PREDICTION OF PAVEMENT SKID RESISTANCE PERFORMANCE*

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ABSTRACT

This paper contains a discussion of the U.K. Transport and Road Research Laboratory (TRRL) and North American approaches to pavement skid resistance characterisation. A mathematical model developed by the TRRL to predict pavement skid resistance performance is shown to be inappropriate for mixes and test methods adopted in the Province of Ontario, Canada.

The development of a model appropriate for dense-graded asphaltic concrete mixes in Ontario is described. The model contains parameters associated with the ability of the mixes to resist consolidation under traffic, as well as those contained in the TRRL model, the polished stone values and traffic volume. The model is shown to have an excellent agreement with site data.

INTRODUCTION

1. In recent years the factors governing tyre-road friction have received considerable research emphasis and are now fairly clear. Kummer (1966), Yandell (1971) and others have concentrated on the theoretical aspects while papers presented at the recent Transportation Research Board, Second International Skid Prevention Conference (1976) covered such wide ranging topics as skid resistance measurement; automobile design; tyre tread pattern and composition; legal implications of skidding accident 'black spots'; and the more practical aspects to the materials engineer in providing mix designs to maintain reasonable levels of skid resistance. It is to practitioners in this last area that this paper is addressed.

2. The factors which have been generally recognised to govern wet road skid resistance are adequate microtexture (in the pitch size range 25 μm to 0.25 mm) to give a high level of friction at low speed (where there is time for the water film to be pierced and direct contact occurs), and adequate macrotexture (in the pitch size range > 0.25 mm) to provide drainage channels for displaced water and to deform the tyre so that frictional energy is consumed by hysteresis in the tyre rubber. A coarse macrotexture can thus provide skid resistance even when there is no direct tyre-road contact, which can be the case at high speeds. Yandell (1971) has shown that there is no cut-off between microtexture and macrotexture and that all tyre-road friction can be explained in terms of hysteretic energy loss. It is usual however, to consider the surface microtexture of the coarse aggregate particles to govern low speed skid resistance, and macrotexture, the projection of these particles from the road surface, to govern skid resistance at higher speeds.

3. Now that the factors governing tyre-road friction have been recognised, it is possible to turn to the problem of predicting the pavement skid resistance performance in particular highway situations. The research described in this paper was directed towards the development of a predictive model for dense-graded asphaltic concrete mixes applied to freeways carrying high speed (legal limit 100 km/h) traffic in Ontario, Canada.

PREDICTION OF SKID RESISTANCE

4. The U.K. Transport and Road Research Laboratory (TRRL), which has provided much of the lead in skid resistance research, recently reported success in the development of a predictive model for site measured skid resistance. This predictive model given by Salt (1976) is based on a knowledge of traffic volume and the polished stone value (*PSV*) (BS 812:1975) of the coarse aggregate used in the surfacing at the site. The relationship was found to have a highly significant correlation (correlation coefficient 0.91 from 139 sets of observations):

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

where SFC_{50} = sideway-force coefficient at 50 km/h;

and q_{cv} = flow of commercial vehicles per lane per day.

5. The authors believe that the good correlation of the TRRL model was due, in no small part, to the use of a low speed, low slip measure of skid resistance, *SFC*, which depends primarily on surface microtexture.

6. The reports of almost all North American research concerned with the prediction of skid resistance have been on the correlation of friction measured by the ASTM Standard E274 locked wheel skid trailer

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The University of Newcastle, Australia, and McMaster University in Canada must be acknowledged for the opportunity provided to B. Heaton to participate in this study through a temporary appointment as Visiting Associate Professor in the Civil Engineering and Engineering Mechanics Department at McMaster University during 1977.

with laboratory aggregate polishing values. The correlation coefficients obtained have sometimes not been reported, e.g. Mullen (1974), or have been reported as low, i.e. 0.55-0.65, e.g. Dahir, Meyer and Hegmon (1971). There are many possible explanations for these poor correlations, and perhaps no adequate correlations may be possible with the types of mixes used in North America and with the effects of the more extreme and variable climate involved.

7. There is, however, one factor which has recently become recognised that was not taken into account in much of the earlier research work, namely the seasonal variation in skid resistance and the interaction between polishing and weathering. This has been reported by Salt (1976), Gramling and Hopkins (1974) and Rice (1977). This interaction has the effect of restricting the fall of initial skid resistance to that reached at the end of the first or second summer for constant traffic volumes. The seasonal variation, in amplitude of up to 15 in skid numbers, and the recurrence of reasonably constant low (fall) values, has been masked to some extent by the gradual increase in traffic flow on most roads. It has now been recognised that it may have been this factor of increased yearly traffic volume which has produced results showing a gradual decline in skid resistance over many years, rather than a dependence of polishing merely on cumulative traffic.

8. The ASTM Standard E274 locked wheel skid trailer used in North America for characterising skid resistance is variously used at speeds of 50, 65 or 100 km/h. The authors feel that in any case the value determined for locked wheel friction (100 per cent slip) is more influenced by macrotexture of the road surface than is *SFC* (10 per cent slip). Because of the need to forecast changes in both macrotexture and microtexture of a road pavement in a model to predict skid number (*SN*), it is likely that the model will be much more complex than that developed at TRRL using *SFC*. It is also likely that the correlation coefficients obtained with this model will be lower.

9. Rizenbergs *et al.* (1976) report ample evidence of a strong correlation between a high incidence of wet weather skidding accidents and a low value of skidding resistance, whether that value is in terms of *SN* or *SFC*. There has been considerable argument as to which is the more correct measure either *SFC*, a measure of the ability to control sideways sliding, or *SN*, a measure of the distance required to stop under 'panic' locked wheel braking. Obviously, both are important and the coarseness of accident statistics makes it unlikely that the argument will ever be fully resolved. A point to note, however, is that 'peak' friction, the demand for which must be exceeded before locked wheel sliding occurs, is more closely related, as far as pavement properties are concerned, to *SFC* than to locked wheel *SN* because of the occurrence of 'peak' friction at near 15 per cent slip.

SKID RESISTANCE TEST SECTIONS IN ONTARIO

10. During 1974, the Ontario Ministry of Transportation and Communications (MTC) constructed 17 asphaltic concrete test sections on Highway 401, Toronto By-Pass, to evaluate methods of improving rigid pavement skid resistance through thin overlays. The asphaltic concrete mixes were provided as 25 mm or 38 mm overlays on a 12-year-old cement concrete pavement with limestone aggregate that had polished badly after being exposed by studded tyres. Traffic on this section of the Highway 401 is extremely heavy (probably the highest volume in Canada) with approximately 199 000 veh/day (in 1976) using the 12-lane system of collector and express lanes. The 17 test sections, over 2.4 km of the west-bound express lanes, carried the traffic levels shown in the appropriate rows of *Table I*, recorded during a 24-hour period in mid-summer 1975.

11. Details of the mixes laid in the test sections and their performance from 1974 to 1977 have been fully described by Corkill (1975) and Ryell, Corkill and Musgrove (1977), and are summarised in *Table III.*

12. The skid resistance level maintained by some of the Highway 401 test sections, incorporating typical mixes which have evolved over many years as being suitable, mainly on structural grounds, for long life on Ontario highways, was significantly lower than anticipated.

13. A summary of the major conclusions during the evaluation by the MTC of the Highway 401 test sections is given in the publication by Ryell *et al.* (1977). This evaluation of the Highway 401 test sections prompted a reappraisal of factors governing skid resistance performance and led to the granting of a research contract, by the Research and Development Division of MTC to the authors, for the express purpose of developing a model for prediction of pavement skid resistance performance.

14. The information available immediately for analysis in a prediction model was restricted to the Highway 401 test sections. The authors have since completed a program of laboratory testing in the Construction Materials Laboratory at McMaster University to obtain the *PSV* of a range (20 samples) of Ontario aggregates so that suitable additional sites could be chosen for analysis to accommodate a range of conditions.

15. The three lanes (separately) of the 17 Highway 401 test sections provided a range of traffic conditions for mixes incorporating three coarse aggregate types: traprock, blast furnace slag and steel slag. Four other sites were chosen which contained limestone coarse aggregate mixes at relatively lower traffic volumes. *Tables I, II* and *III*, respectively, give details of the traffic levels at the test sites; coarse aggregate properties; and the mix composition and analysed skid resistance performance data. Only the dense-graded asphaltic concrete mixes of HL1 or HL3 designation have been evaluated at this time (i.e. Highway 401 Test Sections 1 to 10 and 18.

TABLE I

TRAFFIC DATA

Location	*ADT*	*% Commercial*
Highway 401 Driving lane	12900	29.0
Centre lane	17300	11.0
Passing lane	14600	1.0
Contract 66-155	1800	15.0
Contract 67-147	2125	15.0
Contract 72-515	1275	15.0
Contract 75-068	800	19.0

Other test sites 66-155, 67-147, 72-515 and 75-068). All mixes were of 12 mm maximum aggregate size.

TABLE II

DATA ON AGGREGATES

Symbol	*Description*	*PSV*	*Los Angeles Abrasion Value*	*Aggregate Abrasion Value*
TR	Traprock	45	13.4	2.2
SL	Steel slag	59	30.0	4.3
BF	Blast furnace slag	54	47.2	27.0
L	Limestone	41	23.3	—

PREDICTION MODEL FOR ONTARIO PAVEMENTS

16. An examination of the data contained in *Table III* soon indicated that a model similar to that developed by the TRRL, containing only two variables, aggregate *PSV* and traffic volume, would not be adequate for skid resistance prediction in Ontario.

17. The all steel slag (*PSV* = 59) mix, Test Section 7, the all blast furnace slag (*PSV* = 54) mix, Test Section 9, and the all traprock (*PSV* = 45) mix, Test Section 3, behaved as indicated by their *PSV* value; *SN* = 34, 32 and 27 respectively, after 33 months in the heavily trafficked driving lane. However, where these coarse aggregates were incorporated into mixes containing natural sand and limestone screenings as fine aggregates, their performance was as much as 50 per cent worse, under identical traffic conditions.

18. These results suggested to the authors that parameters such as stability, a measure of the ability of the mix to withstand consolidation, or other measures of the ability of the mix to withstand immersion of the coarse aggregate into the matrix, may prove significant in a predictive model.

19. A multiple linear regression program, SPSS, developed by Nie *et al.* (1975) has been used to evaluate the significance of various mix and aggregate parameters on the skid resistance performance under traffic. To have relevance in a predictive model the parameters chosen were capable of being determined in the laboratory prior to placing on the roadway, e.g. aggregate gradation, *PSV*, Los Angeles abrasion value, aggregate abrasion value, mix stability, flow and void content.

20. The construction of the Highway 401 test sections across three lanes carrying a mixed composition of traffic allowed, first of all, an analysis to be made of commercial vehicle equivalence factors (a commercial vehicle has been defined as a vehicle larger than a van and/or with dual tyres on the rear wheels). *Fig. 1* shows a plot of commercial vehicle equivalence factors (*f*) against values of *R* coefficient obtained in a regression analysis of *SN* against equivalent traffic. The plot shows two separate analyses: one for traffic flow volume, where Equivalent Traffic Flow Volume = AADT + (*f*-1) Commercial Vehicles; and the other for cumulative traffic, where Equivalent Cumulative Traffic = Equivalent Traffic Flow Volume x Service Life.

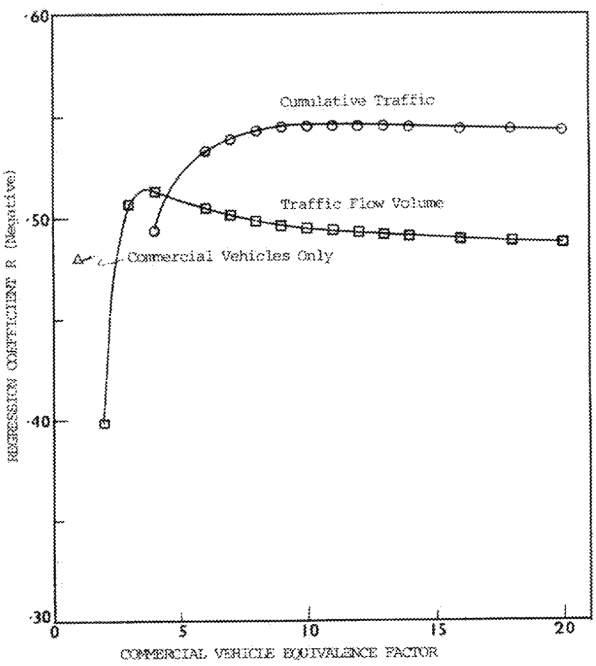

Fig. 1 — Commercial vehicle equivalence factor. Plot of R coefficient obtained in regression analysis of skid number against equivalent traffic. Ontario Highway 401 test strip data

21. Better correlation was obtained with cumulative traffic than with traffic flow. Service life in this analysis of the Highway 401 test strips was a maximum of 33 months. The data indicate that the surfacing at a service life of 21 months had still not reached the constant skid resistance level suggested by Salt (1976), Gramling and Hopkins (1974) and Rice (1977), as obtainable after one to two years. The authors have used, however, a maximum service life of three years for the older roads evaluated in the analysis as there is some evidence from the Highway 401 data that at 33 months, *SN* values are starting to level out. From *Fig. 1*, the commercial vehicle equivalence factor, *f*, has been taken as 10 in terms of cumulative traffic. The equivalent traffic (*EQT*) used in the analysis has therefore been taken as

$$EQT = \left[\text{AADT} + (9 \times \text{Commercial Vehicles})\right] \times \text{Service Life (days)} \times 10^{-6}$$

with a maximum service life (after which *EQT* remains constant) of 980 days (36 months).

22. *Table IV* is a list of the more significant parameters determined by the analysis and their correlation with skid resistance measured by the ASTM Standard E274 locked wheel skid trailer. A total of 56 independent cases were examined.

23. A multiple linear regression analysis of the parameters in *Table IV* provided the following relationship

$$SN_{100\ \text{km/h}} = (0.17 \times PSV) + (1.7 \times MS) + (3.6 \times FLOW) + (0.9 \times VOID) - (0.24 \times EQT) - 9$$

where Multiple *R* Coefficient = 0.93,
Standard Error of Estimate = 2.1,
95% Confidence Limit ±4.2.

TABLE III

HIGHWAY 401 TEST SECTIONS. MIX COMPOSITION AND SKID RESISTANCE PERFORMANCE

Test Section Numbers	*Mix Type*	*Mix Composition % wt of Aggregate Plus Filler*				*Mix Characteristics*				*Skid Resistance SN 100 kmh*					
		Coarse Agg. + 4.7 mm	*Fine Agg. — 4.7 mm*	*Filler Material*	*%* +4.7 mm*	*Bitumen % wt of mix*	*Marshall Stability kN*	*Marshall Flow mm*	*Voids % Vol.*	*Average Initial*	*Driving Lane 21 mo*	*Driving Lane 33 mo*	*Centre Lane 33 mo*	*Passing Lane 21 mo*	*Passing Lane 33 mo*
1	HL 1	45 TR	41 NS, 14 LS	—	43.8	5.4	11.60	2.9	3.7	35	25	22	23	27	24
2	HL 1	45 TR	41 NS, 14 TRS	—	48.2	5.3	12.75	3.4	0.8	35	27	22	24	32	29
3	HL 1	45 TR	55 TRS	—	47.5	4.0	15.15	3.9	2.0	44	36	27	29	40	36
4	HL 1	55 TR	34 NS, 11 LS	—	54.1	4.8	13.45	3.1	1.2	38	25	24	26	32	32
5	HL 1	60 TR	28 NS, 10 LS	2 ASB	58.1	5.7	8.45	5.7	0.9	34	25	24	28	30	32
6	HL 1	60 TR	38 TRS	2 ASB	62.3	5.4	11.40	4.7	3.4	38	35	29	29	37	33
7	Mod HL 1	45 SL	55 SLS		46.8	5.2	16.20	3.4	3.3	48	37	34	33	42	40
8	Mod HL 1	50 SL	38 NS, 12 LS		47.1	5.7	13.30	3.5	1.9	38	28	26	—	—	—
9	Mod HL 1	45 BF	55 BFS		43.2	7.8	14.80	3.8	6.1	38	37	32	34	40	43
10	Mod HL 1	40 BF	45 NS, 15 LS		40.5	6.5	14.00	2.5	2.2	37	25	24	29	34	33
11	Sand Mix	14 TR	84 TRS	2 ASB	5.4	7.0	9.65	10.2	0.2	40	28	28	29	32	34
12	Sand Mix	9 TR	89 TRS	2 ASB	6.9	7.2	8.40	11.5	1.1	32	31	28	28	33	30
13	OG	67 TR	33 TRS		60.5	5.9	6.50	3.2	4.7	42	38	31	29	35	35
14	OG	67 TR	31 TRS	2 ASB	71.5	5.8	7.50	3.0	4.0	38	35	29	30	37	34
15	OG	30 TR	70 TRS		29.3	5.6	11.90	4.9	0.7	42	29	25	28	36	33
16	OG	30 TR	68 TRS	2 ASB	31.4	6.6	9.40	7.7	0.2	40	32	27	27	38	34
17	Mastic	70 TR	19 TRS	9MF, 2ASB	75.2	7.5	8.40	14.4	1.0	29	30	27	26	26	27
18†	HL 1	45 TR	41 NS, 14LS		47.4	5.4	12.55	3.7	0.4	32	22	21	26	26	32
Other Tests															
66-155	HL 3	40 L			38	6	12.05	1.8	4.2		26 at 135 months				
67-147	HL 3	40 L			38	6	10.60	1.8	4.6		28 at 123 months				
72-515	HL 3	40 L			39	6.1	8.90	2.3	3.3		27 at 63 months				
75-068	HL 3	40 L			42	5.6	11.35	2.3	2.3		24 at 27 months				

* Based on field laboratory extraction tests

† As Test Section No. 1 but constructed over a 38 mm thick bituminous basecourse layer

LEGEND

Coarse Aggregate
TR — Traprock
SL — Steel Slag
BF — Blast Furnace Slag
L — Limestone

Fine Aggregate
NS — Natural Sand (Glacial Deposit)
LS — Limestone Screenings
TRS — Traprock Screenings
SLS — Steel Slag Screenings
BFS — Blast Furnace Slag Screenings

Filler Material
ASB — Short Fibre Asbestos
MF — Mineral Filler (Finely Crushed Limestone)

Mix Type
OG — Open Graded
SN — Skid Number
mo — month

TABLE IV

SIGNIFICANT PARAMETERS IN REGRESSION ANALYSIS

Rank Order	*Symbol*	*Parameter*	*Mean Value*	*Standard Deviation*	*R Coeff.*
1	MS	Marshall stability of mix kN	12.9	2.2	0.49
2	PSV	Polished stone value of coarse aggregate	48	6	0.46
3	VOID	Void content of mix — Marshall compaction (%)	2.5	1.6	0.45
4	EQT	Equivalent traffic (see above)	26	14	−0.40
5	FLOW	Marshall flow of mix (mm)	3.5	1.0	0.17

See *Fig. 2* for plot of measured *SN* against calculated *SN*.

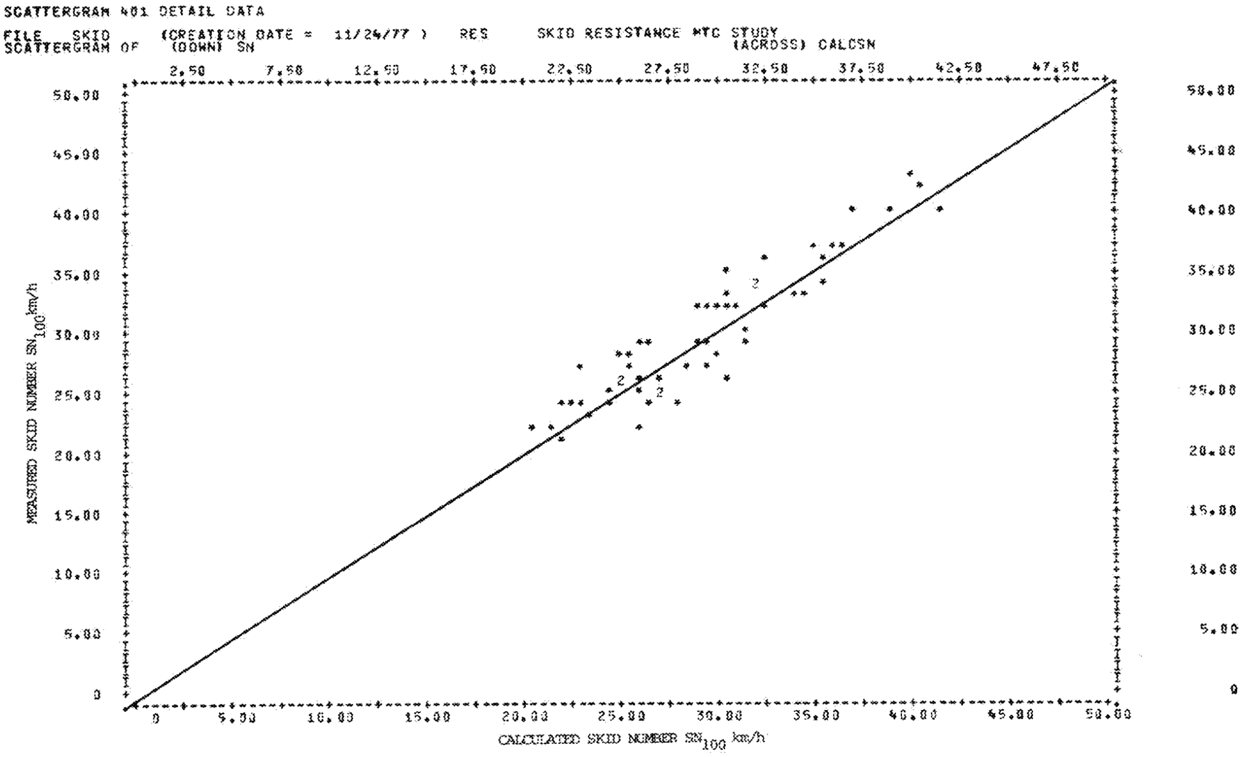

Fig. 2 — Plot of measured skid number against calculated skid number

24. This relationship is quite different from that developed at TRRL and reflects the different skid testing methods (skid trailer *v.* SCRIM), testing speeds (100 km/h *v.* 50 km/h), mix compositions and possibly even climate where the mixes are in service. The parameters Marshall stability (MS), flow (FLOW) and void Content (VOID), not included in the TRRL model, reflect the performance of the dense-graded asphaltic concrete in terms of compaction during laying of the mixes and under the consolidating effect of traffic during the hot summer months. Those mixes with high stability and void content were better able to resist the submerging of the coarse aggregate and to retain a coarse surface texture (Emery 1975). The effect of high flow mixes on field performance is still being considered. It should be noted that the thin surface overlays of the Highway 401 test sections were laid at night in August when cooling rates could be rather high. The prediction relationship presented applied only to dense-graded asphaltic concretes of constant 12 mm maximum aggregate size.

EXTENSION OF STUDY

25. The monitoring of skid resistance performance in Ontario has been largely restricted to test sections on Highway 401 which at present have had three years of service. This time has been insufficient to establish with any confidence that skid resistance does decline to a constant value coupled with a seasonal variation, although there are indications that this does occur after approximately three years under the heavy traffic on Highway 401.

26. The blast furnace slag used on the Highway 401 test sections was, owing to its porous composition, quite weak with Los Angeles Abrasion Value (ASTM Standard C131) = 47.2 per cent and Aggregate Abrasion Value (BS 812:1975) = 27.0. At a service life of three years under extremely heavy traffic, the blast furnace slag mixes are still performing well. This indicates that a limiting Los Angeles abrasion value is perhaps not a

good indicator of abrasion resistance of porous aggregates such as slag. There are some signs, however, that loss of coarse texture due to pavement wear is occurring and abrasion resistance (measured by the BS 812 Aggregate Abrasion Value Test rather than the ASTM Los Angeles Test) may eventually prove a significant parameter.

27. During the course of the study it was revealed that on repeating the friction test portion of the BS 812 *PSV* determination, there was for all aggregates an increase in friction value averaging approximately 5 per cent after eight weeks storage in the laboratory. The increase was least for the hard, dense igneous rocks and greatest (up to 20 per cent) for the steel slag aggregates. This phenomena almost certainly occurs on the road as well and, as reported by Salt (1976), allows blast furnace slag for example, to behave better on the roadway than is indicated by its *PSV* value alone. This characteristic of slag aggregates is the subject of a continuing investigation by the authors.

28. The relationship developed in this study has been restricted to mixes with a maximum aggregate size of 12 mm. In view of the significance of the parameters which contribute to the maintenance of coarse surface texture, other factors such as the use of larger aggregate sizes which may contribute to coarse texture should be examined.

29. An extension of the study to the examination of factors which contribute to the skid resistance performance of open-graded mixes is also being considered.

CONCLUSIONS

30. A mathematical model has been developed for predicting the skid resistance performance of dense-graded asphaltic concrete mixes used in Ontario. The model is presented in para. 23. Terms are defined in para. 22.

31. A model developed by TRRL in the U.K., containing the parameters *PSV* of the coarse aggregate and traffic volume only, was found to have poor correlation with Ontario site data and skid measurement methods. With the inclusion of additional parameters — Marshall stability, flow and void content — associated with the ability of the mixes to resist consolidation under traffic, excellent agreement between model and site data was obtained.

32. The model is still in the developmental stage being based on 56 independent site cases all of dense-graded asphaltic concrete of 12 mm maximum aggregate size. The cases cover two of the more widely used aggregates in Ontario, limestone and traprock with low and medium *PSV*, 41 and 45 respectively and two aggregates of high *PSV*, blast furnace slag 54, and steel slag, 59, which show promise for wider use. Development of the model is to continue with the analysis of further cases and possibly with an extension to a wider range of mix compositions and aggregate types.

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The influence of surface texture on skid resistance is well recognised so its classification in terms of various texture parameters may be of importance. Some possible parameters were presented at the 8th Conference in Perth by Forde, Birse and Fraser (1976). Attaching numerical values to such parameters by visual assessment of photogrammetrically portrayed surfaces could be tedious and time consuming. If this is so, direct measurement still would have to be employed for routine skid resistance inventories. A photogrammetric survey may be useful in the assessment of small areas where surface deformations could effect the directional stability of vehicles or in the monitoring of the development of deformations in such areas.

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DISCUSSION

PREDICTION OF PAVEMENT SKID RESISTANCE PERFORMANCE

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In the preparation of a specification for an asphalt surface material for example, the PSV of the stone is normally given. However, this does not guarantee that a pavement will achieve the desired skid resistant properties.

What is the authors' opinion of specifying a minimum surface texture value?

E.M. BROWN, Deputy Engineer-in-Chief, Department of Main Roads, New South Wales

The Province of Ontario uses the locked wheel trailer to measure skid resistance on the principle routes. Are these results made public, and are the minimum desirable or safe levels generally known to the public?

Australian SRAs are now obtaining SCRIM which will allow surveys on all their main highways annually. This was not possible with the pendulum due to the slowness of operation.

This raises the dilemma — should results be published (or can they be kept confidential in view of freedom of informative legislative) with all the chances of litigation involved arising from skidding accidents?

M. SANDY, Geologist, CSIRO, Division of Building Research

Response of aggregate to physical tests is closely related to the minerology and microscopic texture of the rocks tests. (This includes such features as grain size, grain interlocking, cementation and homogenity of mineral types as well as the percentage of 'unstable' minerals such as clay.) Has any attempt been made, either in this study, or in others known to the authors, to relate these inherent features to skid resistance? Guirguis and Jones in their work (reported in Session 24 of these Proceedings) found that rock type was a critical factor in aggregate reaction to crusher treatment. The rocks: basalt, rhyolite and micro-syenite, although they are all fine-grained igneous rocks, are very different chemically, mineralogically and texturally and these differences were reflected in their respective reactions to crushing.

This discussor believes that all rocks which are proposed for use as road aggregate should undergo at least a basic (and cheap) petrographic examination preferably with an estimation of clay content. The result, it is believed, would be an asset to (certainly not a replacement of) work involving measurement of PSV values, especially where bulk testing is required.

AUTHORS' CLOSURE

Firstly to the discussion leader Mr Hamory we wish to reply to three points raised.

We endorse the view that skid resistance measurements by SCRIM (SFC) may be more relevant than locked wheel skid number (SN), regardless of whether wheel lock-preventing devices are introduced, and this was meant to be implied by the concluding comments of para. 9 of the paper.

The 20 per cent increase in friction test value, exhibited by steel slag following storage of polished laboratory specimens, occurred with some samples which were taken from the Ontario test section site in 1974 but were not polished in the laboratory until 1977. We conclude from this that the increase in friction is not merely due to the use of aggregate cured for an inadequate duration. The phenomenon seems to be a surface effect which occurs on freshly-polished surfaces of all aggregates, to a greater extent with the more active slags, and the authors believe that the seasonal variation in skid resistance is related to this process.

The paper presented at the conference did lack a set of brackets in para. 21 and this is remedied in the Proceedings.

In response to the question by Mr Sandy, concerning petrographic examination replacing or complementing PSV testing, we refer to a TRRL Report by Hawes and Hosking (1972) wherein it was stated

> that resistance to polishing is influenced as much by the degree of bonding between mineral constituents as by any other single factor. However, bonding is not a simple property; it depends upon a combination of phenomena which reflect the nature and mode of origin of a rock and its subsequent geological history . . . polishing characteristics of rock are linked more closely to their capacity for differential wear than to their rate of wear . . . textural fabric is only of marginal importance in promoting differential wear.

The authors have little experience with petrographic analysis but presume from the above reference that the identification of polish resistant stone from a basic petrographic examination may not be easy and that PSV testing has a major role to play in determining polishing characteristics of rocks.

In reply to the question by Mr Grahame, the authors are of the opinion that, particularly for high speed roads, it is necessary to specify a minimum surface texture value of the order 0.6 to 1 mm (by the sand patch method). However, it must be realised that the maintenance of that texture will depend upon the traffic level, proportion of heavy vehicles and, for bituminous concrete, the stability flow and voids of the mix. Because of the combined effect of weathering and polishing on skid resistance any minimum PSV value specified should be related to traffic level.

In reply to Mr Brown, the authors refer to the Proceedings of the International Skid Prevention Conference, Columbus, Ohio, 1977, published as Transportation Research Records 621-624, wherein several papers were devoted to problems of legislation and possible litigation. The dilemma, as to whether standards and/or test results should be published or not, is world-wide and road authorities in most countries are no closer to a resolution than are those in Australia. In the U.K., where a substantial effort to lay down standards was made to the Marshall Committee on Highway Maintenance (1971), the recommendations have never achieved higher status than proposals aimed at providing guidance for maintenance engineers. Even as far as standards for new construction are concerned only in Belgium, Holland and Switzerland are specified minimum limits for skid resistance required of a contractor (Elsenaar, Reichert and Sauterey 1976). A most comprehensive list of requirements depending on site accident risk have recently been proposed by TRRL and these are being considered by the Department of Transport U.K. (Salt 1976).

The direct transfer of minimum standards of skid resistance from one continent to another does not seem to be feasible since accident risk depends greatly on the proportion of time that roads are wet and the cost of providing a particular level of skid resistance depends significantly on the availability of suitable stone. Great Britain has many sources of good stone with PSV > 55 while in North America and Australia wear resistant stone with PSV this high is rare.

Returning once again to the question of litigation we present a quote from Thomas (1976) concerning the legal situation in the United States.

> . . . the duty of the state to correct dangerous conditions arises only when it has notice, either actual or constructive, of the hazard . . . notice may be deemed to exist where the condition has been present for such a time and is of such a nature that the state should have discovered the hazard by the exercise of reasonable diligence.

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CALIBRATION AND USE OF THE BRITISH PENDULUM TESTER FOR THE MEASUREMENT AND PREDICTION OF PAVEMENT SKID RESISTANCE

J.W.H. OLIVER, B.Sc., Ph.D., C.Chem., M.R.I.C., Senior Research Scientist, Australian Road Research Board

J.W. CRUICKSHANK, Pavements Engineer, Cement and Concrete Association of Australia

Has the author any thoughts on extending the test program to concrete pavements, using similar parameters to those described for asphaltic plant mix in para. 44(d)? Current construction of concrete pavements plus in-service old concrete roads appears to warrant this.

J.C. GIFFEN, Principal Chemist, Department of Main Roads, New South Wales

In early studies carried out in 1968 by the Department of Main Roads it was noted that polishing by traffic was somewhat more complicated than simple abrasion of the microtexture of the stone. The study carried out showed that although abrasion took place it was accompanied by the build-up of a surface coating, particularly on basalts with a low Los Angeles abrasion loss. This coating appeared to consist of a conglomeration of rubber, carbon black, bitumen and other fine road detritus. I have never seen this noted in the literature and would like to know if the authors noted this phenomenon and whether in their work on polishing have heard mention of it?

D. van BARNEVELD, Streetworks Design Engineer, Dunedin City, New Zealand

Would the author comment on the repeatability of the pendulum tester?

When testing for seasonal variation, what sort of sample is proposed to avoid parameters other than seasonal variations to influence the results?

H. LUCKHURST-SMITH, Project Engineer, Shell Company, Melbourne

Dr Oliver's paper summarised areas requiring research under Australian conditions, which appears essential due to uncertainty of precise correlation with overseas results.

He mentioned a proposed research program planned by ARRB and SRAs to determine seasonal variations throughout Australia. Could the author please elaborate on