surface, under the existing environmental conditions, to develop frictional resistance. Under dry conditions the friction between the vast majority of pavement surfaces and tires is adequate to accommodate all but the most severe vehicle maneuvers without skidding. However, when wet the ability to develop tire-pavement friction is substantially reduced and becomes much more dependent on the characteristics of both the tires and the pavement surfaces.

Assessment of contributions of pavement surfaces to the reduction of wet-pavement skidding involves driver demands (the intensity of acceleration, braking, and cornering maneuvers) and demands resulting primarily from roadway geometrics (hills, curves, intersections, merging lanes, etc.). Approaches for determining the relative ability of pavement surfaces to make adequate contributions to the needs of traffic have traditionally involved analysis of accident records. This approach combines the influences of driver, vehicle, pavement, and environmental factors on accident experience and identifies locations in obvious need of corrective action. Current recommendations for minimum pavement skid resistance, texture, and other characteristics intended to provide for safe maneuverability during wet weather are generally based on the accident analysis approach.

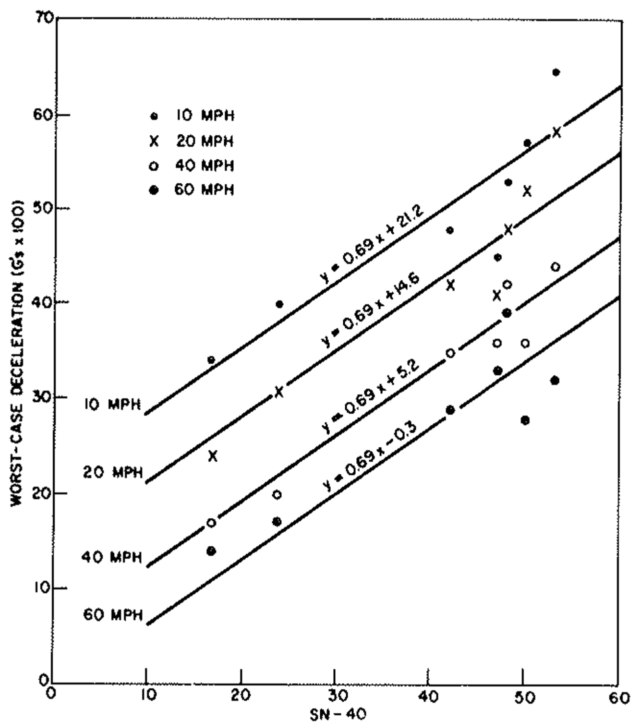
An alternate approach for determining needed pavement surface characteristics to accommodate the needs of traffic involves measurement or computation of the traffic demand or acceleration forces developed by given sets of conditions (maneuver and roadway geometry) and the correlation of these forces with friction forces developed by anticipated vehicle-tire combinations on various pavement surface types. This approach presents the opportunity for determining the pavement surface characteristics required to accommodate the variability of traffic needs on different sections of roadway. For example, different pavement surface characteristics may be desirable to provide for safe maneuverability of traffic during wet weather on rural tangents, residential streets, urban freeway curves, signalized intersections, merging zones, etc.

Acceleration forces, expressed in units of the gravitational constant, g, may range from practically zero for a vehicle coasting on a straight grade to 1.0 g or more during emergency braking. The latter is beyond the capability of conventional automobile brake systems and thus not realistic as an anticipated tire-pavement force. Research has shown that a majority of drivers develop about 0.2 g during normal driving, with an upper reasonable limit of 0.6 g for emergency stops from 95 km/hr (60 mph) within 60 m (200ft) (5). In addition to braking, acceleration forces are developed during such maneuvers as acceleration from stop, passing, steady-state cornering, combined cornering and acceleration, and combined cornering and braking. These result in various longitudinal and lateral forces that can be computed for given speeds and geometries. For generally accepted speeds and modern design standards, practically all of the resulting acceleration forces are within the 0.2 g to 0.6 g range previously mentioned.

Controlled-skid studies to determine relationships between longitudinal acceleration forces and pavement skid-resistance requirements have been conducted. Seven skid pads of varying surface characteristics and two instrumented automobiles, a 1970 Plymouth Fury and 1971 Ford Mustang, were used. Three sets of tires (conventional bias ply, belted bias ply, and radial) were used on the Plymouth and belted bias ply only on the Ford. All tires were relatively new. For the purpose of developing correlations, the skid resistance of each test pad was measured as skid number (SN) at 32, 65, and 96 km/hr (20, 40, and 60 mph) using a locked-wheel skid tester in conformance with ASTM Method E-274 (5).

It is apparent from analysis of the data that complex interactions exist between pavement surface characteristics, speed, tires, and other vehicle factors. No tire-vehicle combination produced the highest maximum deceleration (negative longitudinal acceleration) for all surfaces and speeds. However, a plot of maximum deceleration versus skid number (Fig. 1) (5, p. 24) was developed in which each point is the worst case from the four tire-vehicle combinations at each of the speeds for each of the given skid pads. Each point represents the average of six skid tests. With measured or computed speed and longitudinal acceleration values for braking sites, the figure can be used to select estimated pavement skid-resistance requirements for braking sites (such as intersections).

Figure 1. Minimum locked-wheel braking deceleration values as a function of NBS SN_{40}.



Similar studies have been conducted in an attempt to determine relationships between lateral accelerations and pavement characteristics as measured with a locked-wheel tester in conformance with ASTM Method E-274 and with the University of Michigan Mobile Tire Tester that measures cornering slip number (CSN). The limited amount of data available indicates that neither tester characterized pavement surfaces adequately for development of a reasonable correlation with lateral acceleration forces. The difficulty seems to arise from the strong interaction between pavement surfaces and tire-vehicle characteristics. This is supported by another testing program that found good correlation between locked-wheel skid trailer measurements and maximum automobile cornering speed when the same tires were used on both the skid tester and the automobile (6).

Skid Resistance, Surface Drainage, and Texture

The characteristics of a pavement surface that have been identified as influencing the safe maneuverability of rubber-tire vehicles on pavements, particularly when wet, are skid resistance, texture, and surface drainability. Of these, skid resistance has received the greatest amount of attention from the standpoint of both research and operational programs intended to reduce wet-weather skidding. Current practices in the U.S., as well as recent research findings, are discussed for each of these characteristics.

Pavement skid resistance. Tire-pavement friction is the horizontal force developed when a tire that is prevented from rotating slides along a surface. The development of this force involves both the tire and the pavement. In the highway field, pavement skid resistance is the characteristic or capability of the pavement to develop horizontal friction forces on a skidding tire. It is described as the skid number (SN) measured in accordance with ASTM Method E-274, involving the sliding of a locked standard tire at a constant speed along an artificially wetted pavement surface.

NCHRP Report 37, "Tentative Skid-Resistance Requirements for Main Rural Highways," (7) discusses the problem of determining minimum pavement skid resistance and contains a table listing tentative requirements for main rural highways based on data and information available at the time of its preparation. Table 1 (7, p. 54) gives the tentative minimum SN values for various traffic speeds that are generally applicable for the large percentage of rural roadway mileage. Because skid number measurements and accelerations developed by maneuvers are both significantly influenced by speed, the recommended minimum SN_{40} values vary with mean traffic speed. Although there is no nationally accepted minimum pavement skid resistance, the U.S. Department of Transportation Highway Safety Program Manual No. 12, "Highway Design, Construction, and Maintenance," (8) prepared in response to the Highway Safety Act of 1966, contains the table from NCHRP Report 37 as a general guide. In addition, individual state highway agencies have included skid-resistance requirements in state safety programs. For example, Table 2 (9) is from the Louisiana Department of Highways' Skid Accident Reduction Program as the guide for construction of pavement surfaces that will retain adequate skid resistance under traffic in Louisiana.

The ratio of wet-pavement to dry-pavement accidents is useful in determining critical pavement skid resistance values. A study in Kentucky found that the ratio of wet- to dry-pavement accidents on rural two-lane roads decreased rapidly as the SN_{40} value increased to about 40; further increases in skid resistance resulted in only slight reduction in the ratio (10). The average ratio was about 0.25 for pavement with SN_{40} values above 40 and increased to 0.60 as SN_{40} values decreased.

The construction and maintenance of all roadways with wet-pavement skid resistance comparable to dry pavements may not result in the best use of available materials and funds. Meaningful requirements should be based on actual conditions and traffic demands of a site. For example, higher values of skid resistance are needed on approaches to intersections than on rural tangents, particularly in regions of above-average precipitation. From the results of a study of skid-resistance requirements, it appears that a strong general relationship exists between the pattern of braking decelerations at an intersection and pavement skid-resistance needs (5). A reasonable approach to development of pavement skid-resistance requirements may be the determination of requirements for groupings of roadway site types such as (a) level and nearly level tangents, (b) steep grades, (c) long-radius curves, (d) short-radius curves, (e) intersections, and (f) special situations. It should also be recognized that skid resistance is not the only factor that influences the safety or the hazard potential of a site. Traffic volume and speed plus the prospect for wet-pavement conditions all should be considered when determining surface characteristics for safe operation.

Table 1. Recommended minimum interim skid numbers[a].

MEAN TRAFFIC SPEED, V (MPH)	SKID NUMBER	
	SN[b]	SN_{40}[c]
0	60	—
10	50	—
20	40	—
30	36	31
40	33	33
50	32	37
60	31	41
70	31	46
80	31	51

[a] Skid numbers measured in accordance with ASTM E-274 Method of Test.
[b] SN = skid number, measured at mean traffic speeds.
[c] SN_{40} = skid number, measured at 40 mph, including allowance for the skid number reduction with speed using a mean gradient of $G = 0.5$.

Table 2. Guide values for new construction.

ADT per Lane	Minimum SN_{40}
Less than 200	40
200-999	43
1000-5000	45
More than 5000	47

Drainability. Water depth on a pavement surface has a critical influence on the safe operation of vehicles on pavements. Tire hydroplaning is commonly considered to be the adverse effect from excess water. In actuality, complete hydroplaning, even with smooth tires, is probably a rare occurrence. The vast majority of wet-weather skidding accidents undoubtedly occur as the result of water depths well below those needed for complete hydroplaning. This degradation of tire-pavement friction as a consequence of the presence of water is referred to as partial hydroplaning.

The Texas Transportation Institute has conducted a study of wet-weather performance of ten different tire conditions on five different pavements at various water depths and speeds (11). Wheel spin-down (reduction in wheel speed as it is pulled over a wet pavement) was used as a measure of reduction in tire-pavement friction forces. The testing program demonstrated that increasing water depth decreases the speed at which spin-down is initiated. A wheel spin-down of 10% was considered to result in sufficient deterioration of available tire-pavement friction to adversely affect vehicle steering and braking ability.

Research on methods for predicting pavement water depth as a function of rainfall intensity and pavement geometrics has been conducted by the Texas Transportation Institute (TTI), the British Transportation and Road Research Laboratory (TRRL), and the Goodyear Tire and Rubber Co. It is concluded that pavement width (drainage length) and cross slope are the primary roadway factors affecting the drainability of a pavement surface. On a two-lane crowned roadway with a cross slope of 1.5%, a drainage length of 3.65 m (12 ft), a rainfall intensity of 6.4 mm/hr (0.25 in./hr), and using the TRRL formula, the computed maximum water depth would be 0.7 mm (0.028 in.) Using the same cross slope, rainfall intensity, and formula, the computed maximum water depth for a multilane roadway sloped in one direction only, with a drainage length of 10.4 m (34 ft), would be 1.2 mm (0.046 in.) (12).

A study of accident data for the Ohio Turnpike, as given in Table 3 (12, Table 1), indicates that the ratio of wet-pavement to dry-pavement accidents is several times higher for curves of about 1° than for tangent sections. The drainage lengths are 3.65 m (12 ft) on tangents and 10.4 m (34 ft) on superelevated curves. The cross slope is 1.5% for both tangents and 1° curves. There was no indication that pavement skid resistance was significantly different on tangent and curve sections (12).

A Louisiana study of roadway geometry variables on traffic accidents found that of the ten geometric variables considered, pavement cross slope and the number of roadway access points (conflicts) were the two, interacting with traffic volume, having the greatest effect on accident rates (13). It was also found that cross slope had a more significant influence on accident rates during wet weather than during dry weather. These data indicate a rather dramatic relationship between pavement cross slope, water depth, and wet-weather skidding accidents, and thus the importance of provisions for adequate surface drainage.

In addition to cross slope, porous or open-graded asphaltic concrete improves the drainability of pavement surfaces. The concept involves use of a narrowly graded coarse aggregate with sufficiently large void capacity to provide for a high asphalt content for durability and high air void content for internal drainage. This pavement mix can be used as the surface course of a new pavement or as an overlay over existing pavements. When properly designed and constructed, they provide superior skid-resistance characteristics and, more importantly, quite uniform SN values with increases in speed (rather flat SN-speed gradient curve).

Problems that were experienced during the development and early use stages of the open-graded asphaltic concrete pavements have largely been overcome. "Design of Open-Graded Asphalt Friction Courses" published by the Federal Highway Administration (14), contains detailed instructions on mix design and construction control procedures. The recently completed FHWA Demonstration Project, "Improved Skid-Resistance Pavements," resulted in installation of open-graded surfaces in 12 states and technical assistance in the design of mixes in nine additional states. Use of this type of surface is increasing, with their use extending to a majority of the U.S. state highway agencies.

Table 3. Accident experience by surface condition, Ohio Turnpike.

DEGREE OF CURVATURE	ACCIDENTS NUMBER	PERCENT DRY	PERCENT WET	PERCENT OTHER*
0°0'	3,317	61.5	18.5	20.0
0°1' to 0°21'	619	56.7	27.6	15.7
0°22' to 0°43'	621	54.4	32.2	13.4
0°44' to 1°5'	616	34.9	53.4	11.7
1°6' to 1°27'	96	60.4	27.1	12.5
1°28' to 1°49'	73	56.2	32.9	11.0
1°50' to 2°11'	78	55.1	21.8	23.1
2°12' to 2°33'	133	47.4	21.8	30.8
All	5,553	56.7	25.4	17.9
GRADE, PERCENT				
+1.5 to +2.4	649	57.5	22.2	20.3
+0.7 to +1.4	547	55.9	23.6	20.5
-0.6 to +0.6	2,879	59.9	24.8	15.2
-1.4 to -0.7	642	52.8	25.7	21.5
-2.4 to -1.5	708	49.4	29.2	21.3
-3.5 to -2.5	83	36.1	49.4	14.5
All	5,553	56.7	25.4	17.9

*Consists largely of snow/ice conditions.

Texture. Texture is a characteristic of pavement surface that is interrelated with skid resistance and drainability in providing for safe maneuverability of motor vehicles during wet-weather conditions. It is usually described as "macrotexture" - the more coarse roughness of the surface formed by the presence of individual particles of aggregate or the texturing of mortar while in a plastic state - and "microtexture" - the fine roughness of the pavement surface attributed to the texture of the individual coarse-aggregate particles or the presence of very fine aggregate in the mortar.

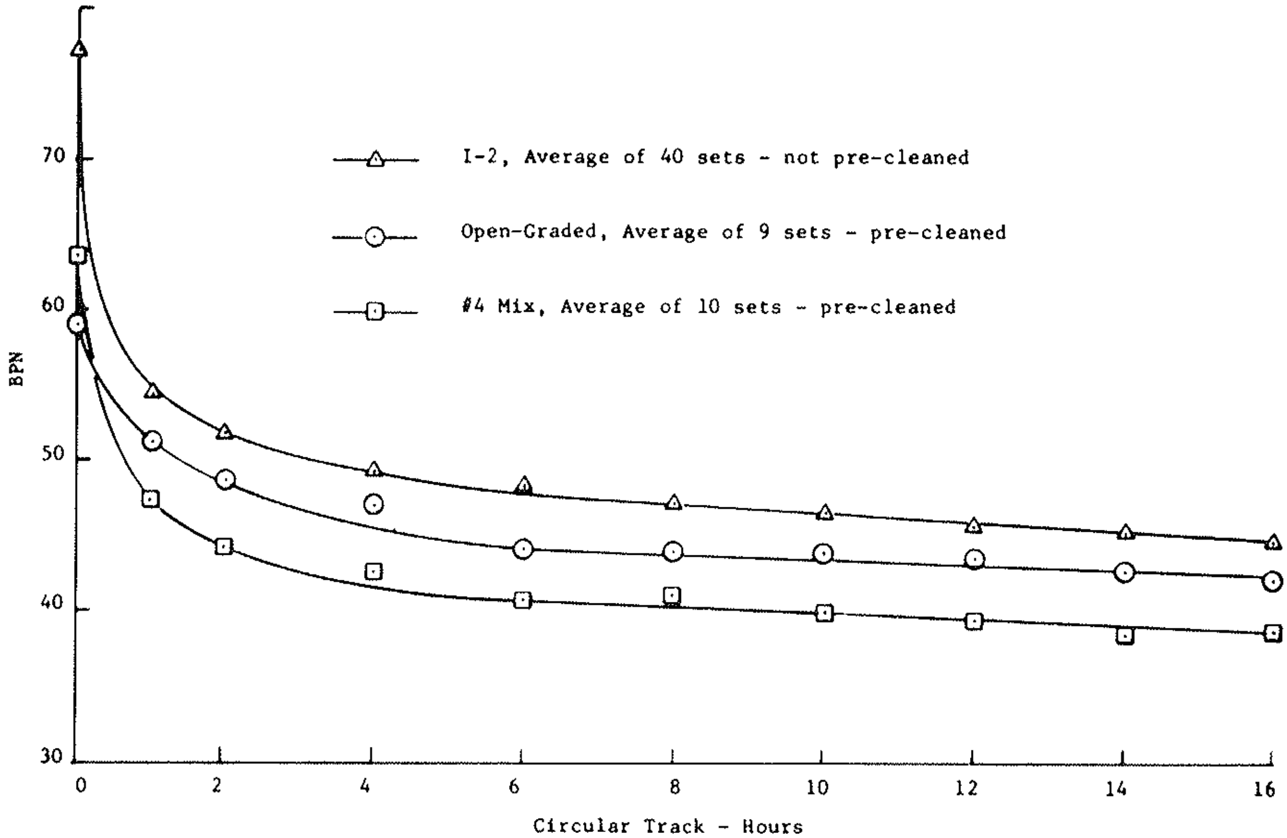
The microtexture of a pavement primarily influences skid resistance at lower speeds. The macrotexture contributes to drainage of water from beneath a tire and thus improves maneuverability at higher speeds and results in a more desirable skid-resistance speed gradient, defined as the slope of the SN-speed curve between the speeds of 50 and 80 km/hr (30 and 50 mph). Texture can be obtained through pavement mix design, size and grading of aggregates, construction procedures, surface finishing methods, and the grooving, etching, or scarifying of hardened surfaces.

In general, the texture of a pavement is at its best level when new or after an initial traffic break-in period. Continuous use by traffic tends to result in a gradual deterioration in the broad categories of polishing or reduction in microtexture and wearing away of macrotexture. In asphaltic concrete the coarse aggregate is primarily subjected to polishing, whereas the fine aggregate and the mortar of portland cement concrete usually becomes polished or worn away. The result is a reduction in skid resistance, particularly in the wheelpaths, consequently deterioration in wet-weather performance.

Because aggregates comprise more than 90% of a pavement mixture, the desirability of selecting wear- and polish-resistant aggregates for pavement surfaces expected to carry relatively high traffic volumes is quite obvious. This involves laboratory evaluation of aggregates and pavement specimens, with the objective of predicting polish-resistance and skid-resistance performance. Laboratory methods found to be useful include circular track devices that simulate field conditions, determination of polished stone value (PSV), and petrographic studies. North Carolina State University has developed methods for determining the polishing properties of aggregates in the laboratory as a step to predicting with reasonable assurance the limits of field polishing of aggregates and pavement mixtures based on the laboratory tests (15). A small-wheel circular track is used to condition laboratory-prepared pavement specimens and friction measurements are made at periodic time intervals using a British portable tester. The British portable numbers (BPN) thus determined have been correlated with skid numbers (SN) measured at 32, 48, 65, and 80 km/hr (20, 30, 40, and 50 mph) with the North Carolina Highway Commission locked-wheel skid trailer. Predictions of the maximum field polishing during the service life of North Carolina pavements can be made. Figure 2 (15, p. 60) shows the relationship between BPN and time of exposure on the circular track for three types of asphaltic pavement mixtures. It appears that an exposure of 6 hr is adequate to establish a polish curve for these North Carolina pavements.

The results of an extensive experimental program

Figure 2. Wide pneumatic tire correlation curves for the standard aggregate.



involving the exposure of 36 pavement sections to simulated traffic of up to 7,000,000 wheel passes on a circular test track generally confirm previous research and experience concerning the importance of aggregate selection to wet-weather performance of pavements. The laboratory test values for each aggregate used in the pavement sections are given in Table 4 (16, Table 3). The Texas polish value was determined in accordance with Texas State Department of Highways and Public Transportation test method Tex-438-A, similar to the British polished stone value test. It was generally found that all pavement sections had high initial skid resistance values, as determined by the British portable tester. The trend was for the skid resistance to drop very rapidly during the first 50,000 wheel passes, continue to reduce at a moderate rate through 1,000,000 wheel passes, and then continue to reduce at a slow rate through the 7,000,000 wheel passes. During this particular test program there did not appear to be a terminal polish level. From a relative standpoint, the skid resistance of the pavement sections was consistent with the polish values of the aggregates used. The other tests did not appear to be helpful in predicting skid resistance (16).

To provide for adequate microtexture of

Table 4. Results of tests on aggregates.

Aggregate	Texas Polish Value	L.A. Abrasion Loss, % 100 rev.	L.A. Abrasion Loss, % 500 rev.	Modified L.A. Abrasion Loss %	Modified L.A. Abrasion Sediment ht., in.	California Durability	Washington Degradation
Crushed trap rock	33	2.5	9.9	9.1	7.4	87	93
Crushed graywacke	46	4	20	18.8	13.9	70	67
Crushed quartzite	34	4.5	19.4	15.9	8.9	96	96
Expanded shale	50	6.6	24.8	---	---	96	87
Calcined bauxite	44	---	---	---	---	100	96
Crushed limestone	22	---	16.6	14.6	8.6	90	84
Typical requirements:	35 min.	10 max.	40 max.	40 max.	13 max.	35 min.	25 min.

Table 5. Tentative recommended polished stone values for various traffic volumes*.

Traffic, Vehicle Passages Per Lane Per Year	Median Polished Stone Value	Range
50,000 to 150,000	28	26.5 - 29.5
150,000 to 600,000	32	30.5 - 33.5
600,000 to 2,500,000	37	35 - 39
2,500,000 to 10,000,000	42	40 - 44
10,000,000 +	47	47 - 49+

*Accelerated Polish Test for Coarse Aggregate TEX 438 (a combination of British Standard 812 and ASTM E 303, The British Wheel and the British Pendulum Tester).

asphaltic concrete pavements, a Texas Transportation Institute study (17) suggests tentative polish values (using Tex-438) for various traffic volumes as shown in Table 5 (17, p. 163).

Pavement macrotexture contributes to wet-weather skid accident reduction from the standpoint of (a) increasing skid resistance and improving maneuverability on wet pavement and (b) improving drainage of water from beneath tires and thus reducing hydroplaning tendency during more intensive rainfalls. The practice of longitudinal and transverse tine finishing of the plastic mortar during construction of portland cement concrete pavements is growing quite rapidly in the U.S. This produces a harsh macrotexture that is somewhat moderated during the first year of traffic exposure, followed generally by quite uniform resistance to wear for many years unless subjected to studded tire or chain wear.

The macrotexture of asphalt pavement is normally developed by the coarse aggregate in asphaltic concrete mixes, precoated aggregate rolled into asphaltic concrete, or use of asphalt seal coats. Performance of these surfaces is influenced by the ability of the asphalt cement to retain the coarse aggregate and by the wear and polish resistance of the particular coarse aggregate used. Open-graded asphaltic concrete is also produced with a rather coarse macrotexture.

Limiting texture values, independent of skid resistance, have not been generally accepted at this time. A study by the Texas Transportation Institute recommends tentative minimum values of 1.0 mm (0.04 in.) for dense pavement surfaces, and 1.3 mm (0.05 in.) for open graded and coarse-textured surfaces, as determined by the modified sand patch method (17). Acceptable noise levels will probably be the limiting factor for maximum macrotexture values. The acceptable noise level in urban areas will generally be lower than in rural areas. For example, asphalt seal coats generate higher noise levels than open-graded surfaces of the same macrotexture. Based on the noisiest pavement type (seal coats), the suggested macrotexture is 3.9 mm (0.15 in.) for rural areas and 2.5 mm (0.10 in.) in urban areas.

The following statement on texturing of plastic portland cement concrete surfaces is from FHWA Notice N 5080.95, September 10, 1976 (18):

> Transverse grooving will provide a pavement surface with good skid-resistance characteristics, will reduce splash and spray and headlight glare from wet roadway surfaces, and will continue to facilitate surface drainage until the depth of the wheelpath ruts exceeds the depth of the grooves. Longitudinal grooving assists vehicle control at curves and sites involving lateral movements. Both types of grooving effectively reduce the hydroplaning potential. The longitudinal grooving of existing pavements, while not necessarily producing an improvement in skid number, has been found to be a very effective means of reducing accidents at sites having high wet-weather accident rates. Although longitudinal grooving may be preferable under some circumstances, transverse grooving is considered to be superior to longitudinal grooving for general use on new construction because of the improved pavement drainage provided.

The notice further states that a burlap or other type of drag finish should not be used as the sole means of providing surface texture on projects with design speeds of 65 km/hr (40 mph) or greater. Metal tines are recommended as being the most practical and dependable method of providing positive texture in plastic portland cement concrete pavements and bridge decks.

Surface Characteristics Measurement

Procedures for determining pavement surface characteristics to accommodate forces developed by traffic are largely empirical at this time. The majority of effort has been directed toward determination of skid resistance as the pavement surface characteristic most closely associated with the prevention of skidding. The method of skid-resistance measurement in widest use in the United States uses a locked-wheel skid trailer conforming to ASTM Method E-274. The pavement skid resistance thus measured is termed the skid number (SN) for the test speed. For example, the SN_{40} value is the pavement skid resistance measured at 65 km/hr (40 mph.). Other pavement surface characteristics important to reduction of wet-pavement skidding are pavement surface drainage, texture, and SN-speed gradient.

Measurement methods, in addition to the locked-wheel type, are described in NCHRP Synthesis 14, "Skid Resistance" (19). Each type of tester measures a different aspect of the friction developed. Even when the same tire or slider is used, speed and modes of operation differ, water film control may not be the same, and other parameters may vary. Therefore, a 1-to-1 correlation between tester results should not be expected.

The results of an extensive research project with the objective being development and verification of methods for improving the ability to measure reliably the skid resistance of wet pavement surfaces with skid testers in conformance with ASTM Method E-274 have recently been published as NCHRP Report 151, "Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques" (20). The study involved (a) contacts with skid tester owners to collect information on equipment and operating procedures, (b) conduct of laboratory and field experiments to determine the influence of specific parameters, (c) computer simulation studies on the influence of equipment dynamics, (d) conduct of a two-week skid tester correlation program, and (e) preparation of recommendations for reducing variability in skid-resistance measurement.

The reliability of skid-resistance measurement depends on both tester precision and accuracy. Precision is a measure of the repeatability of the results of a single tester and accuracy is a measure of correlation among testers. An analysis of the variance performed on data collected during the correlation program indicates that the precision of skid testers, although not completely satisfactory, is generally better than accuracy. Implementation of recommendations contained in NCHRP Report 151 will aid highway agencies in obtaining more accurate pavement skid-resistance measurements with existing locked-wheel testers and, when combined with operation of the two FHWA-sponsored Field Test and Evaluation Centers for skid testers, will provide a sound basis for calibration of skid testers that will bring about substantial improvement in their correlation nationwide. The two Field Test and Evaluation Centers are located at East Liberty, Ohio, and Bryan, Texas.

Quantitative determination of the drainability and texture characteristics of a pavement is quite complex and no methods are generally accepted in the U.S. at this time. One approach is use of the skid-resistance speed gradient, defined as the slope of the SN-speed curve between the speeds of 50 and 80 km/hr (30 and 50 mph), as a measure of the hydroplaning potential of a pavement. Texture depth is described as the mean thickness of a layer of a given quantity of fine sand or putty spread over a pavement surface. An outflow meter measures the rate of water flow from beneath a rubber gasket placed on the pavement and thus can be an indication of macrotexture and drainability. Stereo photography is also used to identify the textural characteristics of pavements and their relation to skid resistance. This is known as the Schonfeld method and described under ASTM Designation E 559-757, "Tentative Recommended Practice for Classifying Pavement Surface Textures Suitable for Skid-Resistance Photo Interpretation." Pavement surfaces are described in terms of six textural elements and correlations have been developed between the textural numbers and skid trailer SN values.

Airfield Pavements

Airport pavements must have a good textured surface that is designed for anti-hydroplaning during wet or flooded conditions and be clean of contaminants such as rubber deposits accumulated during aircraft landing operations (this is associated with aircraft traffic density). The pavement surface must also have both microtexture and macrotexture, and the aggregate in the pavement mix must be resistant to polish and wear and angular in shape.

The Federal Aviation Administration of U.S. DOT recognizes the importance of providing the aviation community with recommended construction techniques and maintenance procedures to ensure safe aircraft operations during inclement weather conditions. Guidance for design, construction, and maintenance of skid-resistant pavements has been published in an advisory circular (21). It is intended for use by airport operators, engineering consultants, and maintenance personnel.

Much of the guidance given in the circular is based on both experience and research. Although results to date are a considerable improvement in the technology, further work is required before final standardization is adopted. The methods described are acceptable until something better is developed.

The contents of the FAA advisory circular are summarized in the following.

Pavement Construction

When new airfield pavements are being constructed, asphaltic concrete pavements should have a porous friction-course overlay, an aggregate slurry seal, or sawed transverse grooves. Portland cement concrete pavements should receive transverse grooves or wire-comb texturing of the plastic concrete, sawed transverse grooves of the hardened concrete, or a porous friction-course overlay. Before placing either grooves or wire-comb texturing, the plastic concrete must receive a brush, broom, or burlap drag finish. This is required to provide a textured overall surface to increase braking skid resistance.

Pavement Maintenance

After the pavements have been properly constructed, the airport sponsor has the responsibility to maintain them as close to the newly constructed condition as possible. The airport manager can determine the average texture depth and rate of deterioration of friction by conducting surveys using the National Aeronautic and Space Administration grease smear texture test and a continuous friction measuring device, such as the Mu-meter, capable of recording average friction values. The data obtained can then be compared to the following measurement parameters:

Texture - (a) When the average texture depth is equal to or less than 0.5 mm (0.02 in.) for more than 50 percent of the runway surface, improvements should be made to increase the average surface texture to 1.3 mm (0.05 in.). Acceptable improvements can be either grooving or porous friction-course overlays. (b) When the average texture depth is equal to or greater than 1.3 mm (0.05 in.), no texture effort is required.

Contaminants - (a) When the average friction value within the contaminated area is 0.49 or less, for a distance of 150 m (500 ft) or more, the entire contaminated area should be cleaned. (b) When the average friction value within the contaminated area is 0.29 or less, for a distance of 75 m (250 ft) or more, the entire contaminated area should be cleaned. (c) When the difference in friction values either between the uncontaminated and contaminated areas or within the contaminated surface itself is 0.25 or greater, for a distance of 75 m (250 ft) or less, the entire contaminated area should be cleaned.

Paint Marking Areas - When the minimum friction value over the length of the runway marking is 0.25 or less and/or difference in friction values between the unpainted and painted surfaces is 0.25 or greater, the painted areas should be completely removed and repainted (without glass beads) in a striated pattern.

Pavement Abnormalities - When the difference in friction values between the flooded depressed areas and the surrounding pavement surface is 0.25 or greater for distances exceeding 30 m (100 ft), or if there is a repetition of ponded areas, corrective action should be taken. Depending on the extent and circumstances of the depressed areas, minimal normal maintenance to a new overlay may be required.

Over-All Pavement Friction Requirements - After the runway has been cleared of contaminants, the average wet friction value should not be less than 0.50 for any 300-m (1,000 ft) lengths tested for the entire runway length. If any increment does not meet this requirement, the entire runway should be corrected by either grooving or adding a porous friction-course overlay.

Survey Procedures - The above parameters are meaningful only if the airport sponsor is consistent in taking friction measurements. The following are a few basic rules of thumb to follow which will result in data that can be qualitatively analyzed:

1. Preliminary Visual Inspections - A record should be established and maintained by the inspector identifying the rubber deposit limits; areas where ponding occurs during rainfall; any significant cracks; areas of pavement wear; changes in surface texture; or any other deficiencies that may affect the frictional characteristics of the pavement surface.

2. Location of Test Runs - Friction measurements should be made about 3m(10 ft) from the runway center line and should encompass the full length of the runway minus the 150 m (500 ft) required for acceleration/deceleration at the runway ends. The test vehicle should operate at 65 km/hr (40 mph).

3. Test Runs on Dry Pavement - When a friction survey is taken for the first time, a test run of the dry pavement surface should be made before the test run using self-watering equipment. This test will be compared to the wet run to establish the extent of friction loss due to wet pavements. Test runs on dry pavements are not required each time a survey is conducted, but should be made often enough to check the rate of wear of the pavement due to aircraft trafficking.

4. Test Run Self-Watering Equipment - For calibrating the skid resistance of runway pavements, test runs should be made using self-watering equipment that has a controlled flow rate of water to maintain a uniformly distributed water depth of 0.5 mm (0.02 in.) in front of the friction-measuring tires.

5. Test Run During Rainfall - To complete the calibration of the runway, tests should be taken during rainfall, when the surface is flooded and the depressed areas filled with water. Test runs should be taken in the ponded areas and water depths taken. The loss of friction in these areas should be recorded and compared to the parameter given for these conditions. Any remedial action to improve this situation can then be determined.

6. Test Runs on Runway Paint Markings - Test runs over painted areas should be taken using the self-watering equipment to determine their skidding characteristics when wet.

The FAA has provided guidance in an advisory circular whereby airport owners can construct and maintain runway pavement surfaces that will provide anti-hydroplaning and skid resistance for safe aircraft operations. The airport owner should make periodic checks of the pavement surface condition, specifically the texture and contaminants buildup. The latter is significant on airport pavements. Hydroplaning is a worrysome problem for airport personnel. The tire-pavement interface must have escape paths for water or the tire will "ride" on the water, thus causing loss of friction and directional control of the aircraft.

Rubber buildup accumulates more rapidly at the high-density airports. Several methods are available to the airport owner for removing rubber deposits. Chief of these is the high-pressure water technique, in which the equipment is mounted on large trucks and operates at pressures between 35 MPa and 55 MPa (5,000 and 8,000 psi). Friction and texture measurements should be conducted before and after the cleaning operation to determine the improvement or deterioration in the effective friction. Further effort may be required if the friction data do not fall within the established parameters.

Since November 1973 the U.S. Air Force Civil Engineering Center has been measuring the skid-resistance properties on airfields. The program requires friction measurements by both a diagonal braking vehicle (DBV) and a Mu-meter (22) (23). It is felt that the data obtained from these friction measuring devices are complementary, and together they provide the skid resistance of an airfield pavement. It is intended to subject all U.S. Air Force runways in the U.S. and overseas to skid-resistance surveys periodically. There is a strong feeling that well-trained and experienced crews and standardized testing procedures should be used in this program.

Summary

Considerable information on pavement skid resistance is available from the findings of research and experience. Implementation of this knowledge should result in a reduction in wet-weather motor vehicle accidents on highways and safer operation of airfields. Some of the general observations noted are as follows:

1. Wet-weather highway accident rates are several times dry-pavement rates, and at certain sites may be 10 to 20 times greater.

2. The ratio of wet-pavement to dry-pavement highway accidents appears to be a promising approach to determining general pavement skid-resistance requirements for road systems.

3. Braking deceleration patterns may be useful in determining skid-resistance requirements at intersections and other braking sites.

4. Although there is no nationally accepted minimum highway pavement skid-resistance value, an SN_{40} value of 37 seems an appropriate minimum for main rural roadways with a mean traffic speed of 80 km/hr (50 mph) or less.

5. There is increasing recognition of the importance of the macrotexture and surface drainage of pavements to reduce the effects of hydroplaning during wet weather. Use of adequate cross slope, particularly on long-radius curves, open-graded asphaltic concrete surfaces, and grooved or tined portland cement concrete surfaces should result in reductions in wet-weather accidents on highways.

6. There is no generally accepted method for measuring the hydroplaning potential of pavements. However, use of skid-resistance values combined

with the skid-resistance-speed gradient provides the best currently available approach for evaluating the wet-weather performance of highway pavements.

7. The locked-wheel skid trailer conforming to ASTM Method E-274 is the most widely used equipment for measuring highway pavement skid resistance.

8. For airfield pavements, major emphasis is on the design, construction, and maintenance of anti-hydroplaning surfaces by use of grooving and porous friction courses.

9. Rubber buildup on airfield pavements and procedures for its removal are unique problems to airfield pavement maintenance.

10. The Mu-meter and diagonal braking vehicle (DBV) are the most widely used equipment in the U.S. for measuring airfield pavement wet-weather performance.

Questions that appear to be unresolved and in need of further study are:

1. What should be considered reasonably acceptable wet-weather accident rates, proportions of wet-weather to total accidents, and wet- to dry-pavement accident ratios?

2. To what extent should minimum standards for skid resistance and other pavement surface characteristics be established for all road categories (freeways, rural two-lane, residential streets, etc.) and specific site types (intersections, curves, etc.)?

3. Can highway pavement surface characteristic requirements be realistically based on traffic needs at specific locations and sites?

4. How can seasonal variations in highway pavement skid resistance be accommodated in routine inventory programs?

5. Should more economical and simpler equipment be developed for routine measurement of highway pavement skid resistance and hydroplaning potential?

6. Can more economical anti-hydroplaning airfield systems be developed?

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This paper is the joint effort of a task force of Subcommittee B of the Conference Program Committee. The task force was assigned the responsibility of compiling available information and preparing a state-of-the-art report on pavement contributions to wet-weather skidding accident reduction in the United States. Along with the companion report on providing skid-resistant pavements, it is intended to be an updating of NCHRP Synthesis 14, "Skid Resistance" (19).

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IMPROVED METHODS FOR CONSTRUCTION AND MAINTENANCE OF RUNWAY PAVEMENT SURFACES

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Since the advent of turbojet operations at airports, the Federal Aviation Administration (FAA) has been involved through research and experience to improve the construction standards of pavements. This includes the pavements structural capacity as well as its surface integrity for effective braking action. To improve on the latter, FAA has promoted grooving as one of the highest priorities to be considered for improving braking friction and mitigating hydroplaning. Today, almost 100 runways in the U.S. are grooved. Another improvement developed through research and experience is a porous friction course overlay. There are some 30 runways constructed with this type overlay. In addition a task group within FAA has prepared a list of some 200 runways which are potential candidates for grooving.

Current FAA Guidance

In 1975, an advisory circular, Methods for the Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces (1) was published to provide airport operators, engineering consultants, and maintenance personnel guidance on methods that can be used to maintain airport pavement surface friction characteristics. The circular covers various treatments for asphaltic and portland cement concrete pavements; discusses various types of friction measuring equipment and describes in detail a specific type; identifies parameters for pavement surface evaluation; establishes procedures for surveys, data acquisition; discusses pavement mix design and material characteristics for skid resistant pavement surfaces; describes construction methods for various surface treatments and maintenance methods; and identifies airport managers' responsibility in maintaining pavement surfaces. Also included in the appendices of the circular are procedures for measuring pavement surface texture depth, and specifications covering grooving, porous friction course, and asphaltic emulsion slurry seal surface treatment.

Implementation

The implementation of a program to reduce the potential of aircraft sliding off wet runway pavements is strictly a voluntary one, as there are no Federal Aviation Regulations covering this aspect at the present time. The advisory circular is designed to fill the gap until such time as it is deemed necessary to incorporate the guidance into a Federal Aviation Regulation.

Eligibility

The FAA encourages construction of skid resistant surfaces by the issuance of grants under the Airport Development Aid Program (ADAP). The requirements for eligibility are given in Federal Aviation Regulations (FAR) Part 152 (2). Another FAR, Part 139 (3) covers the Certification of Airports. Under Part 139.83, Pavement Areas, are specific items the airport operator is responsible to meet. One of the items of chief concern are rubber deposits which cause runways to be very slippery when wet. The rule does not provide a means to determine when rubber deposits are hazardous, just states they should be removed by operational considerations.

When the rule was being drafted, the requirement for measuring runway slipperiness was included. However, in the absence of the development of an approved standard for measuring the coefficient of friction, the requirement was deleted from the final rule.

The requirements for eligibility are given in the Federal Aviation Regulation (FAR) Part 152 which is being revised and will state that:

"New runway pavements, overlays and leveling courses are eligible under ADAP. Overlays are considered eligible only when the structural integrity of the existing pavement does not provide adequate support for aircraft operations. Leveling courses are eligible when used to correct major surface irregularities in pavements that are structurally adequate. Final constructed pavements must have adequate skid resistant surfaces and drainage to mitigate hydroplaning. Porous friction course and grooves constructed on new or old pavements for the purpose of providing skid resistant surfaces on runways at general aviation and small hub airports are eligible. Seal coats applied as normal maintenance for crack sealing, refilling joints, prolonging pavement life, or rejuvenating old pavement surfaces are ineligible. Seal coats to provide skid resistance are not eligible where the sponsor or airport operator has failed to remove rubber deposits as part of a responsible maintenance program."

Management Responsibility

The airport owner must make several judgmental decisions in his efforts to provide and maintain adequate pavement surfaces. He must anticipate the effect of weather conditions on the surface of the pavements; he must choose the most effective surface texture to be applied to both existing and new pavements considering the weather conditions, type of aircraft, and number of aircraft operations; he must develop a proper maintenance program to ensure a safe operational surface; he must continually monitor the pavement surface friction characteristics of his pavements in order to determine the loss of effective braking action; last, but by no means least, he must budget funds for maintaining antiskid pavement surfaces. The purpose of Advisory Circular 150/5320-12, Methods for the Design, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces, is to provide guidance to the airport owner in making these decisions.

Construction Techniques for New Runways

The airport owner can improve the braking action on runway pavements by saw-cut or plastic grooving, wire combing, constructing a porous friction course overlay, or using friction seals.

Grooving

Grooved pavements were a British innovation first tried in 1956 at several aerodromes in England. There are approximately 100 runways grooved in the United States, and the first major airport to groove a runway was Washington National Airport.

Tests conducted at the National Aeronautics and Space Administration (NASA) Wallops Station (4) of 19 groove configurations showed the 1/4" x 1/4" x 1" groove pattern offered the best aircraft tire braking capability. Based on the results of this test program, FAA selected the 1/4" x 1/4" x 1-1/4" groove configuration as its standard. The 1-1/4" spacing was selected to provide a minimum 1" land area between the grooves. Grooving can be accomplished in two ways: sawed in existing or new pavements or formed in concrete while it is still in the plastic state. Sawing is the only satisfactory method which has been developed for grooving asphaltic concrete runway surfaces.

Sawed Grooves

In the United States, airport runways are grooved by sawing the grooves transversely; that is, the grooves are cut crossways to the direction of the aircraft motion. The groove geometry is specified in the following manner; the width and depth measurements of the groove are given first, followed by the pitch, the distance between the grooves, center to center. Grooves are cut in pavements by means of a diamond-studded saw technique or by a flailing technique using hardened steel cutters.

As a preliminary to design, a pavement evaluation survey should be made of the entire area to be grooved. Depressed areas and badly cracked and/or spalled areas in the pavement should not be grooved until such sections are repaired or replaced.

If the survey shows that the existing pavement is not suitable from a strength standpoint, an overlay, either flexible or rigid, will be required. Costs for sawed grooves range from 8 to 15 cents per square foot. Generally, it is cheaper to groove in asphaltic concrete pavements by some 3 to 5 cents per square foot when compared to portland cement concrete pavements.

Plastic Grooves

The Belgians and the British were probably the first to develop equipment for forming grooves in plastic concrete. The advantage of plastic grooving is that the grooves are formed while the concrete is in the plastic condition and is an integral part of the paving train operation. The cost for constructing grooves in plastic concrete is significantly less than sawed grooves.

Paving contractors in the U.S. have constructed grooves in plastic concrete by several methods: one method is a cylindrical tube with ribs on the outside to form the grooves as it is transversely rolled over the plastic concrete pavement; another is a steel-tined comb for forming the grooves in the plastic concrete. There are over ten runways that have been plastic grooved. In the UK, the British use a flat ribbed plate that is vibrated across the pavement. This method simulates closely the saw-cut finish. Another method used is a wire comb which simulates grooves in the plastic concrete pavement. The wire comb method is one of the successful methods used in the U.S. The wire comb provides a configuration that is 1/8" x 1/8" x 1/2". Experience has been very favorable at ten airport runways in the U.S. This technique provides an excellent braking surface with minute channels for water to escape under aircraft tires. The cost for constructing plastic grooves and wire comb surfaces is minimal.

Porous Friction Course

Highway departments of California, Nevada, New Mexico, Utah, Colorado, and Louisiana have been successfully using friction courses for several years and for many miles of highways. The UK initiated the specification and constructed the first porous friction courses for airport runways.

There are 27 runways constructed with porous friction course overlays, jointly funded by FAA and the airport owners under FAA's Airport Development Aid Program (ADAP). The performance of these surface treatments has been excellent. PFC costs range from 8 to 23 cents per square foot.

Other Surface Treatments

The FAA recognizes the need for general

aviation and smaller hub airports to improve the surface texture of their runway pavements. The majority of these runways are not suited for grooving or PFC construction without major reconstruction prior to such surface treatments or because of lack of funds for grooving or PFC. For these runways, FAA recommends using asphaltic emulsion slurry-seal coats or a wire comb finish. When applied for the purpose of increasing skid-resistance, these types of surface treatments are eligible for Federal participation under ADAP.

Restoration of Existing Runways

Tests have shown that wet runway areas contaminated by heavy rubber deposits and/or oil and jet aircraft exhaust deposits provide approximately one-half the braking effectiveness of the same contaminated areas when dry. These contaminated areas very likely have contributed to poor aircraft stopping ability on wet runways. In order to maintain a runway that has good antiskid characteristics, airport owners must determine how, when and where maintenance should be performed. This can be done by conducting periodic friction surveys.

Friction Survey Procedures

Before friction measurements are made, a visual inspection of runway surface conditions should be conducted to determine the limits of rubber deposits, areas of ponding, and other deficiencies. These areas can be designated by runway stationing using existing horizontal control. They should be identified on a runway plan before the friction measurements are taken.

Location of Test Runs

Test runs should be made approximately 10 feet from the runway centerline and should encompass the full length of the runway minus the 500 feet acceleration/deceleration distances at runway ends. Subsequent test runs should be run at the same location to insure realistic comparisons can be made with previous test run data.

Marking Changes in Runway Pavement Surfaces

Before making a test run, traffic cones should be placed adjacent to locations at the beginning or end of areas where there is a visual change in surface characteristics. This would include areas of rubber deposits, change in pavement types, areas of ponding, and runway intersections. The traffic cones will assist the tow vehicle operator in determining when to activate precoded Mu-Meter event markers.

Test Runs Using Self-Watering Equipment

These are the test runs normally used for calibrating runway pavement surface conditions. They will enable the airport operator to determine what remedial action is required as set forth in paragraph on measurement parameters.

Test Runs on Dry Pavement

When surface friction of a runway is being measured for the first time, a test run of the dry pavement surface should be made before the test run using the self-watering equipment for comparison purposes. This will enable the airport operator to determine the extent of the friction loss due to wet pavement. Test runs on dry pavements do not need to be made each time a wet pavement test is conducted. Dry runs should be made often enough to check wear of the pavement surface due to traffic.

Test Runs During Rainfall

If runways have pavement irregularities such as ruts or depressed areas which retain water during rainfall, they should be subjected to surface friction test runs. Because the tests will be run during rainfall, the use of self-watering equipment will not be required. The purpose of conducting tests during rainfall through these areas is to check the relative loss of friction. The depressed areas could cause aircraft directional control problems, hydroplaning, or engine flameouts.

Test Runs on Runway Paint Markings

These areas should be tested occasionally using self-watering equipment to determine if they are slippery when wet.

Data Acquisition

The graph strip chart provides a permanent record for the friction values of a particular runway surface. The gear reduction unit that gives 1 inch equals 150 feet should be used. As such, proper identification of all field observations should be made directly on the graph strip chart immediately upon completion of each test run. This can be done by establishing an event mark code for each runway surface condition encountered during the survey.

Graph Chart

It is important that the stationing of all significant observations be shown directly on the graph strip chart for future reference. The graph strip chart obtained in the next survey can then be compared by the airport operator with the previous test run. The airport operator should emphasize to the test personnel the importance of conducting the survey at the same location as the previous test run, so proper comparisons can be made.

Pertinent Test Information

Certain information should be written on each graph strip chart for record. The following items should be considered: airport name, location, survey date and time, weather, runway designation, and type of pavement.

Measurement Parameters

Several conditions that influence the friction characteristics of wet pavement surfaces are texture depth, contaminants, paint markings, pavement abnormalities, and the overall effective friction level for the runway length. The airport operator should evaluate each of these conditions by the following parameters:

Texture

The first condition for consideration is the average texture depth of ungrooved pavements. Research and experience have shown that pavements with average texture depths near 0.020 inches often have very low coefficient of friction values in the wet condition. The following textural parameters are offered for consideration.

When the AVERAGE TEXTURE DEPTH is equal to or less than 0.020 inches for more than 50 percent of the runway surface, improvements should be made to increase the surface texture to an acceptable level of at least 0.050 inches. Suggested methods for improving texture include grooving, porous friction course, and aggregate seal coats. Average texture depths for pavements can be measured by using the NASA grease-smear method.

When the AVERAGE TEXTURE DEPTH is equal to or greater than 0.050 inches, no further texturing effort is required.

Contaminants

The second condition affecting the surface friction characteristics of runway pavements is rubber deposits and dust particles accumulating over a period of time. One of the main problems facing the airport sponsor concerning the condition of runway pavement surfaces is the rubber deposit buildup. The following parameters are given to assist the airport operator in making the decision on when it is necessary to remove the rubber deposits from the runway pavement surface.

When the AVERAGED MU VALUE within the contaminated area is 0.49 or less, for a distance of 500 feet or more, the entire contaminated area should be cleaned.

When the AVERAGED MU VALUE within the contaminated area is 0.29 or less, for a distance of 250 feet or more, the entire contaminated area should be cleaned.

When the DIFFERENCE IN MU VALUES either between the uncontaminated and contaminated areas or within the contaminated surface itself is 0.25 or greater, for a distance of 250 feet or less, the entire contaminated area should be cleaned.

Paint Marking Areas

A third consideration affecting the skid properties of a pavement is the large painted areas, such as runway markings. The airport sponsor should occasionally check the friction values of these areas according to the following parameter.

When the MINIMUM MU VALUE over the length of the runway marking is 0.25 or less and/or DIFFERENCE MU VALUES between the unpainted and painted surfaces is 0.25 or greater, the painted areas should be completely removed and repainted (without glass beads) in a striated pattern.

Pavement Abnormalities

Runways that have depressed surface areas are subject to ponding during periods of heavy rainfall. Since these ponded areas occur primarily in the aircraft wheel path areas, there is a potential for engine flameout and hydroplaning. For this reason friction surveys should be conducted during rainfall with the Mu-Meter (without the self-watering device) through the puddled areas to detect the relative loss of friction for these conditions. The self-watering device, in this case, is not capable of relating accurately to the ponding situations. The following parameter is offered for consideration.

When the DIFFERENCE IN MU VALUES between the flooded depressed areas and the surrounding pavement surface is 0.25 or greater for distances exceeding 100 feet, or if there is a repetition of ponded areas, corrective action should be taken. Depending on the extent and circumstances of the depressed areas, minimal normal maintenance to a completely new overlay may be required.

Minimal Average Friction Requirement for Runway Pavements

After the runway has been cleared of contaminants, the AVERAGE WET MU VALUE should not be less than 0.50 for each 1,000 foot increments of the runway length. If any increment does not meet this requirement, the entire runway should be corrected.

Cleaning Methods

There are several acceptable methods available to the airport owner for removing contaminants on runway surfaces. They are chemical, high-pressure water, high-velocity impact, and mechanical methods.

Chemical

Chemical solvents have been successfully used to remove contaminants on runway pavements. They must, however, be biodegradable, and washed off the pavement after use so that the dillutant will not harm surrounding vegetation or drainage systems, or pollute nearby streams and wildlife habitats. Chemical costs average around 8 cents per square foot.

High-Pressure Water

Within the last few years, a new method for removing contaminants on runway surfaces, called high-pressure water (HPW), has been used successfully at airports. The principle of this method is very simple. A series of very high-pressure water jets are aimed at the pavement surface and blast off the contaminants. This technique is economic, environmentally clean, and effectively removes all deposits from the pavement surface in minimal downtime to the airport sponsor. Most HPW equipment used today operates between 3000-6000 psi and is capable of pressures exceeding 10,000 psi if needed. HPW costs range from 2 to 4 cents per square foot.

High-Velocity Impact

A relative newcomer in cleaning airport runways, high-velocity impact, looks very promising. The principle of this method uses abrasive particles thrown at high centrifugal force, impacting on the pavement, thus blasting contaminants from the surface. The machine is environmentally clean in that it is self-contained; it collects the abrasive particles and contaminants, removes contaminants, and recharges the particles for use again. Although new to runway cleaning, the method has been used quite successfully in cleaning structural members for many years. It is also used for texturing surfaces for architectural effects.

Mechanical

Mechanical surface grinding machines have been successfully used to remove heavy rubber deposits from runways. They are also used to remove high areas on pavement surfaces such as bumps or at joints where slabs have shifted or faulted.

Improvement of Texture and Drainage

Existing pavements may or may not have surfaces that are suitable for sawing grooves. A survey should be conducted to determine if an overlay or rehabilitation of the pavement surface is required before grooving operations begin.

Reconnaissance Survey

A thorough survey should be made of the entire width and length of the runway. Bumps, depressed areas, bad or faulted joints and badly cracked and/or spalled areas in the pavement should not be grooved until such areas are adequately repaired or replaced. To verify the structural condition of the pavement, tests should be taken in support of the visual observations.

Surface Treatment

If the survey shows that only minor corrections to the pavement are required, then grooves can be saw-cut, or a porous friction course overlay constructed. If the survey shows that the existing pavement is not suitable because of either surface defects or from a strength standpoint, an overlay, flexible or rigid will be required. Either a PFC overlay or saw-cut grooves can be constructed to provide good skid resistant/drainage surface.

Status of Research

Several research projects are now underway to help airport owners in providing pavement surfaces for safe aircraft operations. In 1971, the FAA contracted the U.S.A. Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi, to prepare Item P-402, Porous Friction Course, for use in this country. Two research reports (5,6) have been published, and a final specification is now being prepared for publication. Another study underway at U.S. Naval Air Station at Lakehurst, New Jersey, is the optimization of tire cutting and tire life on grooved runway surfaces, as well as the cost/benefit analysis of constructing a least cost groove configuration.

A study just completed evaluated the effect of periodic cleaning of contaminants by the HPW technique on runway surfaces (7). The results of the study revealed that no deterioration or loss of friction due to the HPW technique was observed during the tests. Also, the HPW was very effective in removing contaminants and paint areas, if required.

Research and experience have shown that grooved pavement surfaces significantly increase surface friction, improve the braking action and directional control of aircraft, retard accumulation of rubber deposits, and lessen the potential for hydroplaning. Maintenance personnel have reported that the rolling action of aircraft tires on thin ice layers tends to break up the ice that forms on grooved runway surfaces. This action gives better control of the aircraft on icy runways. Although grooving of airport runways is the most effective method of providing good antiskid properties during adverse weather conditions, the aviation community will continue to evaluate other methods as well. PFC has also proved effective in dissipating surface water and breaking up thin films of ice.

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USAF STANDARD SKID RESISTANCE TESTING IMPLEMENTATION

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This paper presents a brief summary of the research work accomplished on runway skid resistance and hydroplaning by the USAF. The research objectives were to develop a standard evaluation system for determining the skid resistance and hydroplaning potential of Air Force runways and to develop optimum corrective techniques for improving skid resistance properties of airfield pavements. The paper describes the evaluation system developed around the Mu-Meter and the Diagonally Braked Vehicle (DBV).

Research conducted by USAF, NASA, and FAA has led to the present skid resistance evaluation program used by the Air Force. The recommended improvements, when required, have also resulted from research on methods to improve pavement friction/hydroplaning characteristics.

A brief evaluation and history of these research projects and how they have been consolidated into a standardized skid test system is included to show how the skid evaluation system has evolved and is attempting to use the latest information.

History Leading to Present Skid Evaluation Program

Higher landing speeds of jet aircraft, together with the increased number of wet weather landings permitted by improved instrument landing systems have focused attention on aircraft ground operations during inclement weather. The cost of Air Force skid/hydroplaning accidents has been substantial ($8.5 million between 1970 and 1975 attributed directly to unsafe surface conditions). A comprehensive program of research, evaluation, equipment improvement and procedural change has been developed since the early 1970s. The expectation is that the program will begin to show results in the near future.

Since the early 1960s when the problem was first apparent, there has been an effort underway to develop a technique to assess runway conditions on a near real time basis and to inform the pilot what to expect at touchdown. One of the early devices developed and used for this purpose was the James Brake Decelerometer (Inspection Decelerometer). This device consisted basically of a pendulum connected to an indicating needle; the needle recorded the deceleration due to displacement of the pendulum. The James Brake Decelerometer (JBD), mounted in a stock vehicle (sedan or station wagon), became the standard Air Force equipment to determine the Runway Condition Reading (RCR) of the pavement, a number that could vary from 01 to 26. The number provided the pilot a means of estimating how his aircraft would react when the aircraft touched down on the runway surface (1).

Unfortunately, results from the James Brake Decelerometer were often not repeatable, i.e., results were affected by a number of variables including the driver of the vehicle, the vehicle itself, and the techniques used in conducting the test. In short, the device did not have the capability of predicting the stopping distance of an aircraft nor of predicting when the aircraft was likely to encounter hydroplaning situations. It soon became apparent that this device was not the answer to the question of how to measure skid resistance properties of wet runways. A better method was sought (2, p. 44-48).

In the mid-1960s, the British began development of a device to measure the coefficient of friction of an airfield pavement. The result of this development work was the Mu-Meter, a small trailer unit designed to furnish a continuous graphical record of the pavement coefficient of friction. The Mu-Meter is described later.

In 1968, the National Aeronautics and Space Administration (NASA) developed a promising skid resistance measuring device, the Diagonally Braked Vehicle (DBV). Early exploratory tests indicated a relationship existed between wet to dry stopping distance ratio (SDR) of this vehicle to a similar ratio of an aircraft. In 1969 and 1970, the USAF participated with NASA in a project called "Combat Traction" (2). An instrumented C-141 aircraft was test landed at a number of airfields to measure the aircraft SDR. In addition, SDR measurements were made with a DBV and deceleration measurements were made with a JBD. The test results showed the JBD was unreliable; the DBV, however, did show promise as a measuring device to predict aircraft stopping distances. Project "Combat Traction" was extended to include comparison between a Boeing 727, a DC-9 and the results obtained with the M L Aviation Mu-Meter and a DBV (3 and 4). Based on the comparisons both the Mu-Meter and the DBV showed some promise of being able to predict the stopping distances of aircraft (3, 4, and 5). There is, however, a need for many more experiments. The analysis will require evaluation of the comparison between Mu-Meter and/or DBV results with each individual aircraft and for each type of surface. This would probably result in a relationship between the DBV and/or Mu and each aircraft with pavement type being one distinguishing parameter. Since the stopping characteristics will change with the pavement finish, type of aggregate, wear resistance of the aggregate, etc., the generalized relationship with pavement type as a parameter would probably not be reliable or repeatable.

More recent USAF research has focused on quantifying all the factors affecting aircraft stopping distance performance. With this information, plans were to develop a design for a skid measurement vehicle or utilize a presently available skid measurement vehicle to arrive at an input for a system for predicting the stopping distances of landing aircraft. Presently the funds are not available for continuation of the project and it appears that the research will be terminated prior to final design of skid evaluation equipment. Thus the prediction system will not be finalized at this time.

Another area of skid resistance research is pavement surfaces. FAA and the USAF research has continued on improved surfaces for asphalt type pavements while the FAA has also continued research into developing an optimum pitch/depth pattern for runway grooving. (Because of the potential problems in grooving asphalt the USAF has not generally grooved asphalt runways.) USAF research has also dealt with testing, construction and evaluation of porous friction and surface seal type bituminous treatments. In addition to these major projects, three minor projects are being evaluated for potential improvements in equipment reliability and data analysis.

One project is the evaluation of a self-watering system for the Mu-Meter. The self-watering system will be used to evaluate the surface texture of all areas of the runway, where the present system evaluates only selected parts of the runway. This will hopefully fill the gaps left in the normal testing procedures.

The second project has replaced the original Mu-Meter hydraulic load cell with a strain gauge load cell and graphical readout in the cab of the towing vehicle. This will reduce the workload on the Mu-Meter operator and increase the reliability of the overall system.

The third project is a study of available deceleration curves from the DBV. This is to check if the types (partial, full, viscous, dynamic) of hydroplaning can be distinguished by use of the deceleration curves from the DBV. If the various types can be identified through evaluation of the curves, this will serve as additional information that can be used to develop a more comprehensive report on the condition of the pavement surface.

The present skid resistance evaluation equipment (see the equipment section), procedures, and limits have evolved as a result of the research program. The limits of acceptability resulting from these tests have been set at points where aircraft (B-727 and DC-9) actually locked wheels on landing (see Figures 1 and 2). The logical assumption made was that the SDR and/or Mu-Meter results observed during these lockups, would be an indicator that the surface being tested would be susceptible to hydroplaning (3 and 4). (Note: The limits vary between Figure 2 and Figure 6; this is a result of changing to ASTM-E-524 standard tires on the DBV).

Skid Resistance Test

In the Air Force standard skid resistance test, the skid resistance/hydroplaning characteristics of a runway surface are evaluated by two types of test equipment, the Mu-Meter and the diagonally-braked vehicle (DBV). The test program consists of field measurements of the pavement skid resistance/hydroplaning potential under dry and standardized artificially wet conditions. Other parts of the program include measurement of transverse slopes and surface texture. The slopes and texture measurements are conducted in traffic lanes on each side of the runway centerline to evaluate the surface drainage and texture characteristics.

Equipment

The principal items of field testing equipment consist of the Mu-Meter, the diagonally-braked vehicle (DBV), tank truck for water application, a device for measurement of the slope of the pavement surface and the grease texture measurement kit.

The Mu-Meter is a small trailer unit designed and manufactured by M L Aviation (Maidenhead, Berkshire, England) for the specific purpose of evaluating coefficient of friction (MU) for runway surfaces. The Mu-Meter physically evaluates the side slip force between the tires and pavement surface. Figure 7 shows the towed-out wheels and the load cell used to measure the force pulling the wheels apart. It is a continuous recording device that graphically records the coefficient of friction (MU) versus distance along the pavement. The friction measuring wheels are designed with 10 psi tires so that the test vehicle when towed at 40 mph, gives a speed equivalent to 1.2 times the theoretical hydroplaning speed (33 mph). The system has been modified to replace the standard load cell with a strain gauge load cell and an in-cab readout of the continuous graphical display.

The DBV is a specially instrumented vehicle which was developed by NASA to evaluate the stopping characteristics of runway surfaces. The DBV records the stopping distance of the vehicle in a diagonally-locked wheel mode from a speed of 60 mph (96.6KM/Hr) (2). The diagonally-braked wheels are now equipped with ASTM E-524 test tires.

A water truck is furnished by the fire department at the air base tested. The truck is fitted with a spray bar for water application, tachometer for precise speed control and integral to the truck is a constant pressure discharge system. The water is applied in two passes. The truck is carefully calibrated so that each pass places 0.1 inch (.254cm) of water on the test strip. Testing follows immediately after the second pass.

The slope measuring device consists of a rectangular section of aluminum [10 ft (3.0m) long, 5/8 inch (15.9mm) thick, and 2 1/2 inches (63.5mm) high] with machinist levels attached so as to define slopes from 0 to 2.0 percent to the nearest 0.1 percent. The slope measuring device is used to measure transverse and longitudinal gradients in the wheel path areas.

The grease smear texture kit consists of disposable 30 cc syringes, masking tape, ruler and hard rubber squeegee. Texture measurements are taken in each test section.

Testing Procedure

The field test procedure used for the evaluation of skid resistance/hydroplaning characteristics of the runway surface is described in an Air Force Weapons Laboratory Technical Report (7). An outline of the current test procedures follows:

1. Generally five test areas of 10 feet (3.0m) by 2000 feet (609.6m) are selected as a representative sampling of the entire runway surface (Figure 3). Test sections are selected to examine the pavement traction in (1) the aircraft touchdown areas, (2) the runway interior along traffic lanes where maximum aircraft braking is normally accomplished, and (3) the pavement edge which is representative of non-traffic areas.
2. Transverse slope measurements are conducted at 500 or 1000 foot (152.4m or 304.8m) intervals in the wheel path areas on each side of the runway centerline.
3. Surface texture measurements are obtained in each test section.
4. The water truck is calibrated to discharge 0.1 inch (.254cm) of water.
5. The skid resistance test for the dry pavement condition is conducted using the DBV and Mu-Meter.
6. Skid resistance tests under a standardized artificially wet condition are conducted as follows:
    a. Water is applied to the test area in two passes. Each pass places 0.1 inch (.254cm) of water.
    b. DBV and Mu-Meter tests are conducted immediately following the second pass of the water truck. The test is continued for up to thirty minutes after wetting, depending on the recovery rate. Tests are conducted in both directions.
    c. All water truck, Mu-Meter and DBV operations are recorded versus time to the nearest second. The sequence of operations is controlled by radio.

Test Results

The pavement skid resistance results are reported in terms of coefficient of friction (Mu), as measured by the Mu-Meter, and the wet-to-dry stopping distance ratio (SDR), as measured by the DBV. Research conducted during Combat Traction II has been used to define breakpoints in the values of Mu and SDR which define potential hydroplaning problem (see Figures 1 and 2); these breakpoints are shown on the charts in Table 1. While current technology does not permit exact prediction of aircraft stopping distances, the charts provide a good rule of thumb for interpretation of data. The results are tabulated, analyzed and published in runway skid resistance survey reports for each Air Force base evaluated.

Friction Variation

Figure 4 shows the friction versus distance trace as recorded by the modified Mu-Meter during the first runs after wetting for several different surfaces. It shows the continuous variation of friction within the 2000 foot (609.6m) test sections. Comparisons can be made with dry conditions which are recorded in the data sections of the reports. Sharp dips or rises indicate a change in surface characteristics or the location of local ponding areas. In an evaluation, comparisons may be made between various sections of the runway and the probable hydroplaning areas pinpointed. Typically each runway will have touchdown areas with the highest probability of hydroplaning and edge sections (nontrafficked areas) with the lowest probability. Figure 4 presents several friction traces. The bold trace shows one minor ponding area approximately 440m (1400 ft) into the test section. The reports present only the first trace recorded after the surface is wetted, but as time allows drainage, the traces are closely checked for trends to identify any ponding due to lack of adequate cross-slope or excessive rutting. The transverse slope measurements are used to help point out potential problem ponding areas that are not tested by a wet test procedures. The wet test procedures also show visually when and where there are ponding problems on the runway.

Friction Recovery With Time

Figures 5 and 6 show the effects of time after wetting on changes in surface friction for several typical pavement types. The figures demonstrate the natural drainage characteristics of the runway surface and times required for the friction in the test sections to return to an acceptable condition (assuming recovery in the 30 minute time period). If the section does not recover to an acceptable level during the time period, the runway or section is a prime candidate for runway improvements. These curves were derived by plotting the average coefficient of friction over the 2000 feet (609.6m) test section or SDR versus time after wetting. These recovery curves are typical of several types of pavements and of several areas of the runway. These curves are affected primarily by pavement surface texture and pavement surface drainage. Rates are also affected by weather conditions, such as wind, free air temperature and pavement temperature. All variables are weighted by engineering judgement when final analysis of a particular curve is presented.

Data Reduction Program

The AFWL developed a computer analysis package to process all data gathered in the standard test. Data is recorded on standard forms designed for keypunching directly from the original data. Output from the analysis program includes data summary charts for each test section, plotted curves showing Mu vs time and SDR vs time for each test section. The printout also includes weather data recorded during the testing of each runway (8).

Based on the recovery graphs, slopes, visual observation, grease texture measurements, weather, Mu-Meter traces, and experience, the engineer can develop an evaluation that will provide operators with the expected response of his runway(s) during wet weather operations.

Test Limitations

Research conducted to date allows identification of runways (or parts thereof) where skid potential is at a potentially dangerous level. In these cases, the situation can be pointed out to aircrews and remedial action can be taken by the civil engineer at the base. These recommendations for tower advisories to aircrews or improvements should help prevent potential skid/hydroplaning accidents. This nonquantitative identification of potential problem areas is the best we can do for operators, since at the present time we cannot

Table 1.

MU-METER AIRCRAFT PAVEMENT RATING (7, AFWL-TR-73-165)

MU	EXPECTED AIRCRAFT BRAKING RESPONSE	RESPONSE
Greater Than 0.50	Good	No Hydroplaning Problems Are Expected.
0.42 - 0.50	Fair	Transitional.
0.25 - 0.41	Marginal	Potential For Hydroplaning For Some A/C Exists Under Certain Wet Conditions.
Less Than 0.25	Unacceptable	Very High Probability For Most Aircraft to Hydroplane

STOPPING DISTANCE RATIO/AIRFIELD PAVEMENT RATING (7, AFWL-TR-73-165)

SDR	HYDROPLANING POTENTIAL
1.0 - 2.5	No Hydroplaning Anticipated.
2.5 - 3.2	Potential Not Well Defined.
3.2 - 4.4	Potential For Hydroplaning.
Greater Than 4.4	Very High Hydroplaning Potential.

Note: Technical Report No. AFWL-TR-73-165 (Source of Ratings) Adjusted To Reflect Use of 15 Inch Tires on the Diagonally Braked Vehicle.

with any statistical reliability predict the amount of runway that it will take for a given aircraft to stop under a specific set of circumstances. We will provide information based on breakpoints shown in Table 1 about the relative probability of incurring a hydroplaning situation or other skid phenomena. The USAF standard skid resistance test and subsequent report will (1) determine/report if and where there is a potential hydroplaning problem on the runway, (2) determine how serious the problem is, if one exists, (3) permit base civil engineers to program improvements and (4) give the aircrews better knowledge of what to expect when operating on the runway.

At this time, the USAF considers that the use of both the Mu-Meter and the DBV provides information that would otherwise be unavailable if only one type of equipment was used in the evaluations. An example of this is where excess bituminous material is on the surface. The Mu-Meter will not necessarily point out the problem but the DBV dry stops will generally create enough heat to melt the asphalt and a skid over the melted asphalt will result. This type of condition may present a hazard to aircraft during both dry and wet weather conditions.

Program Operation

The standard USAF skid resistance evaluation program was started in FY74. Since that time improvements have been integrated into the procedures. The program will be continued for the foreseeable future because of the lack of any more reliable system. The Air Force Civil Engineering Center at Tyndall AFB FL is program coordinator for the USAF. To date, most Air Force bases have been evaluated and as base runway surfaces are changed, tests will be conducted to detect any changes caused by new construction. Through a slow process of education, the base level engineers are beginning to become aware of the problems created by lack of attention to specifications or lack of compliance with specifications by contractors. Through this education process, the Air Force will be able eventually to have runway surfaces with such surface characteristics that the only skid/hydroplaning accidents will be a result of either extreme carelessness, mechanical malfunctions, or extremely adverse weather conditions.

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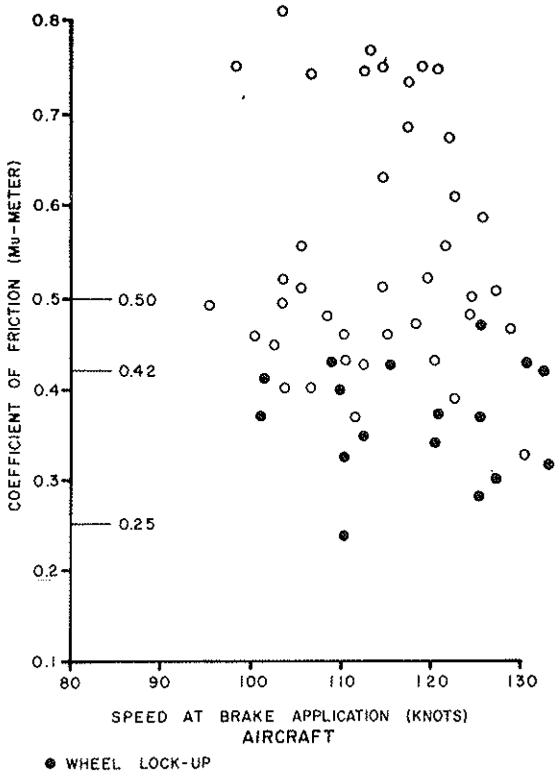


FIGURE 1

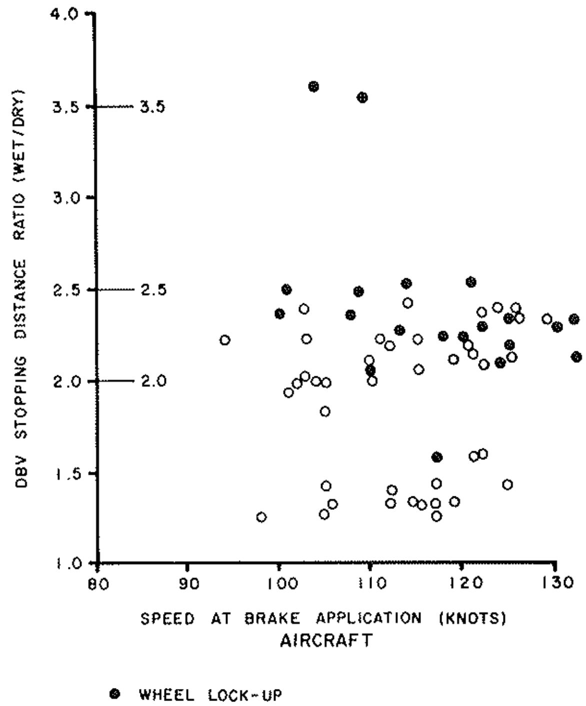
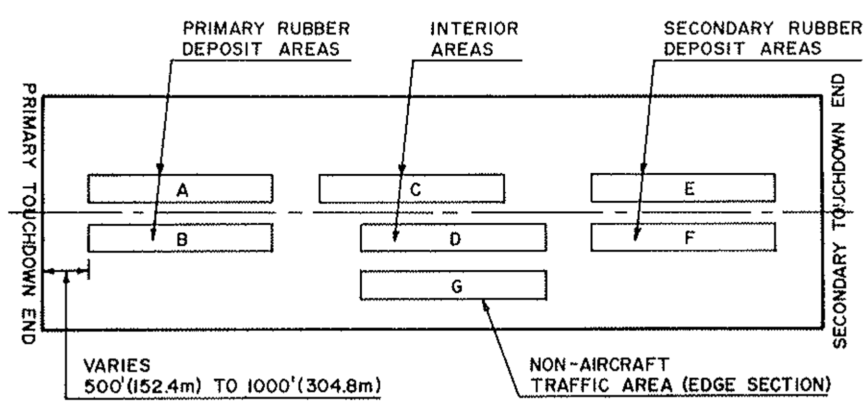


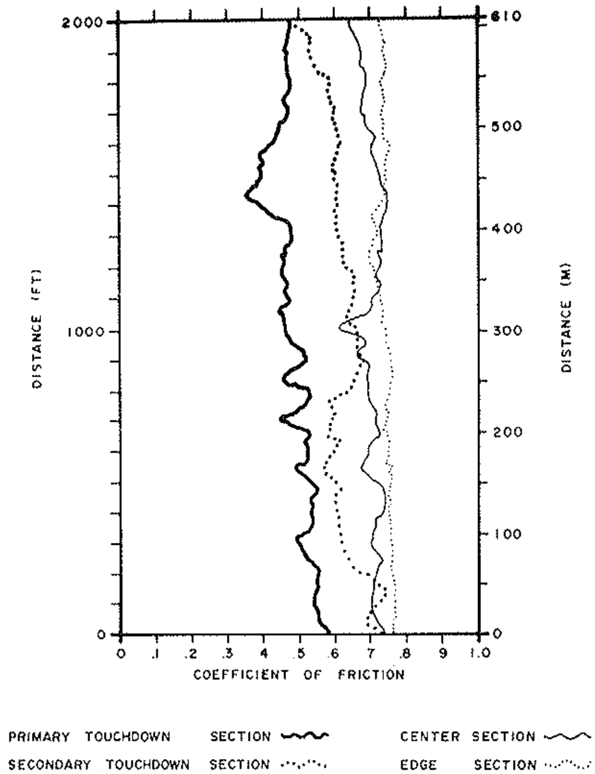
FIGURE 2



NOTE: TYPICAL TEST SECTION DIMENSIONS
10' (3.0m) WIDE BY 2000' (609.6m) LONG

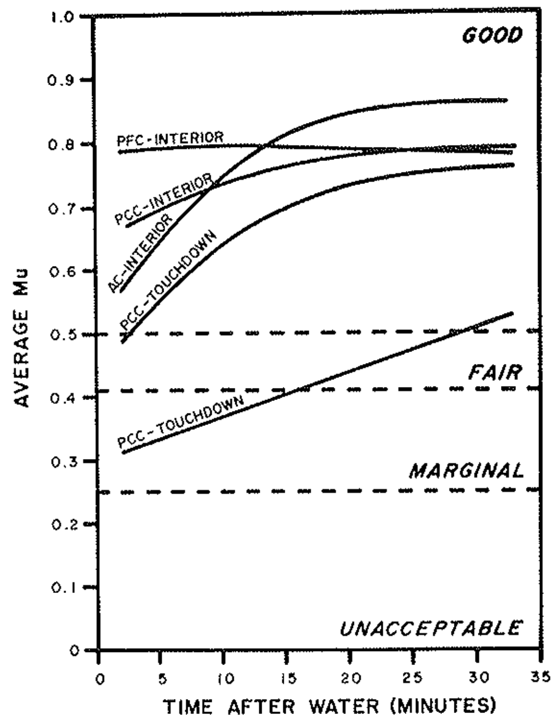
LAYOUT OF TEST SECTIONS

FIGURE 3



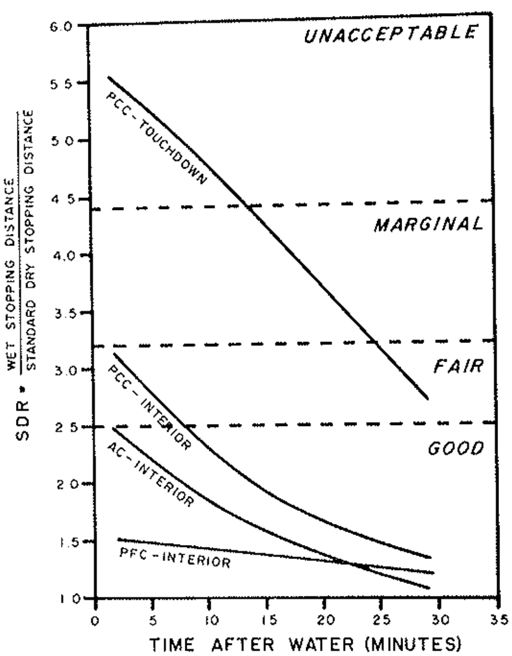
TYPICAL Mu-METER TRACES AT NELLIS AFB

FIGURE 4



RECOVERY RATES

FIGURE 5



RECOVERY RATES

FIGURE 6

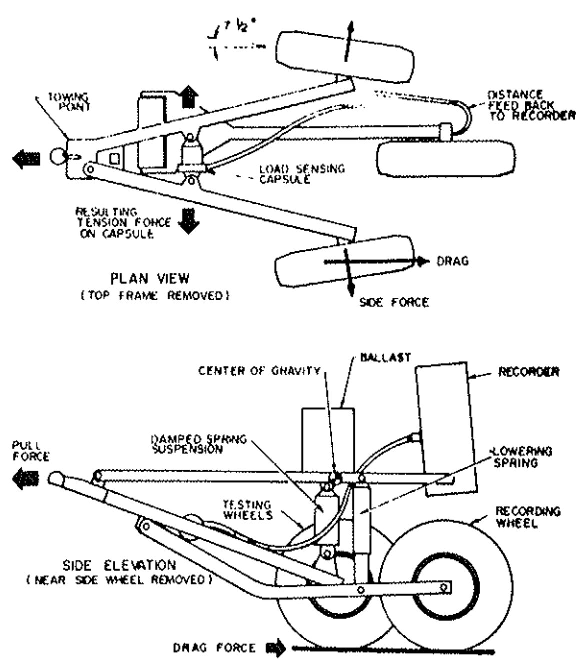


FIGURE 7. DIAGRAMMATIC LAYOUT OF MU-METER.

A PROGRAM FOR REDUCING SKIDDING ACCIDENTS DURING WET WEATHER

Kenneth D. Hankins, Texas Department of Highways and Public Transportation

This paper is specifically directed toward one of the categories in the statewide highway safety improvement programs in Texas. The program for reducing skidding accidents during wet weather includes obtaining and reporting skid resistance information; obtaining and reporting wet weather accident information; selecting and prioritizing locations for treatment and providing skid resistant surfaces. A discussion of each part of the program is included.

Even though attempts were made to provide skid resistant surfaces early in the history of highways in Texas, the first skid resistance measurements were made in 1962. Since then, much time and considerable funds have been expended in the study of skid resistance and in developing methods of reducing wet-weather accidents.

The program for reducing wet weather skidding accidents may be explained in four parts:

1. Development of skid resistance information.
2. Treatment of accident information.
3. Safety improvement program for skid-prone locations.
4. Providing skid resistant surfaces.

Development of Skid Resistance Information

In the past, pavement skid resistance measurements have been obtained using a stopping distance vehicle, skid test trailers, a British Portable Tester and a Penn State Drag Tester. The stopping distance vehicle was used initially and the Penn State Drag Tester was used experimentally. At present, the British Portable Tester is used in connection with laboratory tests. The skid test trailer is used exclusively in the field for inventory work. A history of the development of the unit follows:

1963 - First skid test unit fabricated in the Departmental shops. Used in research studies.

1968 - Three additional test trailers fabricated. Used for statewide skid resistance inventory.

1974 - Four new second-generation skid test units fabricated in the Departmental shops. Texas Transportation Institute assists in the automation of the units. One unit is used for research studies and three units are used in a statewide inventory.

In 1974, a system was devised wherein skid resistance data could be collected in an automated manner (1). This system was developed around a scheme for numbering construction jobs. Each construction job in each district (field) was assigned a unique number, which was termed a Construction Section Number (CSN). Materials, traffic, location and past skid resistance information were collected for each construction job and stored in a (computer) automated file using the CSN number as the file location key. Each skid test unit was fabricated with equipment that resulted in a machine processable punched teletype tape.

The location key punched on the paper tape is the CSN. In other words, the beginning of each construction job is visually located from the truck cab by the unit observer and "dialed in" on the instrumentation provided. As the unit passes the beginning of the construction job, a button is activated which automatically punches the CSN which was dialed, along with temperature and direction of travel. Skid number, velocity, distance from CSN initiation, lane tested and selected comments are punched on the paper tape at each lock-up. Figure 1 is a general view of one of the skid test units. Figure 2 shows several items of equipment on the trailer in addition to part of the watering system. A torque ring is used as the force transducer. Figure 3 shows both the operator console (left) and the observer console (right). The view is from the rear seat facing toward the front of the truck. The center divider contains four digital displays indicating the skid number, water pressure (assures correct water discharge), the distance in miles from the initiation of the CSN, and a distance readout in feet which is used to determine the mileage readout. The frequency at which the test tire is braked may be preprogrammed by dialing a number on a thumbwheel switch. This frequency or lockup interval may be selected from 0.161 km (0.1 mile) to 1.448 km (0.9 mile) at 0.161 km (0.1 mile) intervals. The divider also contains a strip chart recorder. The digital display for the velocity is shown just below the gear shift in the vehicle dash panel. The observers console in the upper left contains thumbwheel switches by which the CSN, temperature, lane and direction of travel may be dialed. The light-colored push butoons are activated to denote standard comments such as "test obtained on a horizontal curve" and "test obtained on a flushed area." Figure 4 shows the teletype and timing or strobing hardware which is located in the rear seat area.

Figures 5 through 11 are examples of seven types of reports that are available to the user. Report 1 on Figure 5 automatically is submitted to the field district when the teletype punched paper tape is processed. The other reports may be obtained whenever needed. It may be noted that field data have been combined with previously stored data for reporting purposes. This is accomplished by using the CSN which is available on both field and computer stored data. Also the low, average and high skid numbers of a given CSN are stored, as the paper tape is processed, eventually forming a history or skid resistance performance of various pavement types and materials. The location information is compatible with accident location information.

Treatment of Accident Information

Historically, the statewide reporting of vehicular accidents in Texas has been a combined effort of the Department of Public Safety (DPS) and the Texas Department of Highways and Public Transportation (DHT) (2). The DPS investigated each accident and filed an accident report. The DHT processed the accident report and stored the information. Originally, this process was limited to rural areas.. Recently, urban areas were added with city police units forwarding accident reports to a central processing group.

To assist DHT personnel in selecting and studying wet weather accident sites, several reports have been developed. Figure 12 is an example of a report indicating both total (all or wet and dry weather) and wet weather accidents, and accident rates (3). The rates are based on 160.9 million vehicular kilometers (100 million vehicle miles) of travel. It may be noted that wet weather accident rates are generally 2 to 3 times higher as compared to the total accident rates. Some wet weather accident rates have been noted which are 10 times greater than the total accident rate. The report shown in Figure 12 is available annually for every state-maintained rural highway and is subdivided by political subdivision (county). The "Cont and Sec" (Control and Section) represent certain lengths or sections along given highways but do not represent construction job limits. Figure 13 is a list of skid-prone control-sections selected by a method to be explained later in this paper. The number of wet weather accidents and the wet weather accident rates are available for perusal.

The example in Figure 14 is also a list of skid-prone locations. The difference between the information in Figures 13 and 14 is that Figure 13 concerns longer lengths of roadway, whereas Figure 14 is for spot (0.161 km or 0.1 mile) locations. Figure 15 is an example of a summary of each individual accident occurring within the skid-prone locations selected as shown in Figures 13 and 14. The control section is shown in the upper left; however, the milepost is shown along the top of the sheet. Each vertical column represents an accident event. The locations are shown to the closest 0.161 km (0.1 mile) and the first location was at milepost 0.6. The last location was at milepost 17.9. The symbol "W" represents an accident in wet weather conditions and of course "D" is for dry conditions. On many occasions a quick glance will indicate certain events that would reduce the probability that the site should be considered as skid-prone, such as the vehicle in collision with an animal. On the other hand, it is believed that greater consideration should be given to those sites with large numbers of single vehicle accidents while wet, and especially those in which the investigating officer recorded, "lost control and skidded."

Safety Improvement Program for Skid Prone Locations

The present Statewide Highway Safety Improvement Program was initiated in December 1974 (4). The program was subdivided into four categories as follows:

1. High Accident Locations.
2. High Hazard Locations.
3. Roadside Fixed Objects.
4. Skid-Prone Locations.

The concern in this paper is the category entitled "Skid Prone Locations." This category contains a method of selecting the locations and then establishing a statewide priority rating. Skid-prone locations are selected using the following criteria:

A. For Spot Locations - Any 0.161 km (0.1 mile) section exhibiting 3 or more wet weather accidents in a one-year period. (See Figure 14)

B. For Long Sections - (1) Any control-section exhibiting 2 or less wet weather accidents annually should not be considered. (2) All control-sections exhibiting 20 or more wet weather accidents annually should be considered without restriction. (3) Control-sections having 3 to 19 wet weather accidents annually should be considered if:

a. $\frac{DVM}{WWA} \leq 3{,}000$

DVM = daily vehicle miles
WWA = number of wet weather accidents

b. The control section length is 0.483 km (0.3 mile) or more.

Figure 13 is an example of a list of control-section locations within one of the twenty-five districts in Texas.

The statewide priority rating is established by the following method:

$$SPI = BCR \times (ADT/1000) \times SNF$$

SPI = Skid-Prone Index
BCR = Benefit Cost Ratio
ADT = Average Daily Traffic (Annual)
SNF = Skid Number Factor

The SNF is determined from:

SN_{40} = <30 30-40 > 40

SNF = 1/30, 1/35, 1/40

The BCR is determined as follows:

$$BCR = \frac{ABAC - AAAC}{AIC}$$

ABAC = Annual Before Accident Cost
AAAC = Annual After Accident Cost
AIC = Annual Improvement Cost

$$ABAC = \frac{BAC}{\text{Number of Years of Accidents}}$$

BAC = Total Accident Cost During the Before Study Period

AAAC = ABAC X (1.00 - RF)

RF = Percent reduction by type of improvement (expressed as a decimal)

AIC = Total Project (Improvements) Cost X CRF

CRF = Capital recovery factor for project service life at 8 percent interest rate.

The annual before accident costs are to be based on:

$82,000 for each fatality.
3,400 for each injury.
480 for each property damage accident.

The project with the largest SPI has first priority. Subsequent projects are ranked in order of decreasing SPI.

It should be noted that both the selection of locations and the statewide priority rating schemes were established arbitrarily and are based on judgement.

Providing Skid Resistant Surfaces

Providing a skid resistant surface in Texas is synonymous with providing a surface with optimum texture, both macrotexture and microtexture. To maintain a skid resistant surface it is necessary to maintain optimum surface texture.

When hydroplaning is considered in providing skid resistant surfaces, the water layer between the tire and the pavement must be reduced, and at times drastically reduced. The water layer on the pavement surface may be reduced through adequate geometric design and through adequate cross-slope or superelevation consideration. The water layer between the tire and the pavement may be reduced by proper pavement mix design and construction procedures. Adequate mix design and construction procedures will provide (1) dynamic water drainage around the macrotexture projections as the tire passes; (2) dynamic internal water drainage into and through the pavement surfaces; or (3) a combination of (1) and (2). A discussion of providing skid resistance for each major pavement type follows.

Portland Cement Concrete

The skid resistance experience in Texas for portland cement concrete paving has been good. In general, the SN_{40} values will be around 50 or above soon after construction and rarely below 35 in the "as polished" condition. However, there are many exceptions to this.

Texas has little studded tire traffic and therefore, the coarse aggregate is rarely exposed. For this reason, when considering skid resistance, considerable emphasis is given to the fine aggregate and very little to the coarse aggregate.

Microtexture is developed from the fine aggregate and mortar. To obtain adequate microtexture, it is necessary to use a fine aggregate that is sharp and angular. To maintain the microtexture, a hard aggregate that will continue to exhibit sharp, angular edges is needed. A durable concrete with an excellent surface strength will hold the fine aggregate in place. Because of this the 1972 Standard Specifications require the fine aggregate to meet a value of not less than 28% by weight when subjected to an acid insoluble residue test (Test Method Tex-612-J) (5, 6) The same requirement exists at the present time. Most of the fine aggregate used since 1972 in both paving and bridge decks has been from a source with silicious origin. Silicious fine aggregate generally has sharp, angular faces in Texas. However, some test is needed which would assure an aggregate with sufficient angular faces. Such a test is not used; however, some postulation has been given to a dry bulking test proposed by Rose and Havens (7).

Macrotexture is developed from the surface finishing process. Surface strength is particularly important in maintaining mactrotexture. In the past several years there has been a trend toward finishing processes that provide greater macrotexture. The trend has advanced from a belted finish to a tine finish. For several years a burlap drag was used and wooden floats, a broom and several types of plastic grooving have been used experimentally. The 1972 Standard Specifications included the first texture values as measured by the "sand patch" method. Basically, these values required 0.635 mm (0.025 inch) on pavement surfaces and 0.889 mm (0.035 inch) on bridge decks at the time of construction. At present a special provision to the standard specifications is being used which requires 1.27 mm (0.050 inch) on both pavement and bridge decks to be developed by use of metal tines at approximately 1.27 cm (1/2 inch) spacings. Transverse tines are required on paving and the direction of the tine application is left to the discretion of the district engineer in the case of bridges.

To assist construction personnel in obtaining texture, lightweight plastic or styrofoam specimens that have four examples of texture depths have been distributed to project engineers and construction inspectors. Being light in weight, the specimens can be carried to the construction job and used as examples to judge the texture of fresh concrete.

Asphaltic Concrete

A large percentage of pavement surfaces in Texas are composed of asphaltic concrete. The vast majority are dense-graded, generally a Type D mix which has a 9.53 mm (3/8 inch) top size aggregate with around 60% to 70% by weight retained on the 10-mesh screen. Asphalt contents vary from about 5% to 7% by weight. At the present time, approximately 160 lane km (100 lane miles) of open-graded asphaltic concrete exist in the State. Most of the open-graded asphaltic concrete is of recent construction. Sand asphalts are rarely exposed to the surface; however, this type of material is used frequently in base courses.

Skid resistance on the usual asphaltic concrete mix is basically derived from the coarse aggregate. Discounting the layer of fines on the coarse aggregate at or soon after construction, the tire is in contact with the coarse aggregate during passage. With age, traffic, and weathering, the fine aggregate-asphalt mortar is generally dislodged, leaving the coarse aggregate in even more intimate contact with the tire.

Microtexture is available from the fine aggregate in the mix, but because of the dominate role of the coarse aggregate, microtexture on the surface of the coarse aggregate particles is essential. Sharp angular facets on the surface of the aggregate particles are also necessary for the coarse aggregate to have good skid resistance properties. If a coarse aggregate can be found which will maintain good microtexture and angular facets under traffic, an asphaltic concrete surface can be constructed which will maintain good skid resistance, provided sufficient water drainage is available.

Macrotexture for the usual dense-graded mix stems from the protrusion of the coarse aggregate particles from the pavement surfaces. The extent of the macrotexture depends on several factors such as void content of the mix, asphalt content, traffic, weather, abrasion resistance of the aggregates, construction techniques. It would be helpful to have available a procedure to assure adequate macrotexture in a dense-graded mix, but at present no method is used in Texas.

The British Wheel Test is presently used to specify coarse aggregate with durable skid resistance characteristics and the test does a good job of predicting the skid resistance performance of aggregate (8). This test has been in use since 1971. The test is not included in the standard specifications, but it is used through special provision clauses. The test procedure has been slightly modified from the parent British BSS-812 test procedure; therefore, the term "polish value" is used to describe the "terminal" polished condition of aggregate rather than the British term polished stone value. The following polish values are specified at the present time:

Minimum Polish Value	Present Average Daily Traffic Grouping
None	0-749
30	750-1999
33	2000-4999
35	5000-Over
35	All Interstate Highways

A British Portable Tester is used in the test to determine polish values. However, an auxiliary scale such as that used by the British is not used to determine the polish value. Therefore, the values indicated above may seem low to some readers. An approximation of values using an auxiliary scale would result if the above values were multiplied by a factor of 1.67. Thus, a polish value of 35 would be about equivalent to a polished stone value of 51.

A small number of jobs have been constructed in the State using an open-graded mix. As compared to a dense-graded mix, the open-graded mix should be mixed, transported and placed in a relatively cool condition. Attempts should be made to reduce the time of transport. The surface to receive the mix should be waterproof and in good condition. An aggregate with good skid resistance characteristics should be used in the mix.

The initial SN_{40} values on the open-graded mixes which have been placed are usually relatively low or around 35 to 40. These values improve with time and are maximum within several hundred thousand traffic applications. When using the same coarse aggregate, the SN_{40} values are lower than that of a penetration seal and about the same or slightly lower than a dense-graded mix. Even though open-graded mixes have not been tested in heavy rainfall conditions, it is believed that the reverse would be revealed or the skid resistance of open-graded mixes would be higher as compared to dense-graded mixes. The reasoning is related to the excellent drainage properties of the open-graded mix. Water is drained into and around the aggregate particles. Because of the large void content, excellent macrotexture is also available.

Because the coarse aggregate again provides the major role in providing skid resistance in the open-graded mix, the British Wheel Test is used in the specifications. The polish values specified are the same as those used in the dense-graded mixes.

Penetration Seals or Surface Treatments

A penetration seal and a surface treatment have similar construction techniques. The term "surface treatment" is used in conjunction with newly constructed sections of roadway. They may be singles, doubles or triples, depending on the number of layers. Multiple courses conform to a "macadam" construction method. The term penetration seal is used in referring to maintaining or upgrading an existing surface. Surface treatments are used extensively in the State as the surface on newly constructed pavements, particularly secondary roads. There is a tendency not to use seals or surface treatments on high-volume highways. Intersections and other geometric locations where high friction is needed show poor results when seals have been used. It is believed that the friction developed between the tire and the rock causes the rock to dislodge. The most used specification requires a Grade 4 in which the majority of the aggregate is retained on the 6.35 mm (1/4 inch) sieve and passes the 9.53 mm (3/8 inch) sieve. The aggregate size ranges from Grade 1, which has a top size of 19.05 mm (3/4 inch) with the majority on the 15.88 mm (5/8 inch) sieve, to a Grade 5, which has a top size of 6.35 mm (1/4 inch) with the majority retained on a number 10 sieve.

The recurring problem with this type of construction is the flushing that occurs from consolidation or aggregate stripping. It is believed that more stripping occurs than consolidation. Recently an attempt was made to use a "one-size" aggregate in surface treatment and seals. With the "one-size" aggregate, more asphalt is generally used. Also, less aggregate is needed and there is a tendency to reduce the aggregate application rate. The "one-size" aggregate change has apparently improved the structural durability of the surfaces and, therefore, the friction.

A skid resistant aggregate with good microtexture and shape should be used in seal coats. The British Wheel Test is used with surface treatments and seals with the same "polish values" as specified with the dense-graded asphaltic concrete.

Sprinkle Treatment

In the sprinkle treatment construction technique, a small quantity of skid resistant aggregate is placed (sprinkled) on the surface of a newly placed asphaltic concrete or portland cement concrete and bound by rolling, vibrating, or tamping. Sprinkled aggregate on portland cement concrete has not been used in Texas. Therefore, the experience with asphaltic concrete will be treated. Sprinkle treatment construction is considered in the State because of the economic benefit. It is possible to use the low-cost local materials in the asphaltic concrete and only a small amount of high-cost skid resistant aggregate as the sprinkled material.

Sprinkle treatment construction was first noted in British publications. Later, specifications and construction procedures were obtained from the Virginia Department of Highways and Transportation. Because of the lack of funds to upgrade our highways for both structural and skid resistance reasons, this type of construction is becoming popular. However, sprinkle treatment construction in Texas should be considered experimental at the present time. In the majority of the jobs to date the sprinkled aggregate has been placed on the usual Type D dense-graded mix previously described. The sprinkled aggregate has usually been precoated to assure adhesion to the asphaltic concrete mat. Various aggregate types have been used as the sprinkled material and various types and quantities of precoating material have been used. There has also been experimentation with aggregate application rates and rock spreading equipment.

The skid resistance history of sprinkle treatment pavement sections has been understandably varied because of the experimental nature. However, the skid resistance level appears highly dependent on the type of sprinkled aggregate, the amount of sprinkled aggregate in place in terms of surface area, and the extent the sprinkled aggregate protrudes from the asphaltic concrete mat.

Rehabilitation of Surfaces

Rehabilitation practices to renew skid resistance generally have been some form of overlay procedure. Dense-graded mixes, open-graded mixes, sprinkle treatments and penetration seals have been used as rehabilitation methods. The procedures in obtaining skid resistance for rehabilitation are not different from those involved in initial construction.

Other methods of improving the skid resistance of existing surfaces have been attempted. These have been pavement grooving (sawed), acid etching, hydra broom (high-pressure water jet), reheating (treating flushed areas with aggregate after reheating), and heater planing (trimming the surface with blades after heating). With the exception of pavement grooving, the methods are considered as only temporary emergency measures until treatments with longer skid resistance life can be applied.

Summary

This paper has described the equipment, information and methods used in a planned program for reducing accidents. The use of pavement skid resistance and accident information in the reduction of accidents is very illusive. It is believed that the illusiveness is due primarily to the time delay in obtaining information, particularly the accident information. In the large reporting network described in the paper, statewide reports have a lag time for initially collected information that is as much as fifteen months. In many cases, rapid treatment is needed at accident sites and long lag times are harmful.

Present efforts involve developing more frequent automated reporting. Many field personnel receive a copy of the reports of the accidents occurring in their area on the day following the occurrence. Using this information, small or spot accident sites can be located early and, at times, treated with small funding.

There are, therefore, two methods for corrective action to be considered. First, with frequent reporting and in local areas, corrective treatment is needed at the locations that can be treated at low cost. Temporary corrective treatment may be considered. Second, the annual information may be used for the more costly long-term corrective treatment methods.

In summary, advancement has been made toward the reduction of wet weather skidding accidents and we are proud of this advancement. However, much continued effort is needed.

Figure 1. The 1974 Skid Test Unit.

Figure 2. Trailer Components.

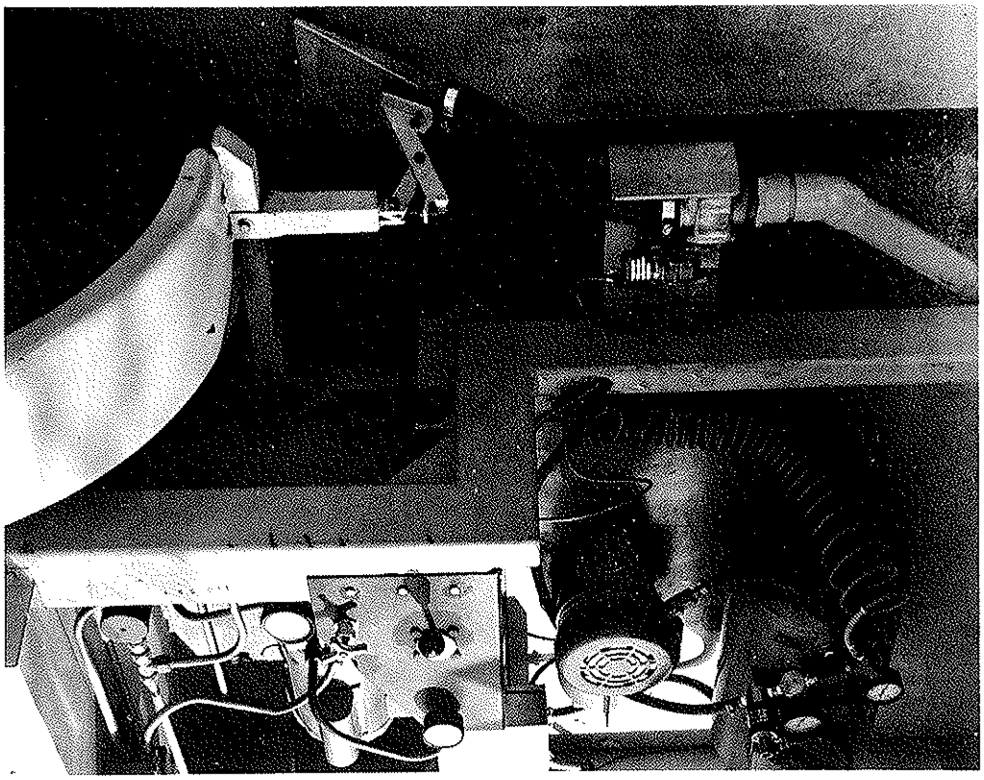


Figure 3. Control Consoles.

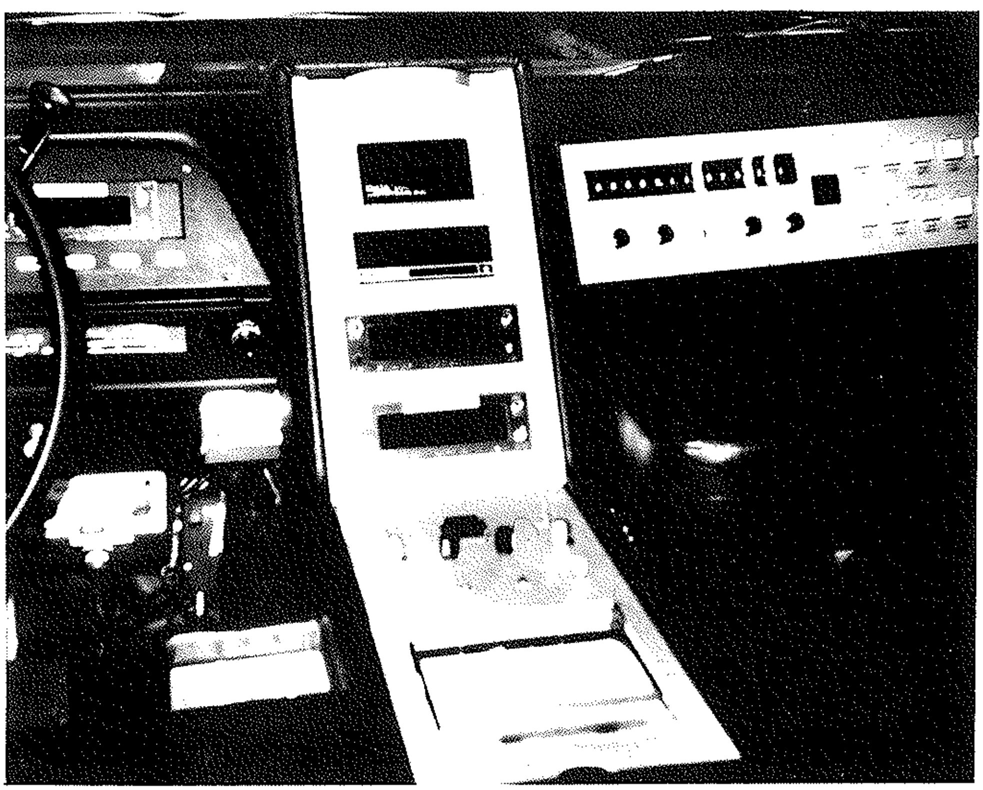


Figure 4. Teletype and Strobing Units.

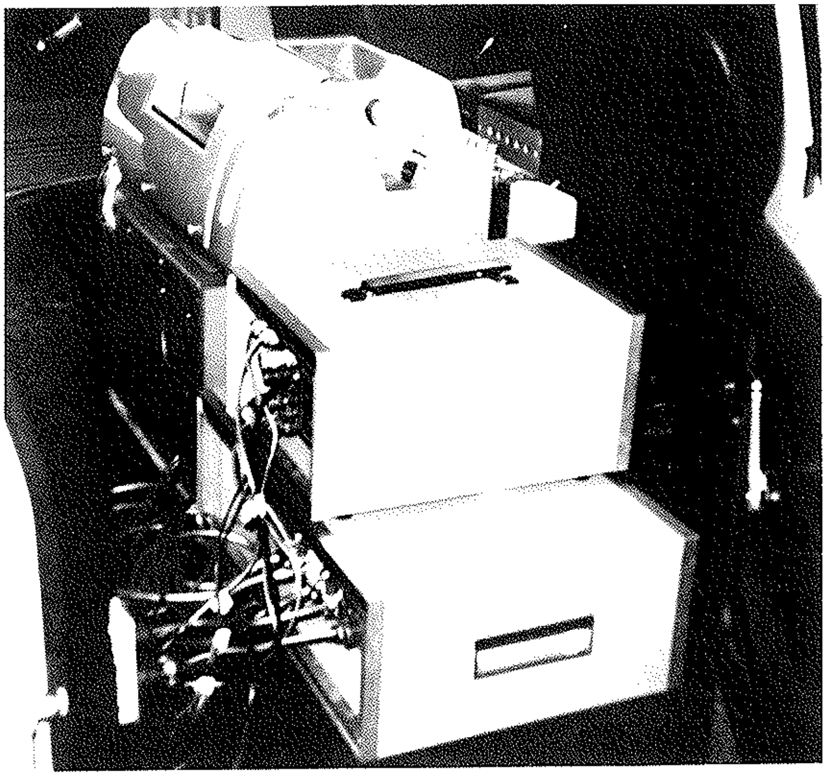


Figure 5. Skid Resistance Report 1.

```
DISTRICT..0 , CSN..0000271 - DETAIL TEST LISTING           SKID RESISTANCE REPORT 1          DATE 02/19/74            PAGE   1

+-- CONSTRUCTION SECTION INFORMATION ---+----- PAVEMENT, MATERIAL, & ------+-- CONTROL-SECTION INFO. --+------- SKID HISTORY -------+
+                                       +       SOURCE INFORMATION        +                           +       TVL    SN      TRAFFIC+
+                                       +                                 + CO.    C-S ·  BMP    EMP  + MO/YR -LN LO/AV/HI  (000) +
+---------------------------------------+---------------------------------+---------------------------+----------------------------+
HIGHWAY... IH   5  ADT...........18,700 + PAVEMENT. HMAC                  +  4     5-.4 25.600 22.939 +
CSN LENGTH  2.661  TRAFFIC....3,459,500 + PLACED... 08/73    BINDER... 9.50 +                         +
FROM..        NO C/L                    + PRI AGG.. TYPE D      LIGHTWEIGHT+                          +
TO.... 01 MI NO SH 3  OP                + 2ND AGG..                       +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                          +
COMMENT1                                + PRI 316-EAGLELIGHT-WACO,TX      +                           +
COMMENT2                                + 2ND                             +                           +
--------------------------------------------------------------------------------------------------------+
CONSTANTS THIS TEST -  (1) TESTED ON  2/13/74      (3) AIR TEMPERATURE AT TEST WAS  62 DEGREES F.         +
                       (2) USING TRUCK NO. 40      (4) TRAVELING ***WITH*** THE FROM/TO DESCRIPTION        +
                                                                                                        +
WARNING - THIS TEST ALONE IS INSUFFICIENT TO ESTABLISH THE SAFE FRICTION VALUE FOR A HIGHWAY             +
--------------------------------------------------------------------------------------------------------+----------------------------
```

-- GENERAL SKID TEST DATA ---***-- SN BREAKDOWN BY LANE --***---------------------- SN BREAKDOWN BY COMMENT --------------------

TEST & LANE	SPEED	CUMM. MILES	SN	A	B	C	D	E & OVER	FLUSH	PATCH	INTER-SECT.	STRUC-TURE	R.R. XING	CURVE	CITY LIMIT	DIST. SELECT
1-A	38	0.0	57	57												
2-B	44	.0.3	**		**									**		
3-B	43	0.3	50		50											
4-A	41	0.6	57	57										57		
5-B	43	0.8	**		**								**			
6-B	39	0.9	51		51											
7-A	40	1.2	56	56										56		
8-B	43	1.5	48		48									48		
9-A	41	1.8	58	58												
10-B	43	2.0	**		**							**				
11-B	41	2.1	50		50											
12-A	42	2.4	52	52												
13-B	41	2.7	51		51											
NUMBER OF TESTS....			10	5	5									3		
SKID NUMBER - LO...			48	52	48									48		
SKID NUMBER - AVG..			53	56	50									54		
SKID NUMBER - HI...			58	58	51									57		

Figure 6. Summary, Sorted by Control Section.

```
CONTROL-SECTION LISTING FOR DISTRICT 0                      SKID RESISTANCE REPORT 3                                  DATE 06/06/75     PAGE   1
+- CONTROL SECTION INFO --+--- GENERAL CONSTRUCTION SECTION (CSN --+-------- MATERIAL AND SOURCE -------+- SKID HISTORY(  . OF 6) -+
+                         +                INFORMATION             +              INFORMATION          + DATE  TVL   CO     TRAFFIC+
+  C-S   BEGIN MP  END MP +                                        +                                   + MO/YR -LN LO/AV/HI  (000) +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
  36- 3   0.000    1.092 + PVT... HMAC              PLACED.. 05/62 + BINDER..  4.80 PERCENT             +  8/74 O-A 38/39/40  10,862
---- --  ------   ------ + FROM.. HUN  CO LINE                      + PRI AGG. TYPE D       SILICEOUS   +  7/74 W-A 39/40/41  10,789
SH  24. D             CO. + TO.... 1.09 MI NE HUN  CO LINE          + 2ND AGG. LIMESTONE                +  4/71 W-A 40/42/44   9,373
MI IN CSN-1702401.. 1.092 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+  4/71 O-A 36/38/41   9,373
ADT...............2,670 + COMMENT1                                 + PRI   9-BRIG    SEG-MOR   PRPTY.+
TRAFFIC.........11,661,150 + COMMENT2                              + 2ND  36-TEXAS INDUS.-ARC SPUR    +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
  36- 3   1.092    4.982 + PVT... HMAC              PLACED.. 11/56 + BINDER..  5.20 PERCENT             +  8/74 O-A 38/40/43  15,422
---- --  ------   ------ + FROM.. 1.09 MI NE HUN  CO LINE          + PRI AGG. TYPE D       SILICEOUS   +  7/74 W-A 36/39/43  15,351
SH  24. DEL           CO. + TO.... 1.6 MI W JCT FM 152  SE          + 2ND AGG. LIMESTONE                +  4/71 W-A 36/40/44  11,950
MI IN CSN-1702402.. 3.890 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+  4/71 O-A 33/35/38  11,950
ADT...............2,660 + COMMENT1                                 + PRI  41-GIFFORD     -ROF    PIT  +
TRAFFIC.........16,216,700 + COMMENT2                              + 2ND  26-DOLE   BROS-DUPANT,OKLA  +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
    - 3   4.982   10.317 + PVT... HMAC              PLACED.. 04/67 + BINDER..  4.80 PERCENT             +  8/74 O-A 33/35/42   6,446
--  --  ------   ------ + FROM.. 1.6 MI W JCT FM 152  E            + PRI AGG. TYPE D       LIMESTONE   +  7/74 W-A 30/33/45   6,374
SH  24. DEL           CO. + TO.... JCT LP 45  COOPER                + 2ND AGG. SILICEOUS                +  4/71 W-A 31/33/35   6,460
MI IN CSN-1702403.. 5.335 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+  4/71 O-A 30/31/32   6,460
ADT...............2,540 + COMMENT1                                 + PRI 305-GIFFORD       SEAGO       +
TRAFFIC..........7,213,600 + COMMENT2                              + 2ND 402-MCK SEG GRAY    CO.       +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
  36- 3  10.317   11.590 + PVT... HMAC              PLACED.. 11/72 + BINDER..  5.90 PERCENT             +  7/74 W-B 48/52/55   1,043
---- --  ------   ------ + FROM.. JCT LP 45  W COOPER               + PRI AGG. TYPE D       LIMESTONE   +  7/74 W-A 52/56/60   1,043
SH  24. DEL           CO. + TO.... BEG CONC PVT                     + 2ND AGG. SILICEOUS                +
MI IN CSN-1702404.. 1.273 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+
ADT...............1,860 + COMMENT1 S LANE                          + PRI 413-WOODMAN     PIT GRAY    CO+
TRAFFIC..........1,652,700 + COMMENT2                              + 2ND 407-TXI BRIDGEPORT, TX        +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
  36- 3  11.590   11.867 + PVT... CRCP              PLACED.. 07/67 + BINDER..  5.00 SACKS/CY            +  7/74 W-B 50/51/51   4,420
---- --  ------   ------ + FROM.. BEG CONC PVT                      + PRI AGG. GRD UNKNOWN SILICEOUS    +  4/71 W-A   /49/     2,190
SH  24. DEL           CO. + TO.... END CONC PVT                     + 2ND AGG. SILICEOUS                +
MI IN CSN-1702405.. 0.277 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+
ADT...............1,890 + COMMENT1                                 + PRI 344-CHOC    MATLS-  CO,OKLA  +
TRAFFIC..........5,038,850 + COMMENT2                              + 2ND 405-SKE   SEG PAR     MAR CO.+
--------------------------+----------------------------------------+-----------------------------------+---------------------------
    - 3  11.590   10.317 + PVT... HMAC              PLACED.. 11/72 + BINDER..  5.90 PERCENT             +  8/74 W-B 49/50/52   1,094
-   --  ------   ------ + FROM.. BEG CONC PVT                      + PRI AGG. TYPE D       LIMESTONE   +  8/74 W-A 56/63/69   1,094
SH  24. DEL           CO. + TO.... JCT LP 45  W COOPER              + 2ND AGG. SILICEOUS                +
MI IN CSN-1702409.. 1.273 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+
ADT...............1,860 + COMMENT1 N LANE                          + PRI 413-WOODMAN     PIT GRAY    CO+
TRAFFIC..........1,652,700 + COMMENT2                              + 2ND 407-TXI BRIDGEPORT, TX        +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
  36- 3  11.867   12.050 + PVT... HMAC              PLACED.. 11/72 + BINDER..  5.90 PERCENT             +  7/74 W-A 43/48/53   1,055
---- --  ------   ------ + FROM.. END CONC PVT                      + PRI AGG. TYPE D       LIMESTONE   +
SH  24. DEL           CO. + TO.... JCT LP 45  E                     + 2ND AGG. SILICEOUS                +
MI IN CSN-1702406.. 0.183 +-CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+
ADT...............1,890 + COMMENT1                                 + PRI 413-WOODMAN     PIT GRAY    CO+
TRAFFIC..........1,674,050 + COMMENT2                              + 2ND 407-TXI BRIDGEPORT, TX        +
--------------------------+----------------------------------------+-----------------------------------+---------------------------
```

Figure 7. Summary, Sorted by CSN.

```
CONSTRUCTION SECTION LISTING FOR DISTRICT C              SKID RESISTANCE REPORT 4                  DATE 06/06/75            PAGE   1

-- CONSTRUCTION SECTION INFORMATION -----+------ PAVEMENT, MATERIAL, --------+-- CONTROL-SECTION INFO. --+- SKID HISTORY(MAX. OF 6) -+
+                                         +  & SOURCE INFORMATION             +                           +        TVL           TRAFFIC+
+ CSN                                     +                                   + CO.   C-S    BMP    EMP   + MO/YR -LN LO/AV/HI    (000) +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
1003801  HWY...FM  3   LENGTH...  1.520 + PAVEMENT. SURF. TRT./SEAL          +  6   49-03  0.000  1.520 +  8/74 O-A 22/25/26    1,670
-------  ADT......384  TRF....1,787,480 + PLACED... 09/62    BINDER... 0.31 +                           +
FROM..  MAR CO LINE                     + PRI AGG.. GRADE 2      LIMESTONE  +                           +
TO.... JCT FM 12                        + 2ND AGG.. PRECOAT AGG             +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                           +
COMMENT1                                + PRI  43-GIFFORD      -PERCH       +                           +
COMMENT2                                + 2ND    -2ND AGG. SOURCE UNKNOWN   +                           +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
1006401  HWY...FM  6   LENGTH...  2.586 + PAVEMENT. SURF. TRT./SEAL          +  6   99-03  1.931  4.517 +  8/74 W-A 33/43/60    1,130
-------  ADT......202  TRF....1,191,750 + PLACED... 04/59    BINDER... 0.29 +                           +
FROM.. JCT FM 12                        + PRI AGG.. GRADE 6      SILICEOUS  +                           +
TO.... S 2.586 MI                       + 2ND AGG..                         +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                           +
CO.  MT1                                + PRI 406-STW.  CONST MTLS BOB      +                           +
COMMENT2                                + 2ND                               +                           +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
1006402  HWY...FM  6   LENGTH...  5.417 + PAVEMENT. SURF. TRT./SEAL          +  6   99-03  4.517  9.934 +  8/74 W-A 33/50/61    1,391
-------  ADT......242  TRF....1,465,250 + PLACED... 11/58    BINDER... 0.29 +                           +
FROM.. 4.5 MI S JCT FM 12               + PRI AGG.. GRADE 6      SILICEOUS  +                           +
TO.... CO RD.1.49 MI E JCT FM 152       + 2ND AGG..                         +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                           +
COMMENT1                                + PRI 305-GIFFORD          SOVILLE  +                           +
COMMENT2                                + 2ND                               +                           +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
1006403  HWY...FM  6   LENGTH...  4.186 + PAVEMENT. SURF. TRT./SEAL          +  6   99-03  9.934 14.120 +  8/74 W-A 22/26/28    1,682
-------  ADT......559  TRF....1,853,055 + PLACED... 05/65    BINDER... 0.30 +                           +
FROM.. 4.18 MI W NL SH 2                + PRI AGG.. GRADE 2      LIMESTONE  +                           +
TO.... NL SH 2                          + 2ND AGG.. PRECOAT AGG             +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                           +
COMMENT1                                + PRI  43-GIFFORD      -PERCH       +                           +
COMMENT2                                + 2ND    -2ND AGG. SOURCE UNKNOWN   +                           +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
1007101  HWY...FM  7   LENGTH...  2.797 + PAVEMENT. SURF. TRT./SEAL          +  6   66-02  0.000  2.797 +
-------  ADT......324  TRF....2,719,580 + PLACED... 06/52    BINDER... 0.20 +                           +
FR   - HUN  CO LINE                     + PRI AGG.. GRADE 6      SILICEOUS  +                           +
TO.... JCT FM 153                       + 2ND AGG..                         +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                           +
COMMENT1                                + PRI 406-STW   CONST MTLS          +                           +
COMMENT2                                + 2ND                               +                           +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
1007102  HWY...FM  7   LENGTH...  1.570 + PAVEMENT. SURF. TRT./SEAL          +  6   56-02  2.797  4.367 +
-------  ADT......241  TRF....1,062,745 + PLACED... 05/63    BINDER... 0.30 +                           +
FROM.. JCT FM 153                       + PRI AGG.. GRADE 5      LIMESTONE  +                           +
TO.... HOP     CO LINE                  + 2ND AGG.. PRECOAT AGG             +                           +
CODE COL-....5...10...15...20...25...30-+- SOURCE NUMBERS & NAMES FOLLOW --+                           +
COMMENT1                                + PRI  43-GIFFORD      -PERCH       +                           +
COMMENT2                                + 2ND    -2ND AGG. SOURCE UNKNOWN   +                           +
------------------------------------------+-----------------------------------+---------------------------+---------------------------
```

Figure 8. Statewide Frequency Distribution.

DISTRICT 99 - SKID RESISTANCE REPORT 5 DATE 05/16/75 PAGE

TABLE OF MILEAGE FOR SKID NUMBER RANGES

SN RANGE	NUMBER OF MILES	CUMMULATIVE NO. OF MILES	PERCENT OF TOTAL	CUMMULATIVE PERCENT
01-05	0.000	0.000	0.0	0.0
06-10	20.240	20.240	0.0	0.0
11-15	343.089	363.329	0.7	0.7
16-20	1,345.679	1,709.008	3.0	3.7
21-25	3,828.589	5,537.597	8.6	12.3
26-30	5,917.068	11,454.665	13.3	25.6
31-35	7,218.594	18,673.259	16.2	41.8
36-40	6,548.778	25,222.037	14.7	56.5
41-45	6,559.233	31,781.270	14.8	71.3
46-50	5,166.002	36,947.272	11.6	82.9
51-55	3,427.501	40,374.773	7.7	90.6
5[illegible]	2,271.227	42,646.000	5.1	95.7
61-65	1,181.739	43,827.739	2.6	98.3
66-70	328.111	44,155.850	0.7	99.0
71-75	114.731	44,270.581	0.2	99.2
76-80	28.742	44,299.323	0.0	100.0
81-85	0.000	44,299.323	0.0	100.0
86-90	0.000	44,299.323	0.0	100.0
91-95	0.000	44,299.323	0.0	100.0
96-99	0.000	44,299.323	0.0	100.0

NOTE -- PROBABLE PERCENT ERROR DUE TO ROUNDING. ''PERCENT OF TOTAL'' INDICAT[illegible] TRUE PERCENTAGE TO NEAREST TENTH. ''CUMMULATIVE PERCENT'' IS FORCED [illegible]

Figure 9. Location of Sections in Frequency Distribution.

DISTRICT [illegible] - SKID RESISTANCE REPORT 5 DATE 06/06/75 PAGE 2

TABLE OF CONTROL-SECTION (OR C-S PORTION) SURFACES FOR SKID NUMBER RANGES

SN RANGE	C-S	BMP	EMP	LENGTH	HWY.	TVL-LN	FROM	TO
01-05	NONE							
06-10	NONE							
11-15	36-06	14.097	14.628	0.531	LP 90	0-A	CLEMENT RD	AT SF RR
11-15	26-01	3.840	5.979	2.139	FM 8	W-A	SH 24	FM 49[illegible]
16-20	72-03	12.132	14.535	2.407	SH 7	W-A	1.5 MI N LP 3[illegible] W	FM 90
16-20	98-02	18.973	19.435	0.462	FM [illegible]	0-A	CO RD RO W PI[illegible] CK	0.462 MI E
16-20	49-01	10.135	10.637	0.502	FM [illegible]7	W-A	.1 MI E FM 118	.3 MI W FM 118
16-20	88-02	18.973	19.435	0.462	FM [illegible]9	W-A	CO RD RO W PI CK	0.462 MI E
16-20	30-02	0.000	1.694	1.694	FM 5	W-A	JCT LOOP 46	1.694 MI NORTH
16-20	9-08	11.588	12.223	0.635	FM 9	W-A	SH 5	FM 51
16-20	17-04	4.634	6.130	1.496	FM 1	W-A	JCT FM 42	VAN ZANDT CO LINE
16-20	39-01	0.000	1.937	1.937	FM 1	0-A	PARK BOUNDARY	FM 157
16-20	36-07	3.407	3.896	0.489	LP C	0-B	LOOP 28	CLEM[illegible] ST
16-20	30-02	7.733	13.388	5.655	FM 5	0-A	1.0 MI WEST OF FAU[illegible]	JCT FM 90[illegible] [illegible]T [illegible]VICE
16-20	30-02	7.145	7.733	0.588	FM 5	0-A	1.6 MI WEST OF FAU[illegible]	1.0 MI WEST OF FAUG
16-20	35-04	19.084	19.942	0.858	FM 5	W-A	SH 1	SH 15
16-20	72-03	12.132	14.535	2.407	SH 37	0-A	1.5 MI N LP 3[illegible] W	FM 90
16-20	97-01	4.289	10.611	6.322	FM 15	0-A	0.3 MI S MILEPOST 4	JCT FM 300
16-20	38-01	0.000	2.941	2.941	FM 15	W-A	JCT FM 279	JCT FM 294 S
16-20	25-01	6.257	14.117	7.860	FM 75	W-A	IH 3[illegible]	FM 156. E
16-20	81-10	0.000	4.173	4.173	US 77	0-A	WILLIS FERRY S END BR	4.1 MI S
16-20	9-09	4.757	3.224	0.933	IH 30	W-B	1.0 MI E JCT FM 49	JCT FM 49
16-20	36-07	3.407	3.896	0.489	LP 30	0-A	LOOP 28	CLEMENT ST
16-20	36-07	3.407	3.896	0.489	LP 30	W-B	LOOP 28	CLEMENT ST
16-20	9-09	10.816	8.463	2.353	IH 30	W-B	0.2 MI W LOO 31	0.1 MI W MILE POST 6
16-20	41-02	0.048	5.121	5.073	FM 67	0-A	US 6	HOPKINS CO LINE
16-20	41-04	9.939	18.457	8.518	FM 67	0-A	SH 1	SH 15

Figure 10. Materials Report.

SURFACE TYPE COMPARISON FOR DISTRICT C　　SKID RESISTANCE REPORT 6　　DATE 06/06/75　　PAGE 7

PAVEMENT TYPE...........C-HMAC　　PRIMARY AGGREGATE TYPE..B-LIMESTONE

TIME IN PLACE YR-MO	CONTROL-SECTION INFO C-S	BMP	EMP	HWY	PHYSICAL DESCRIPTION AS PER CONSTRUCTION SECTION FROM	TO	SKID INFO TVL -LN	AVG SN	TRAFFIC (000)
8	9- 3	0.000	15.376	IH 3.	ROCK CO LINE	LOOP 31	W-B	26	78,389
							W-A	28	78,389
8	9- 3	15.379	C.CCC	IH 3.	LOOP 31	ROCK CO LINE	W-B	24	78,389
							W-A	28	78,389
8	3-04	0.000	8.517	US 6	SH 1	WO CO LINE	W-A	42	272
10	1-01	4.300	14.560	SH 15	SH 1	WO CO LINE	W-A	26	11,451
11	3-11	0.000	7.373	SH 1	FM 279	VAN CO LINE	O-A	45	1
							W-A	42	1
11	21-01	1.035	1.566	LP 48	1 STREET	2 STREET	O-A	31	2,075
11	690-01	20.260	23.533	LP 28	END CONC PVT W SH 1	JCT US 8 W	O-A	38	5,019
11	690-01	16.709	20.C31	LP 28	.74 MI S JCT US 27	BEG CONC PVT	O-A	38	9,757
1- 4	5-18	6.296	17.722	US 8	C.4 MI E JCT FM 90	JCT FM 141	W-A	59	***,***
							W-B	49	***,***
1- 4	5-18	17.722	6.296	US 8	JCT FM 141	0.4 MI E JCT FM 90	W-A	58	***,***
							W-B	50	***,***
2- 2	5-08	0.000	2.228	US 8	FANN CO LINE	2.2 MI E TO FAP MKR	O-A	45	1,296
							W-A	48	1,296
2- 3	5-06	16.258	15.204	US 8	NEY GROVE	MAR CO LINE	W-A	43	1,488
							O-A	42	1,488
2- 7	36-03	11.590	10.317	SH 2	BEG CONC PVT	JCT LP 45 W COOP	W-B	50	1,094
							W-A	63	1,094
2- 7	36-03	11.867	12.050	SH 2	END CONC PVT	JCT LP 45 E	W-A	48	1,C55
2- 7	36-03	12.050	11.867	SH 2	JCT LP 45 E	END CONC PVT	W-B	50	1,107
2- 7	36-03	10.317	11.590	SH 2	JCT LP 45 W COOPER	BEG CONC PVT	W-B	52	1,043
							W-A	56	1,043
2- 9	9 6	8.496	10.501	SH 5	FM 45	IH 3	O-A	44	2,800
							W-A	44	2,800
2- 9	36-02	0.000	1.885	SH 2	LOOP 21 W OF COMMERCE	LOOP 21 NE OF COMMERCE	O-A	41	1,849
							W-A	35	1,849
2- 9	68-01	0.000	1.163	SH 5	SH 2	LOOP 17	W-B	39	4
							W-A	40	4
2- 9	68-01	1.163	0.CCC	SH 5	LOOP 17	SH 2	W-B	39	4
							W-A	46	4
2- 9	690-01	0.000	3.163	US 8	JCT LOOP 26 N AND E	BEG CONC PVT N US 27	W-A	42	2,747
							W-B	35	2,747
							O-A	37	2,747
							O-B	34	2,747
2- 9	321-01	7.129	8.486	SH 5	FM 51	FM 49	O-A	45	2,432
							W-B	45	2,432
2-11	5-18	6.296	C.000	US 8	C.4 MI E JCT FM 90	COOK CO LINE	W-A	63	3,358

* 01 * C-HMAC * B-LIMESTONE *

Figure 11. Materials Report, Sorted by Pavement Type, Aggregate Type and Source.

C-HMAC　　A-SILICEOUS

CONSTRUCTION SECTION	BINDER CONTENT	TRAFFIC AT SKID TESTS	DATE OF TESTS	SN BY DIRECTION OF TRAVEL -- LANE TESTED (SEE PAGE 1) W-A	W-B	W-C	W-D	W-E	O-A	O-B	O-C	O-D	O-E
9-BRIG SEG- TEN PRPTY. 12-TYPE D													
1701901	4.80	14,518,CCC	C7/74	42	38								
1701903	4.80	8,416,000	04/71	39					44				
		13,857,CCC	C7/74	39					40				
1702401	4.80	9,373,CCC	04/71	42					38				
		10,862,CCC	08/74	40					39				
1702410	4.80	8,829,4CC	04/71	41					40				
		10,102,CCC	C8/74	40					42				
41-GIFFORD -BCB PIT 12-TYPE D													
1702402	5.20	11,950,0CC	C4/71	40					35				
		15,422,CC0	08/74	39					40				
6631502	4.50	2,133,CC0	C4/71	51					46				
		5,CC0,CC0	C8/74	32	31				30	30			
6702401	4.90	14,299,CCC	C8/74	33	31				33	33			
6806905	4.50	5,765,5CC	04/71	35					32				
		6,163,2C0	C8/74	33					33				
6806906	4.50	7,977	04/71	32					38				
		8,471	C8/74	30					31				
6806907	5.20	6,709,5C0	04/71	29					34				
		7,154,CC0	08/74	30					34				
44-GIFFORD -K PLANT 12-TYPE D													
9827102	5.80	7,475,CCC	04/71	41					39				
		8,198,0C0	07/74	37					36				
45-GIFFORD -TEX 12-TYPE D													
7808208	4.60	***,***,***	04/71	34					34				
		10,288,CC0	07/74	34					34				
9808201	4.70	***,***,***	04/71	35					38				
		,,***	C7/74	35					35				
304-TEXAS INDUS- GOVILLE,TX 12-TYPE D													
8004701	4.80	88,505	C3/75						40				
305-GIFFORD GOVILLE 12-TYPE D													
6838002	5.20	6,916,300	C4/71	32					33				
		7,574,4CC	C7/74	33					31				

* 01 * C-HMAC * A-SILICEOUS * BRIGGLE SEG-MORTEN PRPTY. THRU GIFFORD HILL-HODT PIT *

Figure 12. Wet Weather Accident Rate Report.

COUNTY - GRAY AVG ANNUAL RAINFALL =38. INCHES DISTRICT PAGE 5

HIGHWAY	CONT	SEC	LENGTH IN MILES	DAILY VEHICLE MILES	FATAL-ITIES	FAT. ACC.	FAT.+ INJ ACC.	TOTAL ACC.	FATALITY RATE	FATAL ACC RATE	FATAL + INJURY RATE	TOTAL RATE	TOT WET ACC	% WET TIME	WET ACCIDENT RATE	RATIO WET RATE TO TOTAL RATE
US 8	4	2	10.64	54402	1	1	9	43	5.0	5.0	45.3	216.6	7	7.9	446.2	2.06
US 8	4	3	6.78	37609	0	0	4	15	0.0	0.0	29.1	109.3	3	7.9	276.6	2.53
US 8	4	4	11.95	46450	1	1	6	29	5.9	5.9	35.4	171.0	3	7.9	224.0	1.31
US 8	4	18	17.74	1739	1	1	10	30	157.5	157.5	1575.5	4726.4	7	7.9	13959.8	2.95
US 8	4	19	0.39		0	0	0	1					0	7.9		
US 6	4	1	3.92	42610	3	2	27	40	19.3	12.9	173.6	257.2	9	7.9	732.5	2.85
SH	4	3	9.74													
US 7	4	3	0.67													
			10.41	33156	0	0	3	23	0.0	0.0	24.8	190.1	0	7.9	0.0	0.0
US 7	4	13	9.41	93131	3	1	9	23	8.8	2.9	26.5	67.7	5	7.9	186.2	2.75
LP 38	4	16	0.34	762	0	0	1	5	0.0	0.0	359.5	1797.7	0	7.9	0.0	0.0
US 37	8	7	16.84	28679	0	0	6	17	0.0	0.0	57.3	162.4	5	7.9	604.6	3.72
LP 44	8	8	4.89	8430	0	0	3	12	0.0	0.0	97.5	390.0	1	7.9	411.4	1.05
US 37	8	10	15.84	30825	1	1	12	28	8.9	8.9	106.7	248.9	6	7.9	675.0	2.71
LP 47	8	15	0.76	84	0	0	0	1	0.0	0.0	0.0	3261.6	0	7.9	0.0	0.0
LP 47	8	16	1.10	572	0	0	1	3	0.0	0.0	479.0	1436.9	0	7.9	0.0	0.0
SH 28	9	1	15.89	19688	1	1	7	20	13.9	13.9	97.4	278.3	9	7.9	1585.3	5.70
FM 15	20	1	1.10	1774	0	0	0	2	0.0	0.0	0.0	308.9	0	7.9	0.0	0.0
FM 12	20	8	7.21													
FM 99	20	8	2.02													
FM141	20	8	2.96													
FM 13	20	8	2.52													
			14.71	30994	0	0	13	44	0.0	0.0	114.9	388.9	11	7.9	1230.8	3.16
FM 69	20	9	14.77	3958	0	0	1	4	0.0	0.0	69.2	276.9	0	7.9	0.0	0.0
US 6	20	13	1.31	2773	0	0	3	6	0.0	0.0	296.4	592.8	0	7.9	0.0	0.0
FM 8	31	2	6.83	5840	0	0	3	4	0.0	0.0	140.7	187.7	0	7.9	0.0	0.0
FM175	31	3	9.16	8766	0	0	4	11	0.0	0.0	125.0	343.8	0	7.9	0.0	0.0
US 6	41	1	11.07	27786	0	0	7	15	0.0	0.0	69.0	147.9	4	7.9	499.2	3.38
US 6	41	2	7.37													
SH 16	41	2	7.37													
			14.74	23687	0	0	7	16	0.0	0.0	81.0	185.1	5	7.9	732.0	3.95
FM 90	51	1	20.27	8331	5	1	2	10	164.4	32.9	65.8	328.9	1	7.9	416.3	1.27
FM 90	51	2	7.98													
SH 1	51	2	5.28													
			13.26	15607	0	0	5	19	0.0	0.0	87.8	333.5	2	7.9	444.4	1.33
FM 89	51	3	2.02	2367	0	0	1	8	0.0	0.0	115.7	926.0	1	7.9	1465.2	1.58
FM 69	66	1	5.30	13054	0	0	6	20	0.0	0.0	125.9	419.8	10	7.9	2656.7	6.33
SH 7	70	1	3.60	13561	0	0	7	15	0.0	0.0	141.4	303.0	3	7.9	767.2	2.53
FM 12	72	1	5.23	15303	0	0	8	20	0.0	0.0	143.2	358.1	2	7.9	453.2	1.27
FM 12	72	2	6.49	6678	1	1	6	19	41.0	41.0	246.2	779.5	4	7.9	2077.3	2.66
FM189	72	3	5.58	4458	0	0	0	1	0.0	0.0	0.0	61.5	0	7.9	0.0	0.0
FM 12	72	1	22.23	9826	0	0	2	9	0.0	0.0	55.8	250.9	2	7.9	705.9	2.81
FM 12	72	2	10.86	6929	1	1	5	9	39.5	39.5	197.7	316.3	0	7.9	0.0	0.0
FM 81	72	3	1.08	238										7.9		

Figure 13. Control Sections Selected for Priority Ranking.

SELECTED CONTROL SECTIONS

DIST	COUNTY	CONT-SEC	NUMBER WET ACCIDENTS	WET ACCIDENT RATE
0	3	18- 5	4	1547.0
0	3	98- 7	5	1609.1
0	3	06- 4	7	1340.2
0	3	65- 1	3	1792.0
0	9	38-15	3	3128.1
0	9	77- 1	11	1317.8
0	9	93- 1	22	1448.0
0	9	24- 2	14	1625.1
0	10	64- 2	10	1192.1
0	10	20- 7	6	1458.9
0	10	89- 1	3	1840.3
0	20	23- 6	5	2170.0
0	20	06- 6	6	1888.0
0	20	45- 3	4	1523.2
0	21	45- 6	19	1144.8
0	21	78- 2	6	1605.6
0	21	92- 1	9	1105.4
0	21	92- 5	5	1922.7
0	21	95- 4	26	589.8
0	21	95- 5	21	503.9
0	21	05- 2	10	1762.2
0	21	20- 6	20	1141.2
0	21	33- 1	3	1764.5
0	23	89- 1	3	1243.0
0	25	95- 9	8	1132.0
0	25	90- 3	22	1459.6
0	25	92- 3	7	1162.2
0	25	47- 1	3	1836.5

Figure 14. Spot Locations Selected for Priority Rating.

1973 1/10 MILE SECTIONS WITH 3 OR MORE WET ACCIDENTS PAGE 10

DIST	COUNTY	HIGHWAY	CONT-SEC	MILE POST	INTERSECTION	NO. OF FATAL-ITIES	NO. OF PERSONS INJURED	TOTAL NO. OF ACCIDENTS 1973	NO. OF WET ACCIDENTS 1973
0	GRE	US 25	38- 1	6.8			1	3	3
0	HEN	SH 3	63- 4	0.6	FM 9		1	11	3
0	RUS	US 8	23- 6	18.7	US 25		4	10	3
0	RUS	US 25	38- 3	0.8			1	3	3
0	RUS	SH 4	07- 3	0.3	SH 14		1	5	3
0	SMI	SH 3	24- 1	14.3	FM 85	1	5	6	4
0	SMI	FM 1	92- 1	15.4	LP 32	2	6	9	4
0	SMI	IH 2	95- 4	12.4	US 6			8	4
0	SMI	IH 2	95- 5	18.6	FM 1		1	4	3
0	SMI	SH 15	20- 6	12.2				3	3
0	SMI	SH 15	20- 6	12.3	LP 32		6	18	6
0	WOO	US 8	96- 2	32.6	FM 1			6	4
0	WOO	US 6	90- 3	3.4	US 8		3	16	4

Figure 15. Summary of Accidents in a Control Section.

```
TOTAL ACCIDENTS= 40     WET ACCIDENTS= 12
DIST.        PG. 55 +M 0 0 0 0 0 0 0 0 0 0 + 0 0 0 0 0 0 0 0 0 1 + 1 1 1 1 1 1 1 1 1 1 + 1 1 1 1 1 1 1 1 1 1 + T
CO. RED             +. 0 0 0 1 1 1 2 4 5 5 + 6 7 7 7 7 7 7 7 9 0 + 1 1 2 3 4 4 6 6 7 7 + 7 7 7 7 7 7 7 7 7 7 + O
CS   89- 2          +P . . . . . . . . . . + . . . . . . . . . . + . . . . . . . . . . + . . . . . . . . . . + T
+++++++++++++++++++++. 6 6 9 4 5 5 7 0 4 8 + 9 3 4 4 4 5 6 7 7 2 + 1 7 2 5 3 9 6 8 5 6 + 6 6 6 6 6 6 6 8 8 9 + .
VEHICLE 1 - TYPE---+--------------------+---------------------+---------------------+---------------------+++
  AUTOMOBILE.........  W D D D D D D   W   + D D D D D D W W W W + W D     D   D   D D +   D D     W W D D W =31
  TRUCK OR BUS.......                D   W +                     +     W D   D   D     + D     D D            = 9
  OTHER..............                      +                     +                     +                      *
VEH1-DIR. OF TRAVEL+--------------------+---------------------+---------------------+---------------------+++
  WITH MILEPOSTS.....  W       D       W   +     D     D     W   +   D W D         D   +     D       W        =12
  AGAINST MILEPOSTS..    D D D   D D D   W + D D   D D   W W   W + W       D D D D   D + D     D   W     D    =24
  LT. OF MILEPOSTS...                      +                     +                     +         D     D      = 2
  RT. OF MILEPOSTS...                      +                     +                     +   D               W  = 2
DATE OF ACCIDENT---+--------------------+---------------------+---------------------+---------------------+++
  MONTH-M1...........  0 0 0 0 0 0 0 1 1 0 + 0 0 0 0 0 0 0 0 0 0 + 0 0 0 0 0 0 0 0 0 0 + 0 0 0 0 0 0 1 0 0 0  *
  MONTH-M2...........  4 6 8 7 5 5 8 2 1 7 + 7 6 3 3 3 7 9 7 6 5 + 1 2 7 6 7 8 4 7 1 1 + 2 3 5 5 6 9 1 6 8 7  *
  DAY-D1.............  1 2 0 2 1 2 2 0 2 2 + 0 1 1 1 1 0 0 1 0 1 + 2 1 2 0 2 3 2 1 1 0 + 2 1 1 2 1 0 2 2 0 1  *
  DAY-D2.............  5 2 7 2 6 9 4 6 4 8 + 1 7 0 0 0 9 5 5 3 1 + 0 4 9 3 4 1 6 4 1 1 + 1 6 2 1 9 2 3 8 3 5  *
  YEAR-Y1............  7 7 7 7 7 7 7 7 7 7 + 7 7 7 7 7 7 7 7 7 7 + 7 7 7 7 7 7 7 7 7 7 + 7 7 7 7 7 7 7 7 7 7  *
  YEAR-Y2............  3 3 3 3 3 3 3 3 3 3 + 3 3 3 3 3 3 3 3 3 3 + 3 3 3 3 3 3 3 3 3 3 + 3 3 3 3 3 3 3 3 3 3  *
VEH1-CONT.FACTORS-+ ---------------------+---------------------+---------------------+---------------------+++
  SPEEDING...........            D     W   +         D     W   W +             D     D +   D         W        = 9
  DISREGARD SIGN/ROW                       +                     +                     +                   W  = 1
  IMPROPER TURN......                      +                     +                     +         D            = 1
  WRONG SIDE OF ROAD                       +                     +           D         +                      = 1
  WRONG WAY ON 1 WAY                       +                     +                     +                      *
  FOLLOW TOO CLOSE...                      +                     +                     +                      *
  ILLEGAL PASSING....              D       +                     +                   D +                      = 2
  ALCOHOL OR DRUGS...                      +                 W   + W                   +                      = 2
  VEHICLE DEFECTS....                D     +                     +   D                 +                      = 2
  OTHER..............                      +                     +                     +                      *
VEHICLE 2 - TYPE---+--------------------+---------------------+---------------------+---------------------+++
  NO SECOND VEHICLE..    D           D W W +   D D D D D W W W W + W D   D     D D   D +   D     D W          =22
  AUTOMOBILE.........      D     D         + D                   +         D D         +     D D       D D W  =10
  TRUCK OR BUS.......  W     D D   D       +                     +     W           D   + D           W        = 8
  OTHER..............                      +                     +                     +                      *
VEH2-DIR. OF TRAVEL+--------------------+---------------------+---------------------+---------------------+++
  WITH MILEPOSTS.....  W     D   D         +                     +     W     D     D   +                      = 6
  AGAINST MILEPOSTS..      D       D       + D                   +         D           +                   W  = 5
  LT. OF MILEPOSTS...          D           +                     +                     + D   D       W D D    = 6
  RT. OF MILEPOSTS...                      +                     +                     +       D              = 1
PART OF HIGHWAY----+--------------------+---------------------+---------------------+---------------------+++
  MAIN LANE..........  W D D D D D D D W W + D D D D D D W W W W + W D W D D D D D D D + D D D D D W W D D W  =40
  FRONTAGE ROAD......                      +                     +                     +                      *
  RAMP...............                      +                     +                     +                      *
  DETOUR.............                      +                     +                     +                      *
  OTHER..............                      +                     +                     +                      *
  UNKNOWN............                      +                     +                     +                      *
VEH2-CONT.FACTORS-+ ---------------------+---------------------+---------------------+---------------------+++
  SPEEDING...........  W                   + D                   +     W               +       D              = 4
  DISREGARD SIGN/ROW         D   D         +                     +                     + D   D       W   D    = 6
  IMPROPER TURN......          D           +                     +                     +                      = 1
  WRONG SIDE OF ROAD                       +                     +                     +                      *
  WRONG WAY ON 1 WAY                       +                     +                     +                      *
  FOLLOW TOO CLOSE...                      +                     +         D           +                      = 1
  ILLEGAL PASSING....                      +                     +                     +                      *
  ALCOHOL OR DRUGS...  W     D             + D                   +                     +                      = 3
  VEHICLE DEFECTS....                      +                     +                     +                      *
  OTHER..............                      +                     +                     +                      *
+++++++++++++++++++++--------------------+---------------------+---------------------+---------------------+++
```

Figure 15. (Continued)

```
DIST: '     PG. 56 +M 0 0 0 0 0 0 0 0 0 0 + 0 0 0 0 0 0 0 0 0 1 + 1 1 1 1 1 1 1 1 1 1 + 1 1 1 1 1 1 1 1 1 1 + T
CO. RED            +. 0 0 0 1 1 1 2 4 5 5 + 6 7 7 7 7 7 7 7 9 0 + 1 1 2 3 4 4 6 6 7 7 + 7 7 7 7 7 7 7 7 7 7 + O
CS   89- 2         +P . . . . . . . . . . + . . . . . . . . . . + . . . . . . . . . . + . . . . . . . . . . + T
++++++++++++++++++++. 6 6 9 4 5 5 7 0 4 8 + 9 3 4 4 4 5 6 7 7 2 + 1 7 2 5 3 9 6 8 5 6 + 6 6 6 6 6 6 6 8 8 9 + .
PAVEMENT CONDITION-+---------------------+---------------------+---------------------+---------------------+++
  WET................ W               W H +             W W W W + W   W               +           W W     W =12
  DRY................   D D D D D D D     + D D D D D D         +   O   D D D D D   D + D D D D D     D D   =27
  OTHER..............                     +                     +                 D   +                     = 1
LIGHT CONDITION----+---------------------+---------------------+---------------------+---------------------+++
  DAYLIGHT...........     D   D D D     H + O           H H H   + H   H   D D D D D   + D   D D D   H D D H =24
  DAWN OR DUSK.......                     +                     +                     +                     *
  DARKNESS........... H O   O       O H   +   D D D D D       W +   O   O           D +   D                 =15
INTERSECTION-------+---------------------+---------------------+---------------------+---------------------+++
  NONE...............   D         D D W H + D D D D D D H H H H + H D H D D D D D     +                     =23
  PVT.CO.RD.CITY ST.. H   D   D D         +                     +                 D D + D D D D D H H D D H =16
  MAJOR..............       O             +                     +                     +                     = 1
CURVATURE----------+---------------------+---------------------+---------------------+---------------------+++
  NONE............... H D D   D D D D W   + D D D D D D   W W W + H D H D D D D D D   + D D D D D H H D D H =36
  0.1-1.9 DEGREES....                     +             W       +                     +                     = 1
  2.0-3.9 DEGREES....       D           H +                     +                     +                     = 2
  4.0-5.9 DEGREES....                     +                     +                     +                     *
  6.0-7.9 DEGREES....                     +                     +                     +                     *
  8.0-9.9 DEGREES....                     +                     +                     +                     *
  10.0-11.9 DEGREES..                     +                     +                     +                     *
  12.0-13.9 DEGREES..                     +                     +                     +                     *
  14.0-15.9 DEGREES..                     +                     +                     +                     *
  16.0-17.9 DEGREES..                     +                     +                     +                     *
  18.0 DEG AND OVER..                     +                     +                     +                     *
TYPE OF ACCIDENT---+---------------------+---------------------+---------------------+---------------------+++
  NONCOLL. ON ROAD...                     +                     +                     +   D                 = 1
  VEH W/ VEH-IN REAR  W           O       + O                   +     H   O       D   +                     = 6
  VEH W/ VEH-LT TURN      O O   D         +                     +                     +                     = 3
  VEH W/ VEH-RT TURN                      +                     +                     +                     *
  VEH W/ VEH-HEAD ON                      +                     +           O         +                     = 1
  VEH W/ VEH-ANGLE...         D           +                     +                     + D   O O     W   O H = 7
  VEH W/ PEDESTRIAN..                     +                     +                     +                     *
  VEH W/ TRAIN.......                     +                     +                     +                     *
  VEH W/ PARKED VEH..                     +             W       +                     +         D W         = 3
  VEH W/ BICYCLIST...                     +                     +                     +                     *
  VEH W/ ANIMAL......   D                 +     D O   D         +                     +                     = 4
  VEH W/ FIXED OBJ...               O     +               W   H +       D     D O   D +                     = 7
  VEH W/ OTHER OBJ...                     +         O           +                     +                     = 1
  VEH WENT OFF ROAD..                 W H +   D             W   + W D                 +                     = 6
OTHER FACTORS------+---------------------+---------------------+---------------------+---------------------+++
  LOST CONTROL/SKID..                   H +                     +                     +                     = 1
  PASSNGR INTERFERED                      +                     +                     +                     *
  ATTENTION DIVERTED                      +                     +                     +                     *
  PROJECTING OBJECT..                     +                     +                     +                     *
  FT SLIP(CLUTCH/BR)                      +                     +                     +                     *
  GUSTY WINDS........                     +                     +                     +                     *
  VEH PASSING(LEFT)..     O       O       +               W     +                   D +                     = 4
  VEH PASSING(RIGHT)                      +                     +                     +                     *
  VISION OBSTRUCTED..                     +                     +                     +                     *
  VEH SWERVED/VEERED                      +         O   H       +                     +                     = 2
  VEH SLOWING/STOPED  W                   +                     +                 O   +               D     = 3
ACCIDENT DAMAGE----+---------------------+---------------------+---------------------+---------------------+++
  1 OR MORE FATAL....                     +               W     +                     +                     = 1
  1 OR MORE INJURY...       D         H W + D D   O D     W W   +   O   D   D         +   D                 =13
  PROPERTY ONLY...... W D O   D D D D     +     O     D H     H + W   W   O   D D D D + D   D D D W W D D W =27
TRAFFIC CONTROL----+---------------------+---------------------+---------------------+---------------------+++
  SIGNAL.............                     +                     +                 O   +                     = 1
  SIGN...............         O O         +                     +                   D + D   O O   H H D   W =10
  STRIPE   VIDER..... W D D D       D W W + D D D D D D H H W W +   D H D D D D D     +   O     O       D   =28
```

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DEVELOPMENT AND IMPLEMENTATION OF A PROGRAM TO REDUCE SKID ACCIDENTS

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Provision of skid-resistant pavement surfaces adequate to meet the needs of the motoring public on a wide range of facilities requires a systematic approach. The system employed should have reliable testing procedures to determine friction, criteria to determine corrective action and predictable specifications for surfacing materials to obtain the desired performance. The Pennsylvania Department of Transportation has adopted procedures based on a long history of research and development to obtain an economical and predictable skid resistant performance for pavements. The testing program, correction criteria and specification development using a Skid Resistance Level (SRL) criterion for aggregates is described.

History

The Pennsylvania Department of Transportation has a long history of involvement in research and development in the area of skid resistance. This research work has evolved through development of skid testing equipment and methods in the early 1960's and later to the properties of pavement surfaces necessary to provide adequate levels of skid resistance in the late 1960's and early 1970's. Much of this work was conducted in cooperation with the Pennsylvania State University and is reported under the Joint Road Friction Program. (1, 2)

Joint Industry-Department Skid Task Force

By 1968 it was recognized that friction values of bituminous concrete pavements were governed primarily by the properties of the coarse aggregate particles used in the mix. Specifications had required natural siliceous sand in portland cement mixes and this had been adequate to minimize friction problems with concrete pavements.

A review of the information available showed that pavements constructed with Pennsylvania's gravels and sandstones were considerably higher in friction than those constructed with carbonate aggregates. The information had been collected using broad descriptive terms to group aggregates in categories such as gravels, slags and stones. The performance of these could be compared to show relative averages, however a broad range of values occurred within each group.

Even with similar pavements constructed with aggregate from the same source, the measured friction was affected by variations in traffic rate, mix design, and conditions during testing.

It was apparent that the aggregate parameters needed a better definition in specification terms in order to construct pavement surfaces that would utilize each aggregate source to the fullest extent possible, give adequate friction for the life of the particular pavement and eliminate those aggregates which would polish. Because of the broad impact that changes in aggregate specifications would have, a Joint Industry-PennDOT Skid Task Force was formed. The Task Force was assigned the objective of developing requirements for construction and maintenance of pavements to obtain adequate levels of friction for the particular facility.

1968-69 Test Strips

Under the auspices of the Task Force, eleven pavement strips were planned and constructed in 1968-69. (3, 4) The test strips included a representative cross-section from the more than 340 sources producing approved aggregates in Pennsylvania. The carbonate group was selected as the "control" since this group overall had the poorest skid history. The test strips were constructed as a part of normal planned resurfacing projects, using a dense graded bituminous mixture of minus 1/2" sieve. They included 156 sections using 64 sources of aggregates in 44 miles of pavement.

A comprehensive record of the mix designs, petrographic properties of aggregates, and friction history was collected until 1974.

Requirements Adopted

In 1975 PennDOT specifications were adopted to govern the use of aggregates, based on the properties of an individual source, and to provide adequate skid resistance for the particular pavement being constructed.

Testing Program

In order to support the data requirements for a sizeable research effort and to address the problem of finding and correcting inadequate surfaces, suitable testing equipment and test site selection methods are needed.

Testing Equipment

The Department operates four single wheel testers in accordance with ASTM Method E-274. The testers are operated routinely and continuously to meet all types of testing needs. Two of the testers were at the Ohio test center for correlation in 1975. Upon their return, the practice of correlating the testers with each other was continued with a greater degree of confidence. It is planned to send one tester annually to the Ohio center and to continue correlation locally.

Test Site Selection

Skid tests are performed to meet the needs of a number of programs. PennDOT is responsible for a 45,000-mile highway system ranging from the Interstate system to rural, low-volume, farm-to-market roads.

The individual programs consist of:

1. Wet pavement accident survey.
2. Special request testing.
3. Research project skid testing.
4. Routine survey testing.

The wet pavement accident survey (WPA) is directly related to locating and testing suspect pavements. The test sites are selected from computer analysis of stored data from accident reports. (5) Corrective actions are scheduled as required.

Special request testing is conducted in response to field requests where pavement surfaces are suspect. They usually originate where recent accident data indicate a problem might exist with the pavement or where experienced observers note an irregular appearance.

The 1975 WPA survey computer printout identified 1,716 sites. The site selection criteria were at least five wet-pavement accidents in a three-year period within a 3,000-ft. section. The wet-pavement accidents were also to be at least 30% of all accidents. Sites were eliminated where prior remedial action had been taken or programmed. In some cases no tests could be run due to traffic congestion. Tests were performed on 1,511 sites with 39% indicating correction was required.

A program is also maintained to skid test pavements for municipalities. Testing is planned on the basis of accident frequency data. The test results are reported to responsible municipal officials, and advice for corrective action is offered.

The research project testing is directed at a continuing effort to better clarify pavement friction properties and in support of research efforts with other objectives where skid tests give useful data or augment the evaluation of the project.

Routine surveys are conducted as manpower and equipment are available. This is done on a system basis with the Interstate system receiving top priority.

Correction of Pavements with Low Skid Resistance

Objective

The objective of the total program is to reduce the number and/or severity of traffic accidents. The Federal Highway Safety Program Standard 12 states that each state shall have a program "... for correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces."

This can often be done by simply providing a new, higher friction surface. At other sites this may not be a complete or permanent solution. A team of highway designers, traffic engineers, safety specialists and maintenance personnel should review the site and determine if other improvements are required. This may include the addition of superelevation, wider shoulders, different or improved signing, improved guardrail placement, pavement markings, or removal of sight obstructions.

Skid Resistance Test Results Action

Corrective measures are the responsibility of the eleven District offices of PennDOT. District personnel are supplied guidelines for the type of pavement surface corrective measures that might be employed.

Skid test results are reported to the Districts with corrective work to be performed in accordance with criteria derived from NCHRP Report 37. (6) The policy is summarized in Table 1.

Table 1. Corrective action policy.

Category	Skid Number (SN40)	Existing Wet Pavement Accident Problem	Action by Engineering District
A	30 or below	Yes	Immediate corrective action
B	31 to 34	Yes	Corrective work as soon as fiscally possible
C	30 or below	No	Same as B with second priority
D	31 to 34	No	Maintain accident surveillance and take corrective action as necessary
E	35 to 40	Yes	Same as D
F	35 to 40	No	Maintain surveillance for future retesting
G	41 or above	--	No action required

Skid test results used to determine the action required and the average for the number of cycles reported for a uniform pavement surface.

Where occasional low test results are reported for a short section of a uniform surface a field review is required to determine the reason.

There are also occasions where tests are run at other than the standard 40-mph speed (SN_{40}). In these cases the results are reported in accordance with Table 1 of NCHRP Synthesis 14. (7)

Responsibilities

The Assistant District Operations Engineer is responsible for coordination of the District team to assure that when corrective measures are taken, all hazardous features at the location are identified and corrected. Standards are provided the District review team to cover updating for slopes, pavement superelevation, shoulder buildup, inlet and end wall modifications, and guardrail replacement. Traffic control procedures are also outlined to provide safety to the traveling public during construction.

Pavement Correction Measures

Pavement corrective measures should be carefully considered by the District and the most economical and suitable treatment should be selected for the particular location. Table 2 outlines the corrective measures currently considered for pavements. It is under constant review and refinement as research work and evaluation continue.

An ID-2 dense-graded bituminous concrete is the prevalent corrective surface on both existing concrete and bituminous surfaces. Grooving of concrete pavements is also used to some extent. With the recently enacted law to ban studded tires in Pennsylvania, more extensive use of grooving seems warranted. Other measures are designated experimental in order to develop a field performance and cost history.

Skid-Resistant Surfaces

The requirements adopted in 1975 meet the objectives of utilizing all of our aggregate sources in bituminous surface courses up to the ability of each individual source to provide adequate friction to meet the needs of traffic in both new and overlayed pavements.

These requirements were developed mostly from the test strip program and analysis. It was found in Pennsylvania that friction values go through an annual cycle roughly approximating a sine curve. Low values usually occur in late summer and early fall, with the amplitude dependent on coarse aggregate characteristics and traffic volume. Initial skid resistance measurements were nearly all adequate and not indicative of future performance. The coarse aggregate properties produce the major effect and the petrographic properties of a particular source can be related to its friction values.

Mix Design Practices

Although the coarse aggregate properties have the major influence, attention must also be given to the mix design. Both asphalt content and fine aggregate affect friction properties and must be considered. It should be noted that a conflict exists between mixes designed for long durability and those designed for friction. Some sacrifice in surface life is usually necessary.

As part of the friction requirements adopted by PennDOT, revised mix design procedures were issued. The revisions contained a more complete explanation of the philosophy to be used to obtain "an optimum bituminous mix" with lower asphalt contents and closer attention to voids filled with asphalt. The use of mixes that showed a slight loss of fines or raveling under traffic was encouraged in order to obtain increased surface texture and exposure of course aggregate particles. This would of course result in some reduced durability.

Major attention was given to the revision of requirements for coarse aggregate, which is the most significant contributor to friction. Each of the 350 approved sources of coarse aggregate in Pennsylvania was assigned a Skid Resistance Level (SRL) designation based upon the particular aggregate properties.

Assigning Aggregate SRL Requirements

The SRL designation for an aggregate is based on its performance in properly designed dense-graded bituminous surfaces. (8, 9) The initial data came from the 1968 test strips, where careful determinations of aggregate properties were made. The results of all skid tests taken for any purpose, are used in assigning SRL designations. Each pavement tested is evaluated by an experienced Materials Engineer who prepares a standard report giving aggregate source, date of construction, ADT and pavement surface condition. The skid test results and field evaluation are carefully considered for the time of year tested in rating an aggregate source.

New aggregate sources are assigned SRL ratings in much the same way as existing sources have been evaluated. Petrographic examinations are made of the material and where close similarity is found to an existing source the same rating is given. Where a rock type not previously used is considered the petrographic examination is supplemented with polished stone values obtained with the British wheel and pendulum tests. These are compared with values from previously rated sources. The SRL rating is determined for each source by plotting skid numbers against average daily traffic (ADT) and calculating a regression line. The aggregate SRL letter is established by the ADT at the intercept with a line at the SN_{40} level.

The SRL ratings of the aggregate sources are continually re-evaluated as additional field data are collected. The various types of aggregate used in Pennsylvania generally fall into SRL designations as follows:

E - Excellent	-	Gravels with less than 10% carbonate particles, Sandstones
H - High	-	Siltstones, Argillites, some Quartzites, Basalts, Gneisses, Granites, Blast Furnace Slags, Gravels with between 10 and 25% carbonate particles.
G - Good	-	Most Quarzites
M - Moderate	-	Carbonates of Cambrian age, Serpentine
L - Low	-	Carbonates younger than Cambrian

Table 2. Guide for corrective measures to restore skid resistance.

Corrective Measure Concrete Surface	good condition[a]		poor condition[b]
1. ID-2 Overlay	Yes		Yes
Thickness	1-1/2"	3"	3"
Estimated Cost (sq.yd.)	$1.75	$3.25	$3.25
Life	<8 yrs.	8 yrs.	8 years
2. Longitudinal Grooving	Yes		No
Estimated Cost (sq.yd.)	$1.00		
Life	5 years @ 5000 ADT		
3. Slurry Seal (Experimental)	Yes(d)		No
Thickness	1/8" to 3/8"		
Estimated Cost (sq.yd.)	$1.10		
Life	4 years @ 10000 ADT		
4. Open-Graded Friction Course (Experimental)	Yes		No
Thickness	3/4"		
Estimated Cost (sq.yd.)	$1.10		
Life	8 years @ 15000 ADT		
5. CRCP (Experimental)	No		Yes
Thickness			6"
Estimated Cost (sq.yd.)			$12.00
Life			25 years
6. Surface Treatment(d)	No		No
Estimated Cost (sq.yd.)			
Life			

Corrective Measure Bituminous	good condition	poor condition
1. ID-2 Overlay	Yes	Yes
Thickness	1-1/2"	1-1/2"(c)
Estimated Cost (sq.yd.)	$1.75	$1.85+
Life	8 years	8 years
2. Longitudinal Grooving	No	No
Estimated Cost (sq.yd.)		
Life		
3. Slurry Seal (Experimental)	No	No
Thickness		
Estimated Cost (sq.yd.)		
Life		
4. Open-Graded Friction Course (Experimental)	Yes	No
Thickness	3/4"	
Estimated Cost (sq.yd.)	$1.10	
Life	8 years @ 15000 ADT	
5. CRCP (Experimental)	No	No
Thickness		
Estimated Cost (sq.yd.)		
Life		
6. Surface Treatment(d)	Yes	No
Estimated Cost (sq.yd.)	$0.40	
Life	4 years @ 1500 ADT	

(a) Structurally sound, stable joints and cracks, rutting less than 1/2 inch.
(b) Faulting joints and cracks, spalling, rutting more than 1/2 inch.
(c) Plus binder and/or leveling as required; may be reduced to 1" where ADT is less than 5000.
(d) ADT 1500 maximum; above ADT 1000 use SRL-M aggregate.

Each wearing surface advertised for bids has a coarse aggregate requirement for SRL dependent upon current average daily traffic for resurfacing, or anticipated initial daily traffic on new facilities as shown in Table 3.

Table 3. Aggregate SRL requirements.

ADT	SRL (Skid Resistance Level)
20,000 and above	E
5,000 to 20,000	E,H, *Blend of E and M or E and G
3,000 to 5,000	E,H,G, Blend of H and Mor or E and L
1,000 to 3,000	E,H,G,M, Blend of H and L, or G and L, or E and L
1,000 and below	Any

*All blends are 50% by weight.

The Department maintains a publication, Bulletin 13 "Tentative List of Commercial Producers of Coarse Aggregates," and each source listed has an SRL assigned to it.

Continuing Research

A great deal of effort has gone into establishing a total system that appears to be working. The research effort is continuing to broaden the corrective measures that can be used and to develop new materials and methods to build skid resistant surfaces. Research projects are active in evaluating other test modes such as incipient slip and side friction. The parameters of hydroplaning are also being investigated.

A problem exists in interpreting the results of skid tests run during the year and making seasonal adjustments to reflect late summer and early fall levels. Historical data are being reviewed and a representative selection of pavement types is being continuously tested to develop methods to predict low values for the time of year tested.

Summary

Attainment of the objective to provide safe skid resistant pavements adequate to meet the needs of the motoring public requires a systematic approach. The elements of the system should include the ability to reliably determine skid resistance values with dependable test equipment, methods of locating and surveying pavement surfaces, and a means of rating pavement performance. Finally, specifications should provide for economic, predictable, and adequate friction properties through the anticipated life of new surfaces or for surfaces placed as a corrective action.

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VIRGINIA'S WET PAVEMENT ACCIDENT REDUCTION PROGRAM

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While a great deal of work on skid resistance has been conducted in Virginia over the past three decades, only within the past year has attention been given to the development of a systematic program for the identification and treatment of high or potentially high wet pavement accident sites. The purpose of this paper is to outline that program. The use of Virginia's automated accident and survey skid data files in the program is described. The site selection process utilizing these two data bases is explained as is the site review process, including the field review. The economic analysis used initially to rank sites for field review, and used again to rank sites for recommended treatments is also explained. In essence, this economic analysis involves the computation of a breakeven value considering the costs of possible site treatments versus projected savings from reductions in wet pavement accidents. As explained in the paper, in the Virginia program there is an emphasis on the use of accident data, with every effort being made to achieve the greatest total reduction in wet accidents with a given amount of funds for improvements.

For many years Virginia has conducted a very active research program in pavement skid resistance. The state's long series of publications on the subject was initiated with the paper entitled "Skid Resistance Measurements of Virginia Pavements", by T. E. Shelburne and R. L. Sheppe, which was published by the Highway Research Board in 1948 (1). The First International Skid Prevention Conference was held at the University of Virginia a decade later (2), with an accompanying correlation of skid test vehicles over various types of pavements throughout the state. A second correlation was made on Virginia highways in 1960; and a third was conducted on specially prepared pavements at Tappahannock, Virginia, in 1962 (3). The first British portable tester to be used in the United States was purchased for research in Virginia and was used in the 1960 correlation study.

Locally, the state has continuously tested pavements for skid resistance since Shelburne and Sheppe's early work; and nationally, Virginia has contributed much through participation in committee activities. In regard to the latter, it is noted that several Virginians played key roles in organizing ASTM Committee E-17 on Skid Resistance.

Early in its program for combatting pavement slipperiness, about 25 years ago, Virginia outlawed the use of certain polish susceptible aggregates in the surface mixes on primary and higher class roads; and since that time state engineers have conducted many field experiments in the development of economical means of providing skid resistant roads.

Perhaps the most important decision made by Virginia highway officials through the years was the adoption of the policy that calls for the resurfacing of pavements that have experienced wet weather accidents and which have a stopping distance number of less than 40 when tested at 64 kph (40 mph). Yet, presently there is not in operation any program for identifying wet pavement accident sites nor for systematically evaluating wet accident or low skid number sites. With the buildup of knowledge in the field of pavement skid resistance, it has become clear that a well conceived program is needed, and for this reason the authors have designed and are implementing the program described in the following pages.

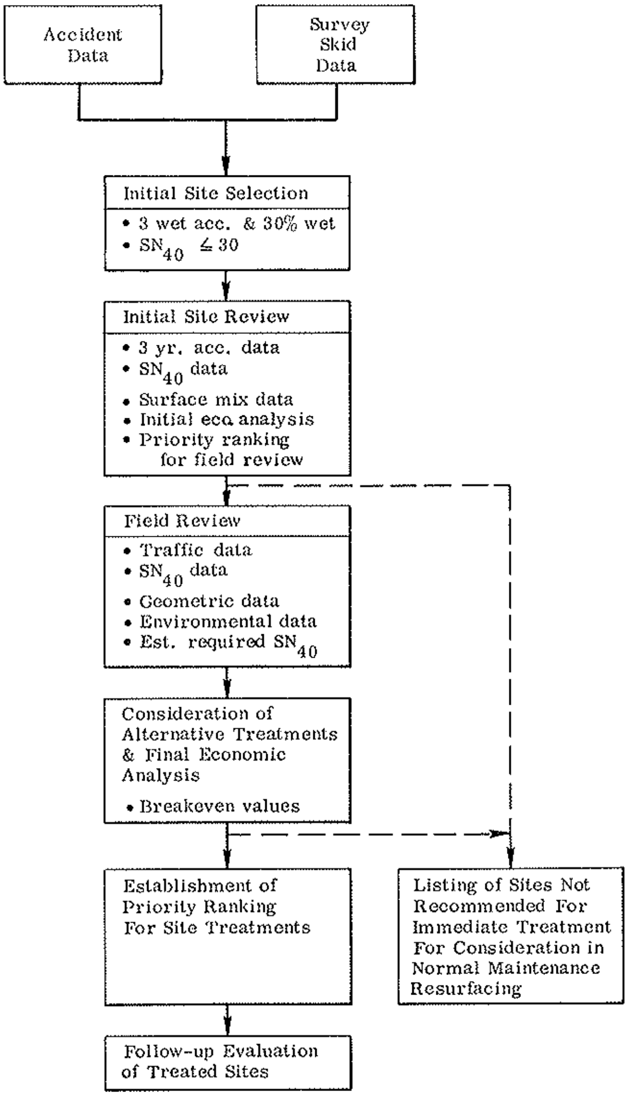
Program Outline

It should be noted that the program outlined pertains to the interstate, arterial, and primary roadway systems maintained by the Virginia Department of Highways and Transportation. Potential high wet pavement accident locations on the secondary road system are evaluated when brought to the attention of those responsible for the program; however, the procedures described herein for locating possible high wet pavement accident sites are not directly applicable to the secondary system.

A generalized flow diagram of the wet pavement accident reduction program is shown in Figure 1. This program is discussed in the following sections, but a brief glance at Figure 1 indicates the prime importance attached to the use of accident data. While it obviously is important to identify and consider improvements to potentially dangerous sites, i.e., sites having low skid resistance, it is more important to identify and correct sites already characterized by a high frequency and proportion of wet accidents.

In addition to accident data, the data collected in Virginia's survey skid program are an integral part of the system. These two data bases are discussed briefly in the following two sections, with the remainder of the paper being devoted to the use of the data in the wet pavement accident reduction program.

Figure 1. Wet pavement accident reduction program.



Accident Data Base

Accident data utilized in the program are obtained from the automated accident files maintained by the Department's Data Processing Division. Table 1 indicates the items of data contained on each accident record, and each item is discussed in detail in "Code for Analysis of Highway Motor Vehicle Accidents" (4). Data considered to be of primary importance for the purpose under discussion are locational data, placement data indicating direction of travel, surface condition (dry, wet, snowy, icy, etc.), number killed, number injured, and property damage. Other items are obviously of importance at times, but the above six items are always considered.

It is worth noting that some deficiencies do exist in the accident data collection procedure in terms of the use of the data in the wet pavement accident reduction program. Primarily these deficiencies relate to determining the direction of travel for the accident-involved vehicles, particularly on divided highways, and to determining the location of accidents occurring in interchange ramps. Clarification of these locational data would enhance the use of the accident data in the accident reduction program. In addition, quantitative data relating to tire tread depth for accident-involved vehicles are desirable information not now collected.

Annual detailed computer listings are furnished the authors for use in the wet accident reduction program. These detailed listings contain all the data items shown in Table 1 for each accident occurring during the preceding calendar year (Jan. 1 - Dec. 31). In addition, a summary listing indicating high wet pavement accident sites is provided annually. This listing and the criteria used for the selection of high wet accident sites are discussed in a later section.

Survey Skid Data Base

A survey skid testing program was initiated in Virginia in 1974. Thus far, the entire interstate system has been tested, with five SN_{40} values being obtained per lane mile. In addition, all of the arterial system and some of the primary system have been tested, with the number of tests per mile having been reduced to three and with testing having been restricted to the traffic lane only. It is anticipated that within several years every lane mile in the three systems will have been tested at least once. In the interim, the Research Council's skid trailer will be used to test identified wet pavement accident sites which have not been tested by the survey trailer, and to retest many sites tested by the survey trailer to verify the survey SN_{40} values. The data from the two trailers can be interchanged through a correlation program designed and conducted by Runkle (5).

Procedures for the collection and computer storage of survey skid data, as well as the utilization of the data considering variabilities present in testing, have been discussed in published reports (6, 7). Data items contained in each skid test record are shown in Table 2. In addition to the items shown in Table 2, the skid number corrected to a 64 kph (40 mph) test speed (SN_{40}) is contained on all skid data computer listings. Since the test speed is usually intended to be 64 kph (40 mph) the difference between the actual and corrected skid number (SN_{40}) is usually small. The correction is based on a skid number-speed gradient of 0.5 per 1.6 kph (1 mile). Also, shown on the skid data listings is the predicted stopping distance number at 64 kph (40 mph) ($PSDN_{40}$) as determined by a regression analysis (8).

Determining High Accident and/or Low SN_{40} Sites

Each year high wet accident sites are selected on the basis of accident data, and low SN_{40} sites are selected on the basis of survey skid data.

Accident Data. Potentially high wet accident sites are selected on the basis of a 0.8-km (0.5-mile) segments, incremented by 0.16-km (0.1-mile) lengths. For example, the initial segment on a route would be from milepoint 0 to milepoint 0.5, the second segment from 0.1 to 0.6, and the third from 0.2 to 0.7. A site is selected as a possible high wet pavement accident site when three or more wet accidents occur in the 0.8-km (0.5-mile) section, provided the wet accidents account for at least 30% of the combined total of wet and dry pavement accidents. (Accidents occurring under icy or snowy conditions are excluded.)

The site selection process just described is performed each year by an automated review of the latest year's detailed accident computer file. The output provided from this process is illustrated in Figure 2. Notice that for each site selected locational information, as well as the number of fatal, injury, and property damage accidents, the number of fatalities, number of injuries, and amount of property damage, is shown for

Table 1. Data items contained in each accident record.

Item	Item
Report Number	Light
Month	Weather
Date	Type of Collision
Year	Fixed Object
Hour	Skidding
District	Zone of Impact
County	Major Factor
Cities & Towns over 3,500	Severity
Towns Under 3,500	Number Killed
Route	Number Injured
Section Number	Number Vehicles Involved
Milepoint	Amount of Property Damage
Surface Type	Card Control
Surface Width	Type of Vehicle (per vehicle)
Kind of Highway	Speed (per vehicle)
Speed Limits	Residence of Driver (per vehicle)
Intersection Type	Vehicle Maneuver (per vehicle)
Intersection Route Number	Placement (per vehicle)
Accident Location	Driver and Pedestrian Action (per vehicle)
Alignment	Condition of Individual (per vehicle)
Surface Condition	Vehicle Condition (per vehicle)
Defective Road Conditions	Visibility Conditions
Traffic Control	

Table 2. Data items contained in each survey skid test record.

Item
District
Residency
County
Route Number
City/Town/County
Test Vehicle
Test Wheel
Calibration
Operators
Date of Test
Time of Test
Weather Condition
Air Temperature
Surface Temperature
Tread Depth
Direction
Lane
Data Type
Milepoint
Speed
Skid Number
Pavement Condition [a]
Time Since Last Rain [a]

[a] Required for test run on control loop only.

Figure 2. Example of computer output for selection of high wet pavement accident sites.

Listing of Wet Accident Sections for the Primary System for the Year 1975

DI	CO	CTY	ROUT	MILEPOINT FROM	TO	WET ACCIDENTS FAT. ACCD	NO. KILL	INJ. ACCD	NO. INJ	P/D ACCD	AMOUNT P/D	TOT ACCD	DRY ACCIDENTS FAT. ACCD	NO. KILL	INJ. ACCD	NO. INJ	P/D ACCD	AMOUNT P/D	TOT ACCD	PCT WET
5	01		0013	.1	.5					3	1100	3								100.00
5	01		0013	3.7	4.1					5	4300	5			1	1	1	700	2	71.43
5	01		0013	4.0	4.4					4	3600	4			1	1	2	4000	3	57.14
5	01		0013	7.5	7.9			3	4	9	14700	12					3	3500	3	80.00
5	01		0013	7.7	8.1			3	4	9	14700	12			1	1	2	1900	3	80.00
5	01		0013	7.8	8.2			2	2	5	8400	7			1	1	2	1900	3	70.00
5	01		0013	13.2	13.6			1	2	3	2400	4					1	100	1	80.00

both wet and dry pavement accidents. The percentage of wet accidents shown is computed by dividing the number of wet accidents by the total of dry and wet accidents.

Should overlaps occur, such as from milepoint 3.7 to milepoint 4.4 and 7.5 to 8.2, the sections are combined so that the entire length is considered as one section. Presently this combining process is done manually by reference to the detailed accident data, but ultimately it will be accomplished in the automated procedures.

Survey Skid Data. Annually, as survey skid testing is completed within a highway district the detailed skid output (Figure 3) is reviewed, and SN_{40} values below 30 brought to the attention of the district engineer and the authors. A copy of a cover letter submitted with the skid data is given in the Appendix and one paragraph is reproduced here: "Although the criteria for identifying high wet accident sites have not been finalized, for the present we intend to extract sites such as these from our regular inventory survey testing which record skid numbers that approach or fall below the SN_{40} value (trailer value) of 30 as recommended by the Virginia Highway and Transportation Research Council. These sites will be studied by Research Council personnel in light of the tentative criteria that have been established by them and recommendations will be made thereafter."

The SN_{40} value of 30 has been selected as a tentative minimum guideline value on the basis of the authors' report presented at the 1977 annual meeting of the Transportation Research Board (9). It is recognized that sites may exist which require an SN_{40} value greater or less than 30 because of geometric or traffic conditions, but 30 is regarded as a minimum value indicative of the need for a review of existing and potential wet accident experience.

Figure 3. Example of survey skid data output showing area with SN_{40} generally < 30.

COUNTY Wise
ROUTE 58

LANE	MILE POINT	DATE	TEST SPEED	ACTUAL SN	CORR SN_{40}	$PSDN_{40}$
WBL1	1.65	6-08-76	38.7	52	51	60
	1.94		40.5	52	52	60
	2.32		41.5	51	52	60
	2.97		38.9	57	56	64
	3.43		40.6	29	29	43
	3.67		40.7	24	24	39
	3.94		40.9	23	23	38
	4.22		40.6	47	47	57
	4.72		40.1	24	24	39
	4.96		39.6	29	29	42
	5.47		40.2	31	31	44
	5.91		40.4	28	28	42
	6.32		40.8	32	32	45
	6.67		40.2	30	30	43
	7.21		39.8	32	32	45
	7.97		39.8	23	23	38
	8.33		38.6	34	33	46
	9.47		42.4	25	26	40
	10.16		41.7	27	28	42
	10.60		39.9	28	28	42
	13.70		40.5	54	54	62
	13.95		40.3	55	55	63
	14.35		39.8	57	57	64
	14.89		40.1	58	58	65
	15.34		40.0	59	59	66

Site Review Process

Once a high or potentially high wet pavement accident site is selected, whether on the basis of accident data or skid data, the review process is essentially the same. The steps involved in the review process are best illustrated through an example, and one is presented for a site selected by the use of accident data.

Development of Accident Site Information. For all sites selected data are entered on an Accident Site Review Sheet (Figure 4), and an indication is made of whether the site was selected on the basis of accident data and/or survey skid data, or by some other process. In the example, the site was selected on the basis of 1975 accident data between milepoints 9.6 and 10.6. Data relative to the site selection process are the beginning and ending milepoints for the section (9.6 and 10.6), the number of wet and dry pavement accidents (8), the number of wet accidents (5), the percentage of wet accidents (62%), and fatalities, injuries, and property damage resulting from the wet accidents (0, 2, and $3,400, respectively). To complete the upper portion of the Accident Site Review Sheet the accident data for the preceding two years (1974 and 1973) are entered and survey skid data are entered if tests have been made. As shown, the accident data for the two previous years substantiate the relatively high proportion of wet pavement accidents for this site. Survey skid data were not available for this site at the time of selection, but subsequent tests on two dates with the Research Council's trailer yielded the skid data shown. It has been concluded that the SN_{40} value in the traffic lane probably is less than 35 for most of the year, since the June tests were run just after a heavy rain and no doubt represent the most favorable skid resistance situation with regard to both seasonal and weather conditions.

Were the site selected on the basis of survey skid data, the same procedure as above would be followed, with the site beginning and ending milepoints being determined on the basis of the skid data.

Development of Surface Mix Site Information. The second step in the site review process (middle of Figure 4) involves the determination of the surface mix section or sections the accident site falls within, and the compilation of the relevant accident data and skid data. Evaluation of the entire surface mix section (s) is considered essential because the surface mix type is obviously of prime importance in providing adequate skid resistance, and the presence of an accident site within a surface mix may be indicative of a problem for the entire mix. The determination of the surface mix section(s) is accomplished by reference to the annual surface mix listing, which indicates, among other things, the direction, beginning and ending milepoints, highway type (i.e., number of lanes), the surface mix type, and the date the mix was placed for all surface mixes along a highway. For the example under discussion, the surface mix type is S-1 (bituminous sand mix) placed in 1967, and includes both directions of a four-lane highway between milepoints 8.00 and 12.00. Were the surface mix information to indicate the mix to be different by directions, the accident information and skid data would be summarized by direction. Also, if the accident site were to overlap two or more surface mix sections, accident data and skid data would be summarized for each section. For these purposes, reference to the detailed accident data is required.

Initial Economic Analysis. The next step in the review process is to perform an initial economic analysis (middle of Figure 4). In this analysis, a breakeven figure is computed based on an estimated reduction in wet pavement accidents and corresponding savings from reductions in injuries and property damages divided by the probable cost of the improvement (usually resurfacing) necessary to bring about the reduction in wet accidents. Thus, the breakeven value represents the time in years required to achieve savings from reduced accidents equal to the cost of the selected improvement. While a more sophisticated analysis could be performed and a discounted rate of return computed for possible alternative actions, it is felt that the simple breakeven computation is sufficient, particularly considering the many variables present and the approximately equal annual savings that may result.

The estimated reduction in wet accidents is computed by assuming that after the reduction, wet pavement accidents should account for approximately 20% of the combined total of wet and dry accidents. Thus, in the example it was estimated that wet accidents could perhaps be reduced by 4 at the accident site and 7.5 for the surface mix section by some type of treatment. The 20% value for wet accidents was determined to be a reasonable general value in a previous study conducted by the authors (10). This value is substantiated by the data shown in Table 3, in which the percentages of wet accidents for the interstate, arterial and primary, and secondary systems for the years 1965 through 1974 are presented. In the future, in order to compensate for possible weather influences, the base value (now 20%) will probably be based on the year for the accident data under investigation. Furthermore, separate values may be utilized for each of the highway districts in the state.

The reduction in property damage is computed by determining the property damage per wet pavement accident based on the actual data and multiplying by the reduction in wet accidents. In the example, for the accident site the property damage per wet accident was computed to be about $680 ($3,400   5), and thus the savings in property damage were estimated to be $2,720 ($680   4). For the surface mix section, the property damage per wet accident was $1,215 ($15,800   13), and the property damage savings $9,112 ($1,215   7.5).

Injury savings are computed in a similar manner, with the dollar value being determined by multiplying the injury reduction by $4,000, which is the figure recommended by the National Safety Council (11). Thus, for the accident site the injuries per wet accident figure was 0.4 (2   5), yielding an estimated reduction in injuries of 1.6 (4   .4), or an estimated savings of $6,400 (1.6 $4000). For the surface mix site the injuries per accident value was 0.38 and the estimated savings $11,400. Currently, in computing savings, values are not placed on deaths, except to the extent that a death is included as an injury. However, the occurrence of a fatality at a site is considered in the final evaluation of that site.

To complete the initial economic analysis, estimated costs of possible improvements must be considered. Generally, various types of resurfacing are anticipated and the estimated unit costs are used to estimate total improvement costs. In this example, two possible improvements were considered:

1. Plant mix $25,000/mile/two lanes, and
2. Slurry seal $6,000/mile/two lanes.

Thus, the cost of improvement for the accident site was estimated to be $50,000 for plant mix and $12,000 for slurry seal, and for the surface mix site four times the above amounts, or $200,000 for plant mix and $48,000 for slurry seal.

As already indicated, breakeven values are computed by dividing the estimated total cost by the projected savings resulting from an improvement. Thus, for the plant mix improvement, the estimated breakeven values are 5.48 for the accident site ($50,000 $9,120) and 9.75 for the surface mix site ($200,000 $20,512). For the slurry seal improvement the breakeven values are estimated to be 1.32 for the accident site ($12,000 $9,120) and 2.34 for the surface mix site (48,000 $20,512).

Priority Ranking for Field Review. Based on the initial economic analysis, sites are assigned priorities for field review on the basis of the lowest to highest breakeven values. Because of the large amount of judgement used in the computation of the breakeven values, the priority for field review is also influenced by the following:

1. Sites or surface mix sections having five or more wet pavement accidents which account for 50% or more of the total wet and dry accidents.
2. Sites on which survey skid tests have not been performed.
3. Sites showing an increasing trend in wet pavement accident percentages.
4. Sites with an average SN_{40} value below 30 in the traffic or passing lanes.

In the example, the 1.32 breakeven figure for the accident site combined with the facts that the site had not been skid tested and had experienced 50% wet accidents considering three years' data indicated that a field review was desirable.

Field Review. During the field evaluation of a site, careful attention is given to geometrics, traffic turbulence, sight distance, roadside development, traffic control, posted speed limit, and general pavement surface condition. If SN_{40} data have not been obtained prior to the field review, they are obtained as part of the field review process. Field review data for the example site are shown in the lower portion of Figure 4.

With the accident and skid data analysis and the results of the field inspection in hand, the reviewers make a judgement evaluation as to the prime causative factor or factors in the wet pavement accidents. If in their judgement higher skid values would be of little value but one or more of the other variables such as traffic control or roadside congestion are the prime factors, they refer the location to the accident reduction team in the Department's Traffic and Planning Division. If on the other hand, the evidence indicates that improved skid resistance would be of value, a second cost/benefit

Figure 4. Accident site review sheet.

COUNTY ______________

ROUTE ______________

Site Selected by: ☐ Accident Data, ☐ Survey Skid Data, ☐ Other

Date Reviewed ___________

By ______________

SITE INFORMATION														
Accident Data										Skid Data				
Year	B.M.	E.M.	Wet & Dry Accidents	Wet Accidents	Percent Wet	F	I	PD	Lane	SN	MPH	SN_{40}	Date

SURFACE MIX SITE INFORMATION																			
Mix Information						Accident Information							Skid Data				
High. Type	Dir.	BM	EM	Type	Yr.	Yr.	Tot	Wet	Percent Wet	F	I	PD	Lane	SN	MPH	SN_{40}	Date

INITIAL ANALYSIS									
Area Analyzed	Length	Lanes	Date	Estimated Reduction Wet Accidents	Injury Savings	P.D. Savings	Total Savings	Break-even	Assumptions and Comments

RECOMMENDATIONS:

FIELD REVIEW DATA

GENERAL GEOMETRY:

POSTED SPEED LIMIT:

ENVIRONMENTAL DATA:

GENERAL COMMENTS:

FINAL ANALYSIS									
Area Analyzed	Length	Lanes	Date	Estimated Reduction Wet Accidents	Injury Savings	P.D. Savings	Total Savings	Break-even	Assumptions and Comments

RECOMMENDATIONS:

Table 3. Percentages of wet pavement accidents.

YEAR	INTERSTATE SYSTEM			ARTERIAL AND PRIMARY SYSTEM			SECONDARY SYSTEM		
	DRY ACCIDENTS	WET ACCIDENTS	PERCENT WET	DRY ACCIDENTS	WET ACCIDENTS	PERCENT WET	DRY ACCIDENTS	WET ACCIDENTS	PERCENT WET
1965	2,799	579	17	22,304	5,285	19	12,461	2,832	19
1966	2,798	753	21	21,281	5,896	22	12,064	3,223	21
1967	3,099	875	22	21,667	5,840	21	12,313	3,317	21
1968	3,773	1,101	23	23,592	5,781	20	13,786	3,589	21
1969	4,332	1,362	24	26,292	6,227	19	15,267	3,989	21
1970	4,689	1,462	24	26,795	6,720	20	15,535	4,103	21
1971	5,393	1,846	26	27,127	7,520	22	16,006	4,878	23
1972	5,821	2,667	31	28,749	9,993	26	12,629	5,085	29
1973	6,305	2,091	25	30,033	7,837	21	19,801	5,943	23
1974	4,747	1,228	21	26,729	7,029	21	19,613	5,972	23

analysis is conducted and modified as appropriate by the results of the field review.

For the site reviewed in Figure 4, items of particular interest determined from the field review and skid tests included:

1. The development in Oakwood between milepoints 9.4 and 10.7 where the speed limit is reduced to 72 kph (45 mph).
2. The indication that an SN_{40} of 40 may be necessary for the area between milepoints 9.4 and 10.7.
3. The fact that the S-1 mix is worn through in several places in the traffic lanes.
4. The difference in the SN_{40} values between the traffic and passing lanes of approximately 10 skid numbers, with the probability that the SN_{40} value in the traffic lanes was less than 35 for most of the year.
5. The generally adequate appearance of the pavement from a structural standpoint.

Note that in item number 2 above, it was estimated that an SN_{40} value of 40 or greater may be required for the area in question. While the estimated SN_{40} required is based largely on judgement at this time, it is anticipated that several levels of SN_{40} requirements for various types of sites will evolve as the program progresses.

Final Economic Analysis. On the basis of the accident data, skid test data, and field review data, a final economic analysis is made. In the example it was evident from the field review that the problem area was in the village of Oakwood between milepoints 9.4 and 10.7. Within these milepoints there was a reduced speed limit of 72 kph (45 mph) with moderate commercial development. Furthermore, the skid resistance was much less in the traffic lanes where the existing S-1 mix (thin sand mix) had worn through. For all these reasons, a slurry seal application in the traffic lanes seemed the appropriate treatment.

The final breakeven value of 0.8 is then computed as shown at the bottom of Figure 4 for the area between milepoints 9.4 and 10.7. Notice that the cost of the slurry seal is estimated as $6,000 per mile, since only the traffic lanes are to be treated.

Priority Ranking for Site Treatment

Sites are ranked for recommended treatment on the basis of the final breakeven value computed. Obviously some judgement is needed in deciding whether the breakeven time justifies corrective action. Some judgements are quite easy to make while others require much reflection. The evaluation is easy if the breakeven time is quite short and the estimated wet pavement accident reduction is high, or if the breakeven time is quite long and the estimated wet accident reduction is quite low. The in between or borderline cases are quite difficult ones. However, it must be kept in mind that the most important consideration is to do everything possible to see that the money available is spent at those locations where the greatest benefits can be derived. It should be indicated that sites not recommended for immediate action nevertheless will be brought to the attention of the Maintenance Division for consideration in establishing normal maintenance resurfacing schedules.

For the example section, it was recommended that the traffic lanes between milepoints 9.4 and 10.7 be resurfaced with slurry seal as shown in the Recommended Treatment Form (Figure 5) submitted to the District Engineer.

Follow-Up Evaluation

As was illustrated in Figure 1, an integral part of the wet pavement accident reduction program is the follow-up evaluation of treated sites. Thus far, all sites recommended for treatment—42.78 km (26.58 miles) on 5 routes in 4 counties—have been resurfaced. For this purpose, each site will be evaluated on the basis of both accident and skid data annually for three years after treatment. In addition, some sites that remain untreated, particularly those with SN_{40} values less than 30, will be monitored for the life of the program.

Hopefully, these evaluations will indicate that the treatments have been beneficial and also indicate to a greater extent than is presently known the levels of skid resistance required for various types of sites.

Figure 5. Accident site recommended treatment form.

RECOMMENDED TREATMENT FORM

Route 460 | Date 5/11/76

County Buchanan | By S. N. Runkle & D. C. Mahone

Mix Information: Type S-1 (wearing through in places) | Year Placed 1967

From 8.00 | To 12.00

Length 4.00 | AVD 10,825 (1974)

Highway Type 4 lane

Accident Data:

Year	Wet & Dry	Wet	Percent Wet	Wet Accidents: Fatalities	Injuries	Prop. Damage
1973	40	9	23	1	1	4,700
1974	30	13	43	0	6	5,500
1975	35	13	37	0	5	15,800
Totals:	105	35	33	1	12	$26,000

Comments: Twenty one of the 35 wet accidents occurred within the milepoints 9.4 and 10.7, while only 45 of the total 105 accidents were within these limits. Not considering this section, there were 60 wet and dry accidents, 14 of which were wet for a percentage wet of 23%. It is noteworthy that the area 9.5 to 10.7 includes the village of Oakwood which has a fairly congested traffic situation at relatively high speeds (posted @ 45 mph-probably higher).

Skid Data:

Lane	SN_{40}	Date Tested	Comments
Traffic	35	4/13/76	
Traffic	42	6/2/76	Ave. both directions
Passing	53	6/2/76	

Because the S-1 mix is wearing through in places, there may be several spots with a considerably lower SN_{40} value, but not reflected in the test results.

Recommended Action: Resurfacing is indicated for the section 9.4 to 10.7. It is estimated that for the geometric and traffic conditions at this site that an $SN_{40} \geqq 40$ is required, and thus, because of the relatively high traffic volume an S-5 non-polishing mix seems necessary, or possibly a slurry seal.

Economic Analysis: Based on the below listed assumptions, and with an estimated reduction of 5 wet accidents per year the breakeven for the site 9.4 to 10.7 is .8 year for slurry seal and 3.12 for plant mix. These breakeven values are computed based on surfacing just the traffic lanes. Obviously if all four lanes were resurfaced, the values would be doubled.

1. Reduction in injuries of 1/3/accident @ $4,000/injury
2. Reduction in property damage of $750/accident
3. Cost of slurry seal of $6,000/mile
4. Cost of plant mix of $25,000/mile

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APPENDIX

COMMONWEALTH *of* VIRGINIA

DEPARTMENT OF HIGHWAYS & TRANSPORTATION
1221 EAST BROAD STREET
RICHMOND, 23219

July 6, 1976

Memorandum

To - Mr. J. F. Turner
Attention - Mr. J. L. Corley
Subject - Skid Tests Report

Skid tests have recently been conducted on all the arterial routes in the Bristol District as part of our regular state-wide skid testing inventory of the arterial system.

Attached are some of the results of these tests which we thought should be brought to your attention. The tests of concern have been marked on the attached sheets for your convenience. Notice that these tests have recorded skid numbers (SN_{40}) that are somewhat lower than those for adjacent sections and are below or approaching SN_{40}=30.

The results of tests presented here are for your information. It is suggested that these sites be kept under observation and that accident data, geometrics, etc. be correlated to determine if any corrective action is needed.

Although the criteria for identifying high wet accident sites have not been finalized, for the present we intend to extract sites such as these from our regular inventory survey testing, which record skid numbers that approach or fall below an SN_{40} value (trailer value) of 30 as recommended by the Virginia Highway and Transportation Research Council. These sites will be studied by Research Council personnel in light of the tentative criteria that have been established by them and recommendations will be made thereafter.

Presently, we feel that a high wet accident site is indicated when three or more wet pavement accidents occur within an 0.5-mile section, and the wet accidents represent at least 30% of the combined total of wet and dry pavement accidents. Once a site is selected in this manner, the procedure is to identify the limits of the surface mix section(s) in which the site is located and to determine the accident experience and SN_{40} data for the section(s). Surface mix sections having 30% wet pavement accidents and/or an SN_{40} value (trailer value) below 30 are selected for field evaluation. Depending on the findings from the field evaluation, a possible treatment to the surface mix section or accident site may be recommended, or further evaluation may be indicated. It should be mentioned that wet accident sites having five or more wet accidents which account for 50% or more of the combined wet and dry accidents will be reviewed in the field, regardless of the analysis for the surface mix section(s) provided, of course, a new surface has not been placed since the occurrence of the accidents.

If more information is necessary, please advise.

J. P. Bassett
Materials Engineer

GTP:slf
Attachment

TRANSPORT CANADA RUNWAY COEFFICIENT OF FRICTION OPERATIONAL MAINTENANCE PROGRAM

W.V. Levitsky, Transport Canada

The objective of this program is to ensure the provision of safe airport runway operating conditions for efficient air transportation in Canada. This is being accomplished by the establishment of standards covering minimum coefficient of friction for runways, procedures and instruments for measurement and by periodical assessment of runway surface conditions. These standards take into account the runway length, runway elevation, wind and the type and weight of scheduled aircraft. The instruments used in measuring runway coefficient of friction were tested by the International Civil Aviation Organization on selected pavements, representing most typical runway conditions, and have useable correlation with aircraft performance for certain aircraft type. During winter months, the runway coefficient of friction is measured and reported on a routine basis as part of snow removal and ice control using James Brake and Tapley Meter Decelerometers at designated airports. Although no comparable program of operational measurement and reporting during rain storms exists in the summer, an ongoing evaluation program of runway calibration under wet conditions is in effect. The Skiddometer BV11-2, a continuous measuring and recording instrument, is used to measure the runway coefficient of friction in conjunction with a self-watering system. The frequency of runway evaluations is based upon the annual number of scheduled aircraft movements and the class of aircraft. A procedure is being established by which air carriers will be notified of runways which lie near the borderline of the minimum established coefficient of friction value. Provision is made to initiate corrective action for those runways whose coefficient of friction under standard wet conditions, falls below the minimum safe values. Remedial measures to restore runway coefficient of friction are dictated by the causes of slipperiness such as rubber contamination, polishing of the surface texture or insufficient surface draining of water. Effective techniques to implement corrective action range from removal of rubber deposits by high pressure water or lateral corrugation, retexturing polished surfaces by impact hammering or grooving to improve lateral drainage of water.

Runway Coefficient of Friction Operational Maintenance Program

The Canadian airport system illustrated in Figure 1 contains 875 licensed airports. The Air Administration of Transport Canada owns and operates 110 of the major airports in the system and owns an additional 66 which are operated by municipalities. As a result of the need for a comprehensive and co-ordinated approach to the provision of airfield pavements at these airports, a pavement management system has been developed. This system involves the evaluation of many activities and parameters related to pavement design, construction, operations and maintenance, from which the average performance and service life estimates can be established and comparisons of design alternatives made. The main purpose of the pavement management system is the provision of safe and efficient runway surfaces which are compatible with current and future aircraft operating requirements. (9,10,11,12,13,14,15).

One very important parameter in runway pavement is the surface coefficient of friction. Runway coefficient of friction requirements vary with the length of runway, the elevation of the runway above sea level, the wind, the type and weight of aircraft using the runway. Long runways, situated near sea level, and used by light aircraft can tolerate a much lower level of safe coefficient of friction than shorter runways, located at higher elevations and catering to large aircraft.

It is possible to calculate the minimum average runway coefficient of friction for each runway based on the runway length, the demonstrated landing distance of an aircraft and a certain factor of safety. However, there are two drawbacks to this approach. Firstly, this theoretical value of the minimum average coefficient of friction would have to be revised as different aircraft are scheduled into service on the same runway. Secondly, since runway lengths are based on the take-off requirements of an aircraft which are much longer than the landing distance requirements, the minimum average acceptable coefficient of friction on most runways would be quite low, in fact below the coefficient of friction required to withstand a serious crosswind condition.

It is possible to set values of the minimum coefficient of friction of a runway at the level higher than the one produced from the aircraft's demonstrated ability to stop on a slippery surface in zero wind conditions. A factor in selecting the minimum coefficient of friction value should take into consideration the prevailing crosswind conditions.

The coefficient of friction of a runway is not constant but varies seasonally on a short term basis throughout its life. As the runway accumulates rubber deposits and is polished by the action of snow removal equipment, the two touchdown zones become more slippery than the rest of the runway under wet conditions. Short slippery runways present a potentially hazardous operating condition.

Transport Canada Coefficient of Friction Standards

It is the policy of Transport Canada to provide airport runway surfaces which will permit safe operations for designated aircraft at all times; to measure and report runway coefficient of friction and surface conditions to airlines upon request during winter season at selected airports and to monitor the change in runway coefficient of friction so that corrective action can be taken before hazardous conditions will arise.

The objective of Transport Canada is to provide for operational purposes a minimum average runway coefficient of friction value of 0.65, under normal wet conditions, as measured by the Skiddometer BV 11-2.

Whenever the average runway coefficient of friction measurement under normal wet conditions falls into the range of 0.65 to 0.50, corrective action to restore the average coefficient of friction shall be planned.

Whenever the average runway coefficient of friction measurement under normal wet conditions falls into the range of 0.50 to 0.40 the operators shall be advised.

Whenever the average runway coefficient of friction measurement under normal wet conditions falls below 0.40 corrective action shall be taken to restore it.

Whenever local areas of runway surface exceeding 150 m in length have an average coefficient of friction under normal wet conditions of less than 0.30, corrective action shall be taken to restore it.

For further details, see (1).

Acceptable Methods of Runway Coefficient of Friction Measurement

About 10 years ago, Transport Canada started to explore better methods of measuring the coefficient of friction of runways instead of accelerating a pick-up truck and putting the brakes on. As a result of this effort, the James Brake Decelerometer was adopted as the standard instrument for measuring the braking action of runway surfaces covered in whole or in part with solid state contaminant such as compacted snow and ice. In the late 1960's, it became the policy of Transport Canada to measure and report runway coefficient of friction on a routine basis using the James Brake Decelerometer during the winter season at a number of designated airports.

In the early 70's an operational circular was promulgated by the Civil Aeronautics Directorate of Transport Canada explaining the application of JBI information to pilots for use in flight planning and during take-off and landing operations. Concurrent with our efforts to provide and disseminate runway condition information to users during the rigours of Canadian winters, the other potential hazard of operating on runways during summer rain storms came into focus triggered by several runway overruns in the late 60's which were attributed to low wet friction characteristics.

At about this time several manufacturers around the world had placed on the market instruments which were designed to measure the coefficient of friction of wet runways and even detect hydroplaning conditions. We participated with International Civil Aviation Organization, National Aeronautics and Space Administration, Federal Aviation Administration and United States Air Force teams evaluating the merits of several of these devices, notably the Diagonal Brake Vehicle, Mu-meter, Skiddometer and a Tapley Meter and have during the past five years tested these units on a cross-section of Canadian airports under both summer and winter operational conditions. For further details, see (2) and (3).

As a result of this evaluation, Transport Canada has adopted the Swedish Skiddometer Model BV11-2 as the standard instrument for evaluation of runway coefficient of friction characteristics under wet surface conditions. We have also adopted the use of Mu-meter Model ML400 as the backup instrument whenever the Skiddometer is not available for this purpose.

The James Brake Decelerometer remains the approved instrument for use in measuring coefficient of friction under solid state conditions during the winter season on an operational basis. It is now being supplemented with Tapley Meters which are identical in operation to James Brake Decelerometer. Over 90 airports at present are served with one of these instruments in Canada.

Transport Canada National Runway Measurement Program

The purpose of this program is to conduct periodical assessment of runway coefficient of friction statistical data in order to produce an inventory of runway coefficient of friction so that any change in conditions affecting the safety of aircraft operations can be detected and corrective action planned before a dangerous condition will develop. For further detail, see (4) and (5).

This program was launched in May 1976 and is divided into 3 phases:

- Phase 1 - Initial application (1976/77)
- Phase 2 - Periodic assessment of runway coefficient of friction
- Phase 3 - Notification and corrective action

Phase 1 activities will lead to the establishment of the scope and extent of Phase 2 program, which will be of an on-going nature. Phase 3 action will take place on an as required basis when substandard runways are detected.

Phase 1 - Initial Application (1976/77). Initial application 1976-77. The following airports have been surveyed based on the parameters shown in (1.) to (4.) below:

Table 1. 1975 annual aircraft movement

Airport	Total	Itinerant	Jets
Toronto International	238,000	228,000	157,000
Dorval International	192,000	186,000	127,000
Mirabel International (December only)	4,000	4,000	2,900
Ottawa International	207,000	77,000	43,000
Quebec City	158,000	78,000	17,000
Hamilton	203,000	63,000	5,000
London	122,000	52,000	6,000
Halifax International	78,000	41,000	24,000

This program was executed along the following lines.

1. Coefficient of friction was measured under dry and wet conditions.
2. The age of the runway pavement surface at the time of friction measurement is determined.
3. Determine total accumulated aircraft movements since the present runway pavement surface was constructed for each runway measured.
4. Establish the relationship between the coefficient of friction, the rate of friction deterioration with surface age and aircraft movements.
5. Determine the usefulness of stereo photography in conjunction with coefficient of friction measurements using the Skiddometer.

See Fig. 2 for a typical coefficient of friction performance chart.

Phase 2 - Periodic Assessment of Runway Coefficient of Friction. National periodic survey of runway coefficient of friction will be established based upon the following criteria:

1. Select airports whose runway pavement friction will be measured periodically based upon the criteria of paved runway and certain minimum jet traffic.
2. Determine the frequency of runway friction measurements based upon the criteria of the number of aircraft movements.
3. Determine the agency that will conduct this program.
4. Estimate the annual cost of this program.
5. Implement the program that is determined as the result of findings of Phase 1 Program discussed above.

Phase 3 - Notification and Corrective Action. Notification and corrective action:

1. Identify runways surveyed to data that are critical in terms of deteriorating surface friction.
2. Notify air carriers of these runways including the estimated reduced landing performance likely to be expected under wet conditions.
3. Identify the causes of slipperiness of these runways.
4. Prescribe corrective action to restore the runway friction and estimated cost.
5. Establish a priority schedule for implementing corrective action based upon the following factors:

(i) the rate of friction deterioration
(ii) the jet traffic movement
(iii) runway category
(iv) runway length in relation to the scheduled aircraft landing requirements
(v) climatic conditions of frequency, duration and intensity of rainfall
(vi) the age of the pavement surface
(vii) program planning in respect of overlay construction
(viii) projected changes in future runway use - change in traffic and/or scheduled aircraft type
(ix) record of aircraft incidents attributable to slippery runway conditions

6. Implement corrective action as required.

See Fig. 3 for a typical relationship between the runway average coefficient of friction and accumulated itinerant aircraft movements.

Approved Methods to Restore Runway Surface Conditions to Acceptable Limits

The three main causes of slipperiness of runway surfaces during rain were identified as follows:

1. Water ponding due to poor drainage.
2. Rubber accumulation at both touchdown zones.
3. Polishing of the surface brought about the use of steel bladed snow removal equipment.

Approved methods to relieve water accumulation during rain are:

1. Resurface the runway by means of an overlay thereby re-establishing the maximum allowable lateral slope and surface drainage.
2. Introduction of lateral drainage channels by such means as grooving, lateral corrugation.

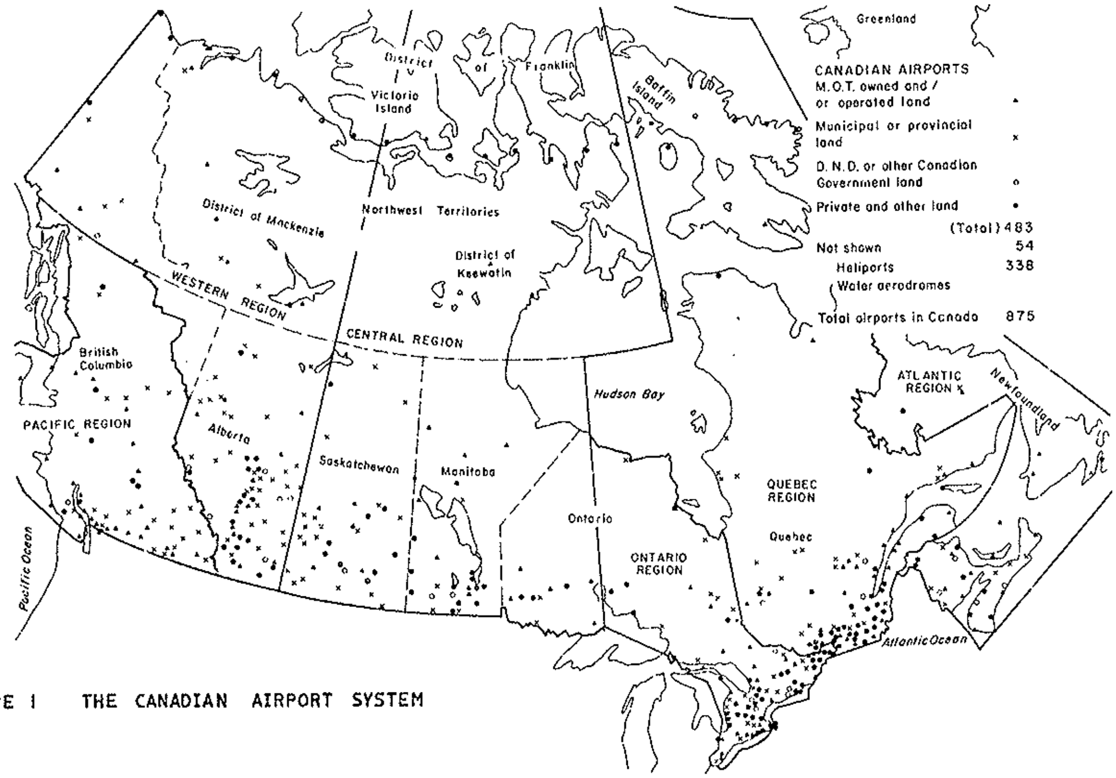

FIGURE 1 THE CANADIAN AIRPORT SYSTEM

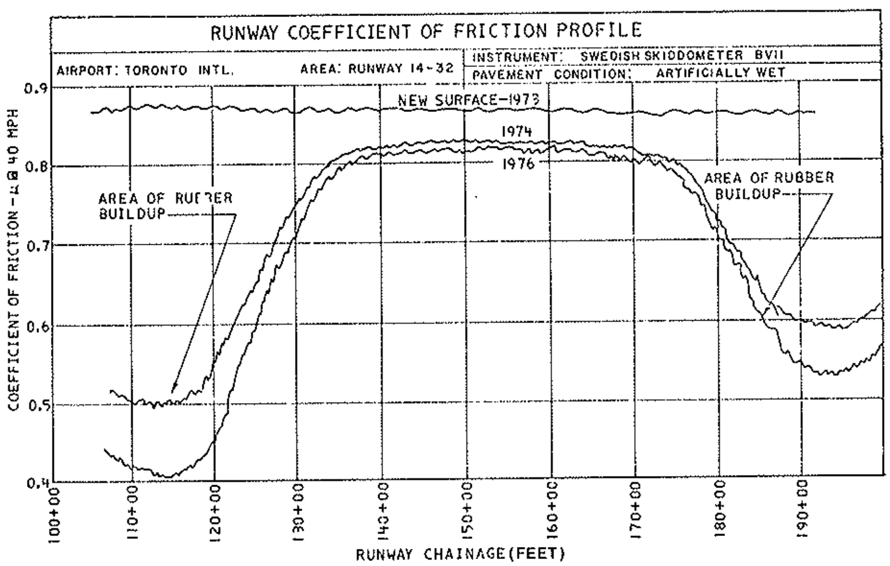

FIG. 2 TYPICAL COEFFICIENT OF FRICTION PERFORMANCE CHART

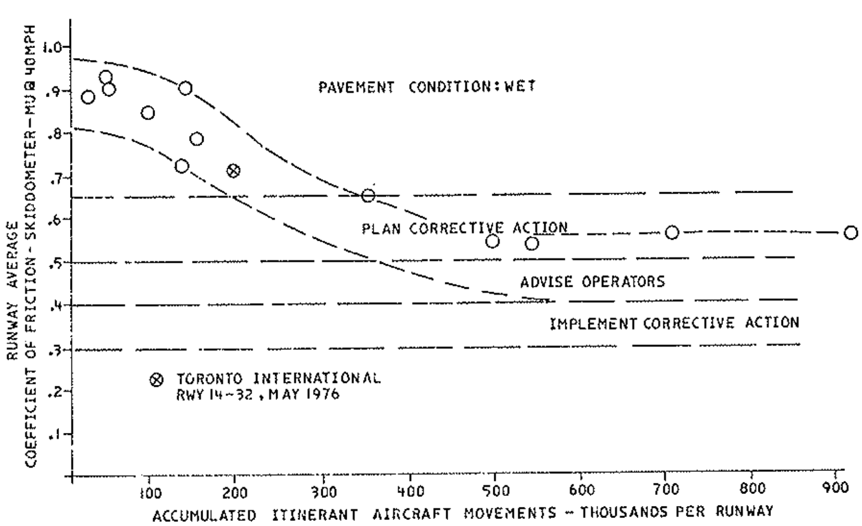

FIG. 3 RUNWAY AVERAGE COEFFICIENT OF FRICTION VS. AIRCRAFT MOVEMENT

If the main cause of slipperiness is identified to be the presence of rubber deposits then obviously the solution is to remove the rubber build-up.

Approved methods of removing rubber are:

1. High pressure water blast.
2. Mechanical grinding.
3. Impact hammering.

Runways that are slippery due to surface smoothness (low macrotexture) can be retextured by the use of impact hammering.

For further details on methods to restore runway surface conditions see (1,6,7,8).

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Abstracts of Papers in French

CHARACTERISTIQUES DES REVETEMENTS ROUTIERS ET ADHERENCE - RAPPORT DU COMITE TECHNIQUE DE LA GLISSANCE ET DE L'UNI de L'A.I.P.C.R. (Association Internationale Permanente des Congrès de la Route)

P.M.W. Elsenaar, Laboratoire National Routier, Pays-Bas. J. Reichert, Centre de Recherche Routière, Belgique. R. Sauterey, Laboratoire Central des Ponts et Chaussées, France.

L'éventail des recommandations adoptées en matière de glissance des chaussées à l'état mouillé est donné pour certains pays membres de l'A.I.P.C.R. Ces recommendations portent sur les caractéristiques des matériaux, notamment la résistance au polissage, la macrorugosité du revêtement, et dans certains cas sur la mesure directe du coefficient de frottement pneu/chaussée. D'autre part, les moyens de mesure permettant une auscultation à grande cadence du réseau routier se développent rapidement.

D'une manière générale, de nombreuses techniques permettent de réaliser des revêtements présentant des caractéristiques superficielles convenables: bétons bitumineux, cloutage des enrobés, enduits superficiels, bétons de ciment avec traitement à la mise en oeuvre... Le choix de la technique résulte d'un compromis technico-économique tenant compte des conditions locales.

La diminution de l'adhérence sous le trafic impose la régeneration des propriétés antidérapantes des revêtements. Il existe une grande variété de techniques, plus ou moins durables, plus ou moins coûteuses, plus ou moins efficaces. Enfin, les ingénieurs routiers se préoccupent de réduire le bruit de roulement que l'on constate sur certains revêtements antidérapants.

RECHERCHES SUR L'ADHERENCE AU T.R.R.L. (1927-1977)

George F. Salt, Transport and Road Research Laboratory, Grande Bretagne.

Les recherches des qualités antidérapantes des routes en Grande Bretagne commençaient en 1927 au Laboratoire National de Physique à Teddington. Au début des ans 1930 cette tâche fut transférée au Laboratoire de Recherches Routières nouveau-établi à Harmondsworth et elle se continue jusqu'à présent à cet établissement qui s'appelle aujourd'hui "Laboratoire de Transports et de Recherches Routières" à Crowthorne. Il en résulte une accumulation de connaissance qui suffit à la rédaction des normes pour matériaux valables pour diverses situations de route aux niveaux de risque différents. Ces travaux sont décrits dans l'article présent. D'abord le développement d'un appareil pour mesurer sûrement les qualités antidérapants est discuté. Une machine prématurée était une motocyclette à sidecar, la roue du side-car montée en biais pour exiter une force transversale. Plus tard cette machine fut remplacée par des systèmes incorporés dans des automobiles à traction avant qui se sont évolués aux appareils d'essai de routine pour l'usage général opérant à la force transversale et produisant une sortie automatisée propre au traitement par calculateur qui sont fabriqués actuellement.

Ensuite l'article décrit le développement des normes pour les qualités antidérapantes nécessaires pour minimiser les nombres d'accidents de dérapage et les travaux qui ont permis de rédiger des normes pour la microtexture nécessaire pour maintenir les qualités antidérapantes à basse vitesse exigées. Puis le dérapage à haute vitesse et la dépendance de la macrotexture, ainsi que les problèmes des effets secondaires (comme le bruit et le jaillissement d'eau) en rapport avec la création de la texture superficielle sont discutés. L'article se conclut par 25 références aux publications importants sur le sujet. Un modèle provisiore d'un schéma compréhensif de normes qui sera adopté probablement avant peu en Grande Bretagne est ajouté.

LA REALISATION DES REVETEMENTS ANTIDERAPANTS

John L. Beaton, Sacramento - California.

Les données et les mesures concernant l'adhérence des revêtements sont très complètes mais dispersées dans toute les publications. On a résumé ici l'état des connaissances et des moyens, y compris la mise en oeuvre pour réaliser des revêtements qui minorent les dérapages sur chaussée mouillée et l'aquaplaning (pour les routes et les pistes d'aérodromes). On a aussi identifié les domains où la pratique est en retard sur les connaissances. C'est aussi une source d'information pour les étudiants sérieux et les chercheurs dans ce domaine.

Les essais sur route et en laboratoire, les spécifications pour les mesures de l'adhérence, la possibilité de les prévoir par avance, sont discutés. La résistance au polissage de differents types

*The abstracts were translated by the Technical Committee on Slipperiness and Evenness of the Permanent International Association of Road Congresses, A. Pasquet (France), chariman, and J. Lucas (France), secretary.

de granulats est donnée, comme l'est l'adhérence de divers revêtements. L'effet des caractéristiques des matériaux et de l'uni de la surface est présenté en liaison avec la conception, la mise en oeuvre et l'entretien des routes et des pistes d'avion. On note les particularités de conception de mise en oeuvre et d'entretien, pour une adhérence efficace. Une liste complète de référence est donnée, permettant à un étudiant de retrouver les détails permettant une connaissance complète des usages actuels et des procédures utilisées.

Ce rapport a été rédigé par des experts, spécialistes dans ces domaines. La section "Le futur" sera particulièrement appréciée par les experts et les chercheurs concernés par l'adhérence. On il y a noté les sujets que la plupart des autorités s'accordent à considerer comme la résolution urgente et d'interêt immédiat pour l'obtention d'un revêtement antidérapant.

CONTRIBUTION DES REVETEMENTS A LA REDUCTION DES ACCIDENTS DE GLISSANCE

Harry A. Smith, Transportation Research Board.

Ce rapport donne l'état aux U.S.A. des analyses sur la diminution des accidents de dérapage sur chaussée mouillée, par l'amélioration des caractéristiques superficielles des revêtements. On a aussi discuté de l'adhérence des pistes d'aérodromes, bien que l'accent soit mis sur les revêtements des chaussées et des rues. En fonction des chaussées, le rapport traite des exigences concernant les caractéristiques superficielles en liaison avec la géometrie, le trafic, la nature du revêtement employé et des méthodes de mesure. Les données de la recherche et les pratiques usuelles considérées comme favorable sont rappelées. L'adhérence, décrite par le coefficient de frottement dans les conditions standard, définies par la norme ASTM. E.274, est la valeur la plus employée pour caractériser la surface de la chaussée. Le drainage de l'eau, par la surface et par le matériau lui-même sont des caractéristiques que l'on reconnaît de plus en plus souvent. La méthode de mesure la plus largement employée aux U.S.A. est l'emploi d'une remorque bloquée, correctement étalonnée, conforme à la norme ASTM.E.274. Il n'y a pas de coefficient de frottement minimal réglementaire. On admet le plus généralement une adhérence mesurée selon la méthode normalisée de 37 à 64,4 km/h (SN-40) pour la plupart des grandes autoroutes, supportant un trafic dont la vitesse moyenne est 80,5 km/h (50 mph).

AMELIORATION DES METHODES DE MISE EN OEUVRE ET D'ENTRETIEN DES PISTES D'AERODROMES

Thomas H. Morrow Jr., Federal Aviation Administration.

Des pistes glissants diminuent beaucoup les capacités de freinage et de contrôle directionnel durant l'atterrissage.Plusieurs services du gouvernement féderal et le communauté aéronautique combinent leurs efforts dans toutes les conditions atmosphériques défavorables.

Ce rapport discute quelques-unes des méthodes employées pour la mise en oeuvre et l'entretien des surfaces des pistes et l'avancement des recherches pour résoudre le problème de la glissance des pistes.

ESSAIS D'ADHERENCE REALISES PAR LES FORCES AERIENNES DES ETATS-UNIS

George D. Ballentine et Dannie O. Burk, Centre des Ingénieurs Civils de L'U.S. Air Force.

Le rapport donne un résumé des recherches effectuées par l'U.S. AF sur l'adhérence et l'hydroplanage sur des pistes d'aérodromes, ainsi que les procédures d'essai d'adhérences standard pour l'U.S. Air Force. Le rapport décrit les recherches pour le développement des méthodes d'essai et les études sur les revêtements. On donne les procédures standard et les appareillages employés.

UN PROGRAMME DE REDUCTION DES ACCIDENTS DE GLISSANCE SUR CHAUSSEE MOUILLEE

Kenneth D. Hankins, Texas State Department of Highways and Public Transportation.

Ce rapport est orienté de façon spécifique vers l'un des objectifs du programme d'amélioration de la sécurité dans l'Etat du Texas. Le programme pour la réduction des accidents par temps de pluie comporte l'obtention et l'analyse des accidents sur chaussée mouillée; la sélection et le classement par priorité des zones à traiter par la mise en oeuvre de revêtements antidérapants. Chaque partie du programme est analysée.

DEVELOPPEMENT ET REALISATION D'UN PROGRAMME POUR REDUIRE LES ACCIDENTS DE DERAPAGE

Wade L. Grambling, Pennsylvania Department of Transportation.

La réalisation de revêtements présentant une adhérence suffisante pour satisfaire les besoins des usagers, dans une large gamme de situations demande une approche rationnelle. La méthode employée doit comporter des procédures d'essai fidèles pour mesurer l'adhérence, des critères pour déclancher des actions correctives, et des spécifications éprouvées qui permettront d'obtenir des revêtements ayant les caractèristiques voulues.

Le Département des Transports de Pennsylvania a adopté des spécifications basées sur de longues recherches et des applications pour obtenir de façon économique et sûre des revêtements ayant les caractéristiques voulues.

Le programme d'essais, les critères d'intervention et les spécifications pour une adhérence minimale (SRL) sur les roches, sont décrits.

LE PROGRAMME POUR REDUIRE LES ACCIDENTS SUR CHAUSSEES MOUILLEES EN VIRGINIE

Stephen N. Runkle et David C. Mahone, Virginia Highway and Transportation Research Council.

On décrit les diverses étapes de la procédure du programme de Virginie pour la réduction des accidents sur chaussée mouillée, en analysant certains de ses points. Lorsque c'est possible, on fait référence aux rapports donnant le détail des procédures et leur justification. On notera que le programme ne concerne que les réseaux routiers interétats, principal et primaire du ressort du Département des Routes et des Transports. Les zones à risque potentiel élevé d'accidents sur chaussée mouillée du réseau secondaire seront étudiées si elles sont indiquées aux responsable du programme; toutefois les procédures décrites pour la détection des zones dangereuses par temps de pluie ne sont pas directement applicables au réseau secondaire.

Les zones sont détectées soit à partir des données des accidents soit à partir des mesures d'adhérence. Ces données sont obtenues à partir des fichiers automatisés gérés par le Département.

Les données primordiales pour la sélection des zones où des traitements sont possibles sont les nombres d'accidents sur chaussée sèche et sur chaussée mouillée et le pourcentage d'accidents sur chaussée mouillée, les tués, blessés et accidents matériels dûs aux accidents sur chaussée mouillée, et la valeur de l'adhérence. On prend également en compte la géométrie et l'environnement de la chaussée et le trafic.

PROGRAMME D'ENTRETIEN OPERATIONEL POUR L'ADHERENCE DES PISTES D'AERODROME AU CANADA

W.V. Levitsky, Transport Canada.

L'objectif du programme est de garantir une exploitation sûre des aérodromes pour une bonne efficacité des transports aériens au Canada. Cela est obtenu par l'établissement de normes pour l'adhérence, fixant une valeur minimale pour les aéroports, par la normalisation des appareils et méthodes de mesure de l'adhérence et par une auscultation périodique de l'état des pistes.

Ces normes prennent en compte la longueur de la piste, la pente de la piste, le vent et le type et la masse des aéronefs utilisés. Les appareils utilisés pour la mesure de l'adhérence ont été vérifiés et certifiés par le Groupe d'Etude de l'action du freinage sur les pistes, qui appartient à l'Organisation de l'Aviation Civile Internationale, et qui dispose de corrélations utisables avec les avions pour certains types d'appareils. Durant les mois d'hiver, le frottement sur la piste est mesuré et constitue l'un des critères de l'entretien hivernal pour le déneigement et le déverglaçage, en utilisant le frein Jame et le déceleromètre Tapley sur des aéroports préalablement désignés.

Bien qu'il n'existe pas un programme opérationel comparable pour les mesures d'adhérence durant les fortes pluies d'été, on utilise un programme pour l'appréciation de l'adhérence sur pistes mouillées. Le Skiddomètre BV-11-2, approuvé par la Groupe d'étude de l'OACI est utilisé comme appareil de mesure de l'adhérence avec un système de mouillage autonome.

La fréquence des auscultations dépend du nombre annuel moyen de mouvements aériens et de la classe des appareils. Une procédure est en cours d'établissement qui permettra de renseigner les équipages lorsque le niveau d'adhérence de la piste tend vers la valeur minimale. Des actions correctives sont prévues pour les pistes présentant une adhérence inférieure à la valeur contractuelle de sécurité. Une action pour améliorer l'adhérence peut être provoquée par des causes telles que dépôts de gomme, polissage superficiel ou drainage superficiel de l'eau insuffisant. Les remèdes s'étendent depuis l'enlèvement de gomme par de l'eau à haute pression ou le striage transversal, l'augmentation de la macrotexture par rainurage par percussion ou le rainurage pour améliorer le drainage latéral de l'eau.

Abstracts of Papers in German

OBERFLÄCHENMERKMALE UND GRIFFIGKEIT: BERICHT DES TECHNISCHEN KOMITEES FÜR STRASSENGRIFFIGKEIT UND STRASSENEBENHEIT DER AIPCR (STÄNDIGER INTERNATIONALER VERBAND DER STRASSENKONGRESSE)

Peter M. W. Elsenaar, Rijkswegenbouwlaboratorium, Niederlande; J. Reichert, Centre de Recherches Routières, Belgien; R. Sauterey, Laboratoire Central des Ponts et Chaussées, Frankreich

Auf der Grundlage neuerer Informationen durch die Mitglieder und der Berichte des Technischen Komitees für Straßengriffigkeit und Straßenebenheit zu den Welt-Straßenkongressen in Prag (1971) und Mexico (1975) wird der gegenwärtige Erkenntnisstand in den Mitgliedsländern erläutert. Es wird ein Vergleich angestellt zwischen den Empfehlungen und technischen Vorschriften in Bezug auf die Griffigkeit neuer und in Gebrauch befindlicher Straßendecken. Es wird dargelegt, daß man in wachsendem Maße die Notwendigkeit erkennt, Standard-Griffigkeitswerte für neue und für in Gebrauch befindliche Straßendecken einzuführen. Für neue Straßendecken sind technische Vorschriften, die sich auf die Baustoffe, dabei insbesondere auf den Polierwiderstand der Gesteine beziehen, von besonderer Bedeutung.

Die Bedeutung systematischer Untersuchungen des Straßennetzes auf Griffigkeit wird unterstrichen. Es werden Angaben darüber gemacht, wie diese Aufgabe in einigen Ländern praktisch gelöst wird, und die dazu benutzten Meßgeräte werden beschrieben. Es wird ein Überblick gegeben über Zusammensetzungen und Einbauverfahren für ausreichend griffige bituminöse Fahrbahndecken und Zementbetondecken. Aus den zahllosen Möglichkeiten, griffige Fahrbahndecken zu erzielen, sollte die Wahl nach wirtschaftlichen Gesichtspunkten besonders im Hinblick auf die Verwendung örtlich verfügbarer Materialvorkommen sowie unter Berücksichtigung der Fähigkeiten der Bauunternehmer und der Erfahrungen der Straßenbauingenieure getroffen werden. Für bereits in Gebrauch befindliche Straßendecken werden die Verfahren angegeben, mit denen die Griffigkeit wiederhergestellt werden kann. Im Problemkreis Verhütung von Rutschunfällen ist es erforderlich, einen Kompromiß zu finden zwischen einerseits der Griffigkeit, also Sicherheit, und andererseits der Erzeugung von Fahrgeräusch, also Umweltbeeinträchtigung.

Zusammenfassend läßt sich feststellen, daß Forschung und Erfahrung allgemein zu Bauverfahren geführt haben, die es ermöglichen, dem Verkehrsteilnehmer ausreichend griffige Fahrbahnen zur Verfügung zu stellen. Wesentlich ist die Verbreitung dieser Erkenntnisse im Rahmen der Fortbildung der Ingenieure. Gleichzeitig bedarf es einer wirtschaftlichen Bewertung griffiger Oberflächen. Besondere Aufmerksamkeit in der Zukunft verdienen die Probleme der Fahrgeräuscherzeugung sowie der duldbaren Wasserfilmdicke in Abhängigkeit von der geometrischen Ausbildung der Straße.

FORSCHUNG ÜBER STRASSENGRIFFIGKEIT IM TRANSPORT AND ROAD RESEARCH LABORATORY (1927 - 1977)

George F. Salt, Transport and Road Research Laboratory, Großbritannien

Die Forschung über Straßengriffigkeit begann in Großbritannien im Jahre 1927 am Nationalen Physikalischen Institut in Teddington, in den frühen dreißiger Jahren wurden diese Aufgaben jedoch auf das neu gebildete Road Research Laboratory in Harmondsworth übergeleitet. Sie wurden dort (heute als Transport and Road Research Laboratory in Crowthorne) bis in die Gegenwart fortgeführt, und es liegt ein beträchtlicher Fundus von Wissen über dieses Sachgebiet vor.

Der Beitrag gibt einen Überblick über diese Arbeiten, beginnend mit der Entwicklung von Meßgeräten zur zuverlässigen Bestimmung der Straßengriffigkeit. Eine frühe Entwicklung war das entsprechend abgewandelte Motorrad mit Beiwagen, wobei das Beiwagenrad in einem Winkel zur Fahrtrichtung gehalten wurde, um eine Seitenkraft zu erzeugen. Später ging man zu frontgetriebenen Meßfahrzeugen über, bei denen das Meßsystem im Innern des Fahrzeuges untergebracht war. Schließlich entwickelte sich hieraus der heutige, kommerziell produzierte Seitenkraft-Meßwagen für Routinemessungen (SCRIM), der für die allgemeine Anwendung verfügbar ist und automatisch die Meßergebnisse in einer für die Weiterverarbeitung im Computer geeigneten Form auswirft.

Der Beitrag fährt fort mit der Erörterung der Entwicklung von Standardwerten für die Straßengriffigkeit, die erforderlich sind, um die Anzahl der Rutschunfälle auf ein Minimum zu senken; er beschreibt ferner die Untersuchungen, welche es ermöglicht haben, technische Vorschriften für die Gesteinsbaustoffe aufzustellen, um ein bestimmtes Niveau der Mikrotextur zu erzielen, das notwendig ist, um entsprechende Griffigkeitswerte im Bereich der unteren Geschwindigkeiten aufrechtzuerhalten. Daran anschließend wird die Griffigkeit bei hohen Geschwindigkeiten und ihre Abhängigkeit von der Makrotextur diskutiert, zusammen mit Nebeneffekten (Fahrgeräusch, Sprühfahnenbildung), die aus der Schaffung

*The abstracts were translated by K.—H. Schulze, Technische Universität, Berlin, Federal Republic of Germany.

einer entsprechenden Oberflächentextur resultieren. Der Beitrag schließt mit 25 Literaturangaben über die hauptsächlichsten Veröffentlichungen auf dem Gebiet. Es wird noch ein Ausblick gegeben auf die voraussichtliche Form eines umfassenden Spezifikations-Werkes über Griffigkeit, das möglicherweise demnächst in Großbritannien eingeführt werden wird.

BAU GRIFFIGER FAHRBAHNDECKEN

John L. Beaton, Sacramento, California

Die Angaben und Daten über die Griffigkeit von Fahrbahndecken sind umfassend, aber in der Literatur weit verstreut. Hier wird der Stand der Erkenntnisse und der praktischen Anwendung zusammengefaßt und besprochen, eingeschlossen verschiedene Methoden des Baus von Fahrbahndecken (Straßen und Flugpisten), die geeignet sind, Rutsch- und Aquaplaning-Unfälle bei nassem Wetter zu reduzieren. Es werden auch die Bereiche dargelegt, in denen die Praxis hinter den Erkenntnissen noch zurückliegt. Außerdem werden Quellenangaben für Studium und Forschung auf diesem Sachgebiet vermittelt.

Außen- und Laborversuche sowie technische Vorschriften für Griffigkeitsmessungen und Griffigkeitsvorhersagen werden erörtert. Der Polierwiderstand verschiedener Arten von Gesteinsstoffen wird zusammengestellt, ebenso entsprechende Angaben über die Griffigkeit verschiedener Arten von Fahrbahnoberflächen. Der Einfluß der Merkmale der Baustoffe sowie der Oberflächenausführung beim Fahrbahndeckenbau wird dargelegt in Beziehung zur Konzeption, Herstellung und zur Unterhaltung von Straßen- und Flugplatzdecken. Einzelheiten bezüglich Konzeption, Herstellung und Unterhaltung im Hinblick auf die Erzielung einer guten Griffigkeit werden berührt. Eine umfassende Liste mit Literaturangaben ist beigefügt, so daß der Studierende alle notwendigen Einzelheiten zum vollständigen Verständnis der gegenwärtigen Praxis und der Verfahren, die für die Reibung Reifen/Fahrbahn maßgebend sind, heranziehen kann.

Der Beitrag wurde von einer Gruppe von Experten des Sachgebietes ausgearbeitet. Besondere Bedeutung für den Sachverständigen und Forscher, der mit Fragen der Fahrbahngriffigkeit (Reibung Reifen/Fahrbahn) befaßt ist, hat der Abschnitt "Die Zukunft". Hier sind diejenigen Themen aufgeführt, die von den meisten Autoritäten als dringend zu lösende Probleme angesehen werden, darunter das Problem, eine anhaltend griffige Fahrbahndecke darzubieten.

DER BEITRAG DER FAHRBAHNDECKE ZUR REDUZIERUNG DER RUTSCHUNFÄLLE BEI NASSEM WETTER

Harry A. Smith, Transportation Research Board

Dieser Beitrag bespricht den Erkenntnisstand in den USA bezüglich des Beitrages der Merkmale der Fahrbahnoberfläche zur Reduzierung der Rutschunfälle bei nassem Wetter. Wenn auch der Nachdruck bei den Fahrbahndecken von Land- und Stadtstraßen liegt, so werden doch auch die Probleme der Oberflächeneigenschaften der Decken von Flugpisten und deren Gebrauchsverhalten bei Nässe erörtert. Mit Bezug auf Straßendecken ist der Beitrag so angelegt, daß er die Anforderungen an die Merkmale der Fahrbahnoberfläche in Beziehung zur geometrischen Ausbildung und zum Verkehr darlegt, ferner die Arten der gegenwärtig gebräuchlichen Oberflächen sowie die Meßmethoden zum Erfassen der Oberflächenmerkmale. Gegenwärtige Praxis und Forschungsergebnisse, soweit zur Anwendung geeignet, werden behandelt. Die Messung der Griffigkeit, ausgedrückt durch eine Reibungszahl (engl. skid number, SN), die in Übereinstimmung mit der ASTM-Methode E-274 gemessen wird, stellt die weitestverbreitete Methode zur Kennzeichnung der Fahrbahndecken dar. Mehr und mehr wird aber auch erkannt, daß Textur und Oberflächenentwässerung als Merkmale zu betrachten sind. Die in den USA am weitesten verbreitete Methode der Griffigkeitsmessung benutzt sorgfältig kalibrierte Meßanhänger für Reibungsmessungen am blockierten Rad entsprechend dem ASTM-Standard E-274. Bisher gibt es keine in den gesamten USA anerkannten Anforderungen an die Oberflächeneigenschaften von Fahrbahndecken. Eine Reibungszahl von 37 (Gleitbeiwert 0,37), gemessen bei 64,4 km/h (40 mph, daher Formelzeichen SN_{40}) wird jedoch für Hauptverkehrsstraßen außerhalb bebauter Gebiete mit einer mittleren Verkehrsgeschwindigkeit von 80,5 km/h (50 mph) als Anforderung in weitestem Maße akzeptiert.

VERBESSERTE METHODEN FÜR BAU UND UNTERHALTUNG DER DECKEN VON FLUGPISTEN

Thomas H. Morrow, Jr., Federal Aviation Administration

Glatte (schlüpfrige) Oberflächen von Start- und Landebahnen beeinträchtigen in schwerwiegendem Maße den Kraftschluß der Flugzeugreifen und die Richtungsstabilität beim Landen. Verschiedene Dienststellen der Bundesregierung und der Flughafenverwaltungen vereinigen ihre Anstrengungen, griffige Deckenoberflächen zu schaffen, die zu einem sicheren Kraftschluß der Flugzeugreifen unter allen widrigen Wetterbedingungen beitragen.

Dieser Beitrag erörtert einige der in Gebrauch befindlichen Bau- und Unterhaltungsmethoden für Decken von Start- und Landebahnen und umreißt die laufenden Forschungsbemühungen, die auf eine Lösung des Problems der glatten Pistenoberflächen gerichtet sind.

DIE VON DER US-LUFTWAFFE EINEFÜHRTE METHODE DER GRIFFIGKEITSMESSUNG

George D. Ballentine and Dannie O. Burk, U. S. Air Force Civil Engineering Center

Dieser Beitrag faßt die von der US-Luftwaffe durchgeführten Forschungsarbeiten zum Problem Griffigkeit der Flugpisten/Aquaplaning zusammen und beschreibt die von der US-Luftwaffe eingeführte Standard-Meßmethode zur Ermittlung der Griffigkeit von Start- und Landebahnen. Der Beitrag beschreibt die abgeschlossenen Forschungsarbeiten, die zur Entwicklung der Standard-Griffigkeitsmessung geführt haben zusammen mit der Erforschung der Eigenschaften der Decken der Start- und Landebahnen. Schließlich wird der Standard-Ablauf der Griffigkeitsmessung zusammen mit der Meßausrüstung aufgeführt.

EIN PROGRAMM ZUR REDUZIERUNG DER RUTSCHUNFÄLLE BEI NASSEM WETTER

Kenneth D. Hankins, Texas State Department of Highways and Public Transportation

Dieser Beitrag richtet sich besonders auf einen der Aspekte des Programms zur Verbesserung der Sicherheit im Straßenverkehr in Texas. Das Programm zur Reduzierung der Rutschunfälle bei nassem Wetter schließt die Ermittlung von Griffigkeitswerten und die Berichterstattung darüber ein; ferner die Ermittlung von Angaben über Rutschunfälle und deren Auswertung; schließlich die Auswahl und Dringlichkeitsreihung von Straßenabschnitten, die einer griffigkeitserhöhenden baulichen Behandlung bedürfen. Zu jedem Teil des Programms ist eine Diskussion angefügt.

DIE ENTWICKLUNG UND REALISIERUNG EINES PROGRAMMS ZUR REDUZIERUNG DER RUTSCHUNFÄLLE

Wade L. Gramling, Pennsylvania Department of Transportation

Die Vorhaltung griffiger Fahrbahnoberflächen, die den Anforderungen der motorisierten Öffentlichkeit auf den unterschiedlichsten Arten von Straßenanlagen gerecht werden, erfordert eine systematische Arbeitsweise. Das angewendete Arbeitssystem muß einschließen: ein zuverlässiges Verfahren zur Messung der Straßengriffigkeit, Kriterien für die Notwendigkeit baulicher Verbesserungsmaßnahmen sowie geeignete Prüfverfahren für die Baustoffe der Deckschichten, um das gewünschte Griffigkeitsverhalten sicherzustellen.

Das Pennsylvania Department of Transportation hat ein Arbeitssystem eingeführt, das sich auf langjährige Erfahrungen in Forschung und Entwicklung stützt, um auf wirtschaftliche Weise ein vorhersagbares Griffigkeitsverhalten der Fahrbahnen zu erreichen. Das Meßprogramm, die Kriterien für Verbesserungsmaßnahmen sowie die Entwicklung der technischen Vorschriften für Gesteinsbaustoffe, von denen ein bestimmtes Griffigkeitsniveau gefordert wird, werden beschrieben.

VIRGINIAS PROGRAMM ZUR REDUZIERUNG DER UNFÄLLE AUF NASSER FAHRBAHN

Stephen N. Runkle und David C. Mahone, Virginia Highway and Transportation Research Council

Verallgemeinerte Arbeitsschritte in Virginias Programm zur Reduzierung der Unfälle auf nasser Fahrbahn werden dargelegt und in gewissem Umfang diskutiert. Wo möglich, wird auf frühere Berichte verwiesen, die mehr Details zu den einzelnen Maßnahmen und deren Begründung enthalten. Es wird erwähnt, daß sich das Programm nur auf die Interstate- und Hauptverkehrsstraßen sowie auf die Straßen erster Ordnung bezieht, die der Unterhaltung durch das Virginia Department of Highways and Transportation unterliegen. Unfallschwerpunkte bei Nässe im Sekundärstraßennetz werden ausgewertet, wenn sie den für das Programm verantwortlichen Stellen zur Kenntnis gebracht werden; die in diesem Beitrag beschriebene Verfahrensweise zum Auffinden von Unfallschwerpunkten bei Nässe läßt sich jedoch nicht unmittelbar auf das Sekundärstraßennetz anwenden.

Straßenabschnitte zur weiteren Behandlung werden entweder auf der Basis der Unfallzahlen oder durch systematische Griffigkeitsmessungen lokalisiert. Unfallzahlen und Ergebnisse von Griffigkeitsmessungen, die für das Programm benutzt werden, sind bei dem Department auf Datenträgern gespeichert.

Die bei der Auswahl von Straßenabschnitten für mögliche Abhilfemaßnahmen wesentlichen Daten sind die Anzahl der Unfälle auf trockener und auf nasser Fahrbahn, der Prozentanteil der Unfälle bei Nässe, die Schwere der Unfälle, die sich bei Nässe ereigneten (Tote, Verletzte, Sachschäden) sowie die Griffigkeitswerte der Fahrbahn. Ferner werden betrachtet die geometrische Ausbildung der Fahrbahn sowie die Verkehrs- und Umweltbedingungen der betreffenden Straßenabschnitte.

DAS PROGRAMM VON TRANSPORT CANADA ZUR AUFRECHTERHALTUNG DER FÜR DEN BETRIEB ERFORDERLICHEN REIBUNGSKOEFFIZIENTEN DER START- UND LANDEBAHNEN

W. V. Levitzky, Transport Canada

Das Ziel des Programms ist es, auf den Start- und Landebahnen der Flughäfen sichere Betriebsbedingungen für einen leistungsfähigen Luftverkehr in Canada zu gewährleisten.

Dies wird dadurch erreicht, daß technische Vorschriften erlassen wurden für den Reibungskoeffizienten der Start- und Landebahnen, für die Meßdurchführung sowie die zu verwendende Meßausrüstung und daß in periodischen Abständen der Oberflächenzustand der Start- und Landebahnen abgeschätzt wird.

Diese Vorschriften berücksichtigen die Bahnlänge, die Bahnneigung sowie Art und Gewicht der verkehrenden Flugzeuge. Die Meßgeräte zum Bestimmen der Reibungskoeffizienten der Start- und Landebahnen wurden durch eine besondere Arbeitsgruppe (Runway Braking Action Study Group) der Internationalen Organisation der Zivilluftfahrt (ICAO) geprüft und zur Anwendung vorgesehen und ihre Ergebnisse stehen in einer brauchbaren Korrelation zum Verhalten der Flugzeuge bestimmter Typen.

In den Wintermonaten wird der Reibungskoeffizient der Start- und Landebahnen in routinemäßiger Weise gemessen und berichtet, um die Notwendigkeit von Eis- und Schneebeseitigungen anzuzeigen. Als Meßgeräte dienen Verzögerungsmesser der Typen "James Brake" und "Tapley Meter", die auf ausgewählten Flugplätzen eingesetzt werden.

Obwohl ein vergleichbares Programm zur Messung und Anzeige der Betriebsbedingungen bei Gewitterregen im Sommer nicht existiert, so wird doch ein Bewertungsverfahren für die Verhältnisse der nassen Start- und Landebahnen laufend angewendet.

Der Skiddometer BV 11-2, zugelassen durch die ICAO-Arbeitsgruppe, wird als Meßgerät zur Ermittlung der Reibungskoeffizienten der Start- und Landebahnen in Verbindung mit einem mitgeführten System zur Annässung der Bahn vor dem Meßrad angewendet.

Die Häufigkeit der Messungen auf den Start- und Landebahnen richtet sich nach der jährlichen Anzahl der planmäßigen Flugbewegungen sowie nach der Kategorie der Flugzeuge.

Ein Verfahren befindet sich in der Einführung, durch das die Fluggesellschaften über Start- und Landebahnen unterrichtet werden, deren Reibungskoeffizienten nahe dem eingeführten Minimalwert liegen. Vorkehrungen werden getroffen, um Verbesserungsmaßnahmen für solche Flugpisten in die Wege zu leiten, deren Reibungskoeffizient unter den Bedingungen der standardisierten Annässung unter die als sicher angesehenen Mindestwerte absinkt.

Die Art der Abhilfemaßnahmen, um einen ausreichenden Reibungskoeffizienten der Bahnoberfläche wiederherzustellen, richtet sich nach den Ursachen der Glätte, wie z.B. Gummiablagerungen, Polierung der Oberflächentextur oder ungenügende Wasserabführung von der Bahn.

Die wirksamen Verfahren für Abhilfemaßnahmen reichen von der Entfernung der Gummiablagerungen durch Wasser unter Hochdruck, über den mechanischen Abtrag (Querriefelung), das Wiederherstellen der Oberflächentextur durch Hammerschlag bis zum Einschneiden von Rillen in die Bahnoberfläche zur Verbesserung der seitlichen Wasserabführung.