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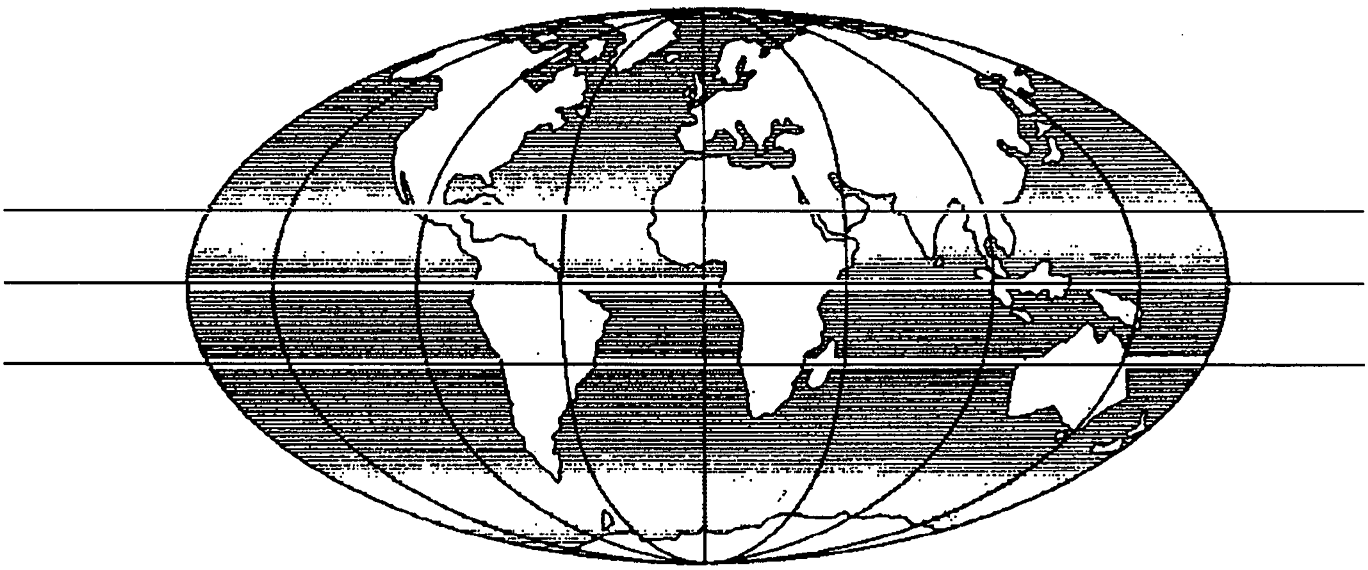

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PERFORMANCE OF SLURRY SEALS USED IN PAVED ROAD MAINTENANCE IN MALAYSIA

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SUMMARY

This paper describes the performance of slurry seals used to maintain asphaltic concrete surfaced roads in Peninsular Malaysia. In the study 22 kilometres of road, having differing surface conditions, were sealed using three types of seal and combinations of seals. A model has been developed that predicts the effectiveness of a general purpose slurry in sealing cracks over a period of 2 years based on the intensity of cracking prior to treatment, commercial traffic flow and pavement deflection. The results show that the seals have performed well when applied to uncracked surfacings but have been only partially successful in sealing even minor cracking. The relative performance of the different types of slurry is also reported. The skid resistance provided by the general purpose slurry was acceptable after two years but on roads with high traffic flows the surface texture had reduced to a value lower than that of the original asphaltic concrete surfacing.

INTRODUCTION

A slurry seal is essentially a thin asphalt overlay. It is usually applied to an old bituminous surfacing to extend the life of the road pavement by sealing the surfacing, thus preventing water penetration and more extensive pavement failures. It can also be used to restore or improve the skid resistance properties of the existing surfacing. The principal materials used in a slurry are fine aggregate, bitumen emulsion, water and a filler which is usually cement. These materials are mixed immediately prior to application and laid at ambient temperature with thickness ranging from 3-11 mm.

Although slurries have been used extensively since the early 1960's it is only recently that the technique was introduced to Malaysia as a potentially more cost effective alternative to the existing maintenance technique of thin asphaltic concrete overlays. The construction guidelines for the use of slurries have been developed in regions of the world where the type and condition of the road pavement and the environmental conditions are different from those found in Malaysia. To establish appropriate local construction guidelines it was therefore necessary to carry out a programme of research to study the performance of different types of slurry on roads having different levels of traffic, a range of surface condition and a range of pavement strength.

The research falls broadly into two parts. Firstly, a study of the effectiveness of the different types and combinations of types of slurry in sealing cracks of various intensities. Secondly, a study of how a general purpose slurry improves the skid resistance characteristics of an existing asphaltic concrete surfacing.

The construction of the seals began in March 1988 and their performance up to January 1991 is reported.

SLURRY SEAL SPECIFICATION AND DESIGN

There are three types of slurry defined by the International Slurry Seal Association. These are described in Table 1.

Table 1 Types of Slurry Seal

Sieve size (mm)	Per cent passing		
	Type 1	Type 2	Type 3
9.50	100	100	100
4.75	100	90-100	70-90
2.40	90-100	65-90	45-70
1.18	65-90	45-70	28-50
0.600	40-60	30-50	19-34
0.300	25-42	18-30	12-25
0.150	15-30	10-21	7-18
0.075	10-20	5-20	5-15
Bitumen content*	10-16	7.5 - 13.5	6.5 - 12

* Per cent of dry aggregate

Each type of slurry has a particular function and should only be used when the nature and the condition of the existing road pavement and the expected traffic levels are appropriate. For example, Type 1, the finest of the mixes, is generally used where maximum penetration into cracks is required and Type 3, the coarsest, is used where crown correction is necessary. The most common mix is Type 2, a general purpose slurry. The aggregate used in all three types of slurry in this study was crushed granite, the filler was Portland cement and the binder was a cationic emulsion SS1K (CSS-1 equivalent). The emulsion had a residual bitumen content of 61 per cent having a mean penetration of 96 at 25°C. The mix designs for each of the slurry types used at the different experimental sites are shown in Tables 2 and 3.

Table 2 Mix Design - Type 2 Slurry

Test	Specification	Site No		
		1-6	7-12	13-22
Cement (%)	-	0.5	0.5	0.5
Emulsion (%)	-	15.0	15.0	15.0
Water (%)	-	15.5	14.0	15.0
Consistency (%)	20-30	25-30	25	20-25
Wet Track Abrasion (gm/sq ft)	<75	23.6	24.0	25.0
Sand Equiv. Test (%)	>45	68	75	74

Table 3 Mix Design - Site No 16-22

Test	Specification	Type 1	Type 3
Cement (%)	-	0.5	1.5
Emulsion (%)	-	17	13
Water (%)	-	17	13
Consistency (%)	20-30	30	20-30
Wet Track Abrasion (gm/sq ft)	<75	53	21
Sand Equiv. Test (%)	>45	67	67

SITE SELECTION AND LAYOUT

In order to evaluate how effective the different types of slurry seal were in sealing existing cracked asphaltic concrete surfacings a factorial experimental design was employed, the variables being pavement condition, pavement strength and traffic level.

The performance of the general purpose slurry, Type 2, was assessed using 16 one kilometre sites located throughout Peninsular Malaysia. The relative performance of the Type 3 seal and combinations of Type 1 overlaid by Types 2 or 3 were assessed in two sets of experiments where these different treatments were constructed adjacent to a Type 2 seal. The location of the sites and the treatments are shown in Table 4. To monitor the performance of each site it was found convenient to sub-divide them into 100 blocks in both directions, each block being 10 metres long. The performance of each block was then monitored as a discrete unit in terms of its surface condition before sealing and in the progression of surface deterioration after sealing.

PRE-CONSTRUCTION AND POST-CONSTRUCTION MEASUREMENTS

The condition of the road pavement was quantified by the measurement of the extent and intensity of cracking and its surface characteristics by skid resistance and texture depth tests. The strength of the sites was assessed using pavement deflection tests and traffic volume obtained by manual classified counts.

CRACKING

The intensity of the cracking in each block was recorded using the following scale.

0	-	No cracks
1	-	Single crack
2	-	More than one crack - not connected
3	-	More than one crack - interconnected
4	-	Crocodile cracking

Although the extent and intensity of cracking of dense bituminous surfacings can be assessed in the manner described above, the method does not define the depth of the crack or identify the critical stresses that caused the crack to develop. In tropical climates cracks frequently start at the top of the surfacing (Rolt, et al 1986) because of embrittlement of the binder in the top few millimetres of the layer (Smith, et al 1990) (Hasnur 1990). The stresses that initiate the crack can be shrinkage stresses in the bituminous material caused by the loss of volatile oils, stresses caused by thermal expansion and contraction, stresses imposed by vehicles and combinations of all three.

Cracks can also start at the bottom of the dense bituminous layer and propagate upwards. This type of crack is caused either by traffic induced fatigue or a reflection process whereby cracks start immediately above existing cracks in a lower layer.

Cores were taken through cracks appearing in the slurries to determine whether they had penetrated the existing asphaltic concrete surfacing or whether they were confined to the top few millimetres of the slurry. The analyses of these cores helped to identify the likely cause of the crack.

The extent and intensity of the cracking on the sites prior to construction is shown in Table 4.

SKID RESISTANCE

Skid resistance tests, using the Pendulum Tester (Road Research Laboratory, 1969), were carried out at 20 test chainages in the vergeside wheelpath along each site at approximately 6 monthly intervals. To ensure that these tests were carried out in the same place each time, thus reducing testing error, a nail was driven into the road pavement at each chainage at a fixed offset to act as a marker.

The values of skid resistance have been corrected to a standard temperature of 35°C using a relationship developed in Malaysia for dense bitumen macadam surfacings (Beaven and Tubey 1978). The relationship, given below, was validated during skid resistance/temperature tests on a Type 2 slurry.

$$SRV\,35 = \frac{(100 + t)}{135} \times SRVt$$

t = Temperature at test
SRVt = Measurement value at temperature t
SRV 35 = Corrected value at 35°C.

It was considered more appropriate to select 35°C as a standard temperature to minimise correction. This means that the readings will be 3-5 units lower than for comparable surfacings in the UK, which are corrected to 20°C

SURFACE TEXTURE

The surface texture of the slurry seal was measured using the Sand Patch Method (Road Research Laboratory 1969) at the same chainages as were used for the skid resistance tests. These tests were carried out at the end of the study.

DEFLECTION MEASUREMENTS

Pavement deflection surveys were made with the Road Rater at approximately 12 monthly intervals. At each site, fifty equispaced points in the vergeside wheelpath were tested every 40 metres. The mean values of central deflection over the period of the study, corrected for an applied load of 8.9 KN, are shown in Table 4.

Research carried out in a parallel study (Chong 1990) allows the Road Rater deflection to be converted to the equivalent Falling Weight Deflectometer result using the following relationship.

$$D(FWD) = 0.0246 + 6.87 \times D(RR)$$

where
D(RR) = Deflection (mm) at applied load of 8.9 KN
D(FWD) = Deflection (mm) at applied load of 49.5 KN

TRAFFIC

The unidirectional average daily number of commercial vehicles (ADCV) was estimated from 16 hour classified counts by multiplying by 1.3, a factor derived from national 24 hour traffic counts. In this paper medium and heavy goods vehicles and buses are classified as commercial vehicles. The average values of ADCV over the period of the study are shown in Table 4.

Table 4 Site Details

Road No.	Site No.	Type of Slurry	Crack extent by intensity+ prior to sealing (per cent)					Road Rater Deflection (mm x 10^{-3})	ADCV
			0	1	2	3	4		
11/70	1	2	91	3	0	6	0	60	1280
11/72	2	2	96	1	0	3	0	63	1280
11/74	3	2	94	5	0	1	0	70	1280
11/83	4	2	95	4	0	2	0	54	1280
10/52	5	2	89	1	0	5	5	53	950
10/58	6	2	68	1	1	4	26	47	950
3/226	7	2	53	12	15	18	2	83	325
3/228	8	2	15	4	24	55	2	104	325
3/342	9	2	40	23	22	14	1	99	945
3/343	10	2	65	6	16	13	0	95	945
3/350	11	2	58	7	19	12	4	78	945
3/351	12	2	62	8	14	15	1	81	945
54/2	13	2	92	1	3	3	1	111	970
54/23	14	2	75	14	7	3	1	72	970
5/410	15	2	29	11	23	42	5	110	2325
5/411	16	1 + 2	9	5	13	44	29	125	2325
5/415	17	3	13	3	20	38	26	119	2325
5/416	18	1 + 3	8	4	12	47	29	119	2325
5/444	19	2	11	5	28	45	11	76	1850
5/445	20	1 + 2	21	7	34	30	8	72	1850
5/446	21	3	10	5	26	47	12	80	1850
5/447	22	1 + 3	16	5	17	36	26	90	1850

+See text

CONSTRUCTION MEASUREMENTS

The testing undertaken during the construction of the slurry seals was as follows.

MATERIAL PROPERTIES

During the application of each slurry at each site, six samples were taken to record the aggregate grading and bitumen content. This was accomplished by sticking a 300 mm square of grease-proof paper onto the road surface prior to sealing, and then removing the sample after the slurry had cured. The results from the tests showed that the mean grading of three types of seal were within the specified aggregate grading envelopes given in Table 1. The bitumen contents of the different slurries are given in Table 5.

Table 5 Bitumen Content

Type of Slurry	Design (%)	Bitumen Content (%)	
		Mean	Range
1	10.2	8.9	7.9 - 10.2
2	9.0	9.4	6.9 - 13.6
3	7.8	6.9	5.7 - 8.5

CONSISTENCY TEST

The consistency test is a means of measuring the workability of the mixed slurry. All the slurries complied with the specifications described in Tables 2 and 3.

THICKNESS AND CURING TIME

The thickness of the newly laid slurry was measured using a simple mechanical depth gauge. The thickness of the different types of slurry is shown in Table 6. These materials are very fluid when applied hence, when they are laid on a smooth surface such as asphaltic concrete, their thickness is largely controlled by the size of the coarse aggregate in the mix. Although within the specified envelope, the Type 3 slurries were relatively fine, which explains why thicknesses were not significantly greater than the Type 2 slurries.

Table 6 Thickness and Curing Time

Type of Slurry	Thickness (mm)		Curing Time (Hrs)	
	Mean	Range	Mean	Range
1	3.4	3.0-4.3	3.2	2.5-3.9
2	5.4	4.3-6.6	3.7	3.4-6.4
3	6.1	5.0-8.0	4.3	3.4-6.4

One of the disadvantages of the use of slurries in climates of high humidity and frequent rainfall is the length of time taken by the bitumen emulsion in the seal to cure before the road can be reopened to traffic. If heavy rainfall occurs before curing is complete, the slurry surface is damaged and another layer is required to repair it. The curing time recorded during the construction of the slurries was therefore taken as the time from application of the slurry to the reopening of the road to traffic. These results are also shown in Table 6.

The curing time will not only depend on environmental factors such as temperature and humidity but also on the type of bitumen emulsion and the thickness of the applied layer. A similar emulsion, SS1K, was used for all types of slurry, therefore the curing time depended on layer thickness as illustrated in the Table.

CRACK SEALING

The crack intensity prior to the application of the slurry was recorded for each block as described above, and then regular surveys were carried out after construction to measure the effectiveness of the Type 2 slurries in sealing cracks of different intensity. It has been reported previously (Jones, et al 1990) that the early results showed that the rate of reflection cracking was dependent on the initial crack intensity (ICI) prior to sealing. With the completion of the study it is now possible to model this behaviour.

TYPE 2 SLURRY

To model the probability of reflection cracking in a general purpose slurry, the sixteen Type 2 sites described in Table 4 have been used.

The estimates of the effects of the different variables contributing to reflection cracking were assessed by fitting a model using the computer program GLIM (Baker and Nelder, 1978). The assumption in the model is that at some time, T, after the application of the slurry, a number of blocks on the site will have cracked. Only two conditions are possible, either a block has cracked or it remains uncracked. In general linear modelling, this is a binomial error structure. The probability of cracking, P, must lie between 0 and 1 and a graph of P against T is 'S' shaped, where P is dependent on some function of time, traffic, deflection and ICI.

The model that best described the probability of cracking is shown in equation 1. Only two sites had an appreciable number of blocks with ICI 4 therefore the model is confined to those blocks having ICI 1, 2 and 3.

$$P/(1-P) = \exp(K + aT + bD + cTT) \qquad \text{-------------- (1)}$$

where P = Probability of cracking

T = Time in months after sealing

D = Deflection in mm by Road Rater

TT = Total commercial traffic in time T (ADCV x 30 x T)

K = -5.9

a = 0.1

b = 40.6

c = 2.659×10^{-6} (ICI 1)

= 6.197×10^{-6} (ICI 2)

= 6.856×10^{-6} (ICI 3)

$R^2 = 0.88$

The estimate 'c' is variable, as shown above, and depends on the condition of the existing asphalt concrete surfacing in terms of ICI. The accuracy of the model (Equation 1), in terms of the predicted number of blocks cracked at any time compared to the actual number measured during the study, is shown in Figure 1. Figure 2 illustrates the probability of reflection cracking with time for the three categories of ICI and four levels of traffic. In this figure deflection has been held constant at 0.09 mm, the mean value measured at the Type 2 sites during the study period. The figure has been truncated at four months as this was the time by which all the first condition measurements had been completed. Figure 2 shows that the onset of reflection cracking is extremely rapid. At the highest traffic level, 50 per cent of ICI 3 cracks had reflected through the slurry after only four months and 100 per cent after approximately one year. At the lowest intensity of cracking (ICI 1) and traffic level, 50 per cent of the cracking reappeared after 19 months.

Figure 3 compares the probability of reflection cracking for cracks of different categories, traffic volume and deflection being held constant. The results show that the general purpose slurries were more effective in sealing ICI 1 cracks, with ICI 2 and 3 cracks reflecting through the seal at a similar but faster rate.

Table 7 illustrates how the time to cracking is affected by the strength of the road pavement and traffic level for ICI 1 cracking. The time to 50 per cent cracking shows that general purpose slurries are partially successful in sealing minor cracks on roads having low traffic and low pavement deflections. This is an unlikely combination because low traffic roads are not designed and constructed with high structural strengths.

Table 7 Time to cracking - ICI 1

Traffic (ADCV)	Road Rater Deflection (mm)	Time to cracking (months)	
		10% Cracking	50% Cracking
250	0.05 0.09 0.13	13.9 0.3 -	32.3 18.7 5.1
500	0.05 0.09 0.13	11.9 0.2 -	27.7 16.0 4.3
1000	0.05 0.09 0.13	9.3 0.2 -	21.5 12.4 3.4
2000	0.05 0.09 0.13	6.4 0.1 -	14.9 8.6 2.3

PERFORMANCE OF DIFFERENT SEALS

The general purpose slurries were ineffective in sealing cracks in asphaltic concrete surfacings, particularly those having crack intensities of ICI 2 and 3. To investigate the relative performance of Type 3 slurries and also Type 1 overlaid with Types 2 or 3, two sets of experiments were constructed where these alternative seals were applied adjacent to a Type 2 slurry. Both sets of experimental sections were on roads with relatively high and similar traffic flows as shown in Table 4.

The performance of the different seals was also modelled using the GLIM program but, in this case as traffic flows were similar, probability of cracking was dependant on pavement deflection and type of seal, but not on ICI. The probability of cracking 8 months after construction for ICI 2 and 3 and a deflection value of 0.1 mm. is shown in Table 8.

Table 8 Probability of Cracking

MONTHS AFTER CONSTRUCTION	TYPE OF SLURRY			
	2	1 + 2	3	1 + 3
8	0.96	0.90	0.93	0.77

The results show that none of the seals were effective in sealing ICI 2 and 3 cracks in asphaltic concrete surfacings; in general, over 90 per cent of the cracks reflected through the seal after 8 months.

Only the combination of a Type 1 followed by a Type 3 slurry gave any significant improvement in performance over a general purpose slurry but this improvement was small and would not be cost effective.

SKID RESISTANCE CHARACTERISTICS

SKID RESISTANCE

It has been established that, for bituminous surfacings in the UK (Szatkowski and Hosking 1972), the skid resistance, as measured by the Sideways Force Coefficient Routine Investigation Machine (SCRIM), decreases over the first year of trafficking and then remains at a constant value. This value is dependent on the Polished Stone Value of the aggregate and is inversely proportional to the daily flow of commercial vehicles. Similar relationships have been found for both granite and limestone aggregates in Malaysia (Beaven and Tubey 1978) using the Pendulum Tester.

Figure 4 shows the relation between the SRV at 35°C (SRV 35) of the Type 2 slurries and the volume of commercial traffic at the end of the study period. Superimposed on the figure are the SRV 35 values measured on the same sites soon after construction. The results show that the SRV 35 values of the granite aggregate has decreased over the period of the study and that the decrease is related to the flow of commercial vehicles.

A comparison with previous specifications used in the UK (Road Research Laboratory, 1969), based on Pendulum Tester measurements, indicates that the granite aggregates would be suitable for major roads up to traffic levels of 1500 ADCV. However this specification does not consider the risk factors relating to different site conditions (Salt and Szatkowski 1973) and therefore may be conservative. If current research into accident statistics were to show that wet road skidding is a significant contributory factor in road accidents in Malaysia, then the use of a machine such as SCRIM would be an effective method of identifying lengths of road surfacing that needed to be improved and eventually national standards of skid resistance could be established.

TEXTURE DEPTH

It has been shown in the UK (Salt and Szatkowski 1973) that the skid resistance provided by bituminous surfacings changes with the speed of the vehicle and that the rate of change is dependent on the texture depth of the surfacings. That is, the greater the texture depth, the greater the resistance to skidding at higher speeds.

Figure 5 shows the relation between the texture depth of Type 2 slurries and the daily volume of commercial vehicles for free flow traffic conditions, determined at the end of the study. It was not possible to record the texture depth of the AC surfacings prior to sealing but recent research work in Malaysia (Han and Morosiuk, 1991) has determined a typical range of values for different surfacing types. Superimposed on Figure 5 is the envelope of results from 21 AC sites included in their study.

The results indicate that, up to traffic levels of 1500 ADCV, Type 2 slurries do not enhance the texture depth of the original AC surfacing and, at higher traffic flows, the resultant texture depth of the slurry could be less than the original surfacing.

The results also showed that the texture depth of Type 2 slurries was less in areas of slow moving traffic such as sharp bends, long gradients and in built up areas, than in free flow traffic conditions.

CONCLUSIONS

1. The general purpose slurries applied to structurally sound asphaltic concrete surfacings with no rutting or cracking have performed well at low volumes of commercial traffic.

2. General purpose slurries were ineffective in sealing cracks in asphaltic concrete surfacings. The rate at which cracks in the existing asphaltic concrete surfacings reflected through the slurry depended upon the intensity of cracking prior to sealing, the volume of commercial traffic and the pavement deflection. For example, on roads with ADCV levels ranging between 250 and 2000, 50 per cent of minor cracks (ICI 1) in asphaltic concrete surfacings reflected through a general purpose slurry within 9-19 months after construction . Fifty per cent of more serious cracking (ICI 3) reflected through in 4-15 months with an equivalent range of traffic.

3. Type 3 slurries and combinations of slurries were no more effective in sealing cracks (ICI 2 and 3) in asphaltic concrete surfacings at high traffic levels than were general purpose slurries.

4. The decrease in skid resistance (SRV) of the granite aggregates was related to the flow of commercial vehicles. A comparison with UK standards indicates that the material is suitable for surfacing roads with traffic levels up to 1500 ADCV, however further research is recommended to establish national standards for skid resistance.

5. Measurements at the end of the study showed that the texture depths of general purpose slurries were related to the flow of commercial vehicles. For traffic flows up to 1500 ADCV the texture depth provided by the slurry was no greater than that of a typical asphaltic concrete surfacing. At flows greater than 1500 ADCV the texture depth could be less than for an asphaltic concrete surfacing.

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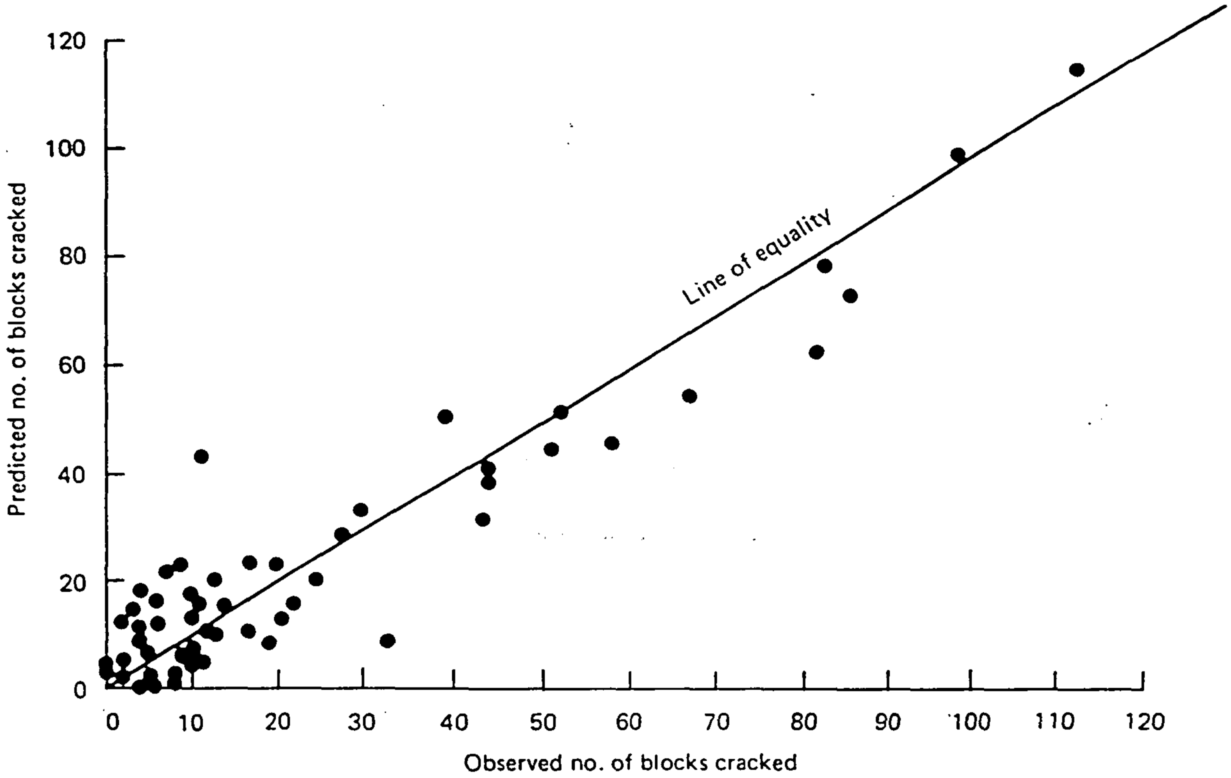

Fig. 1 Predicted vs. observed - Equation 1

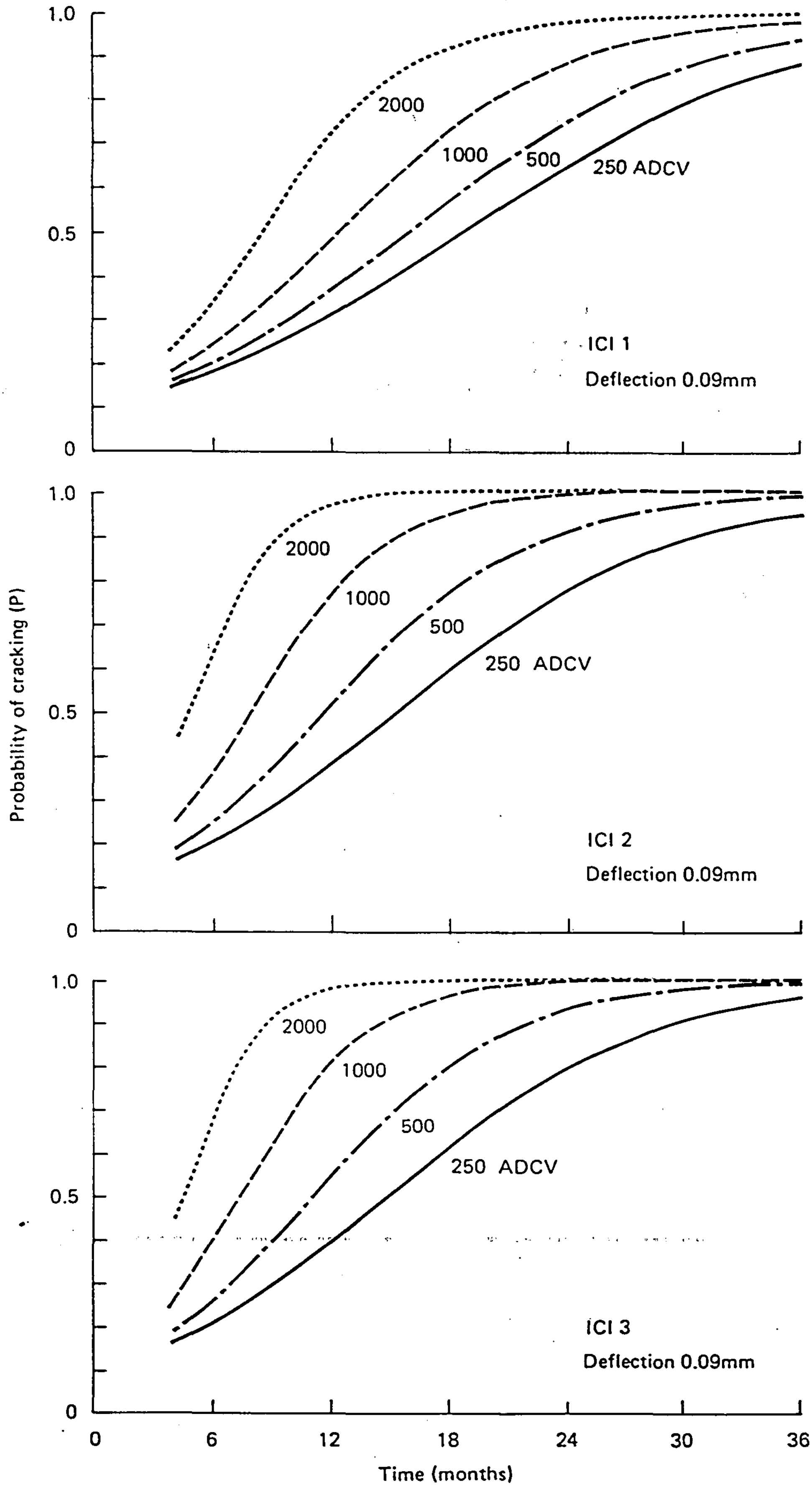

Fig.2 Probability of cracking

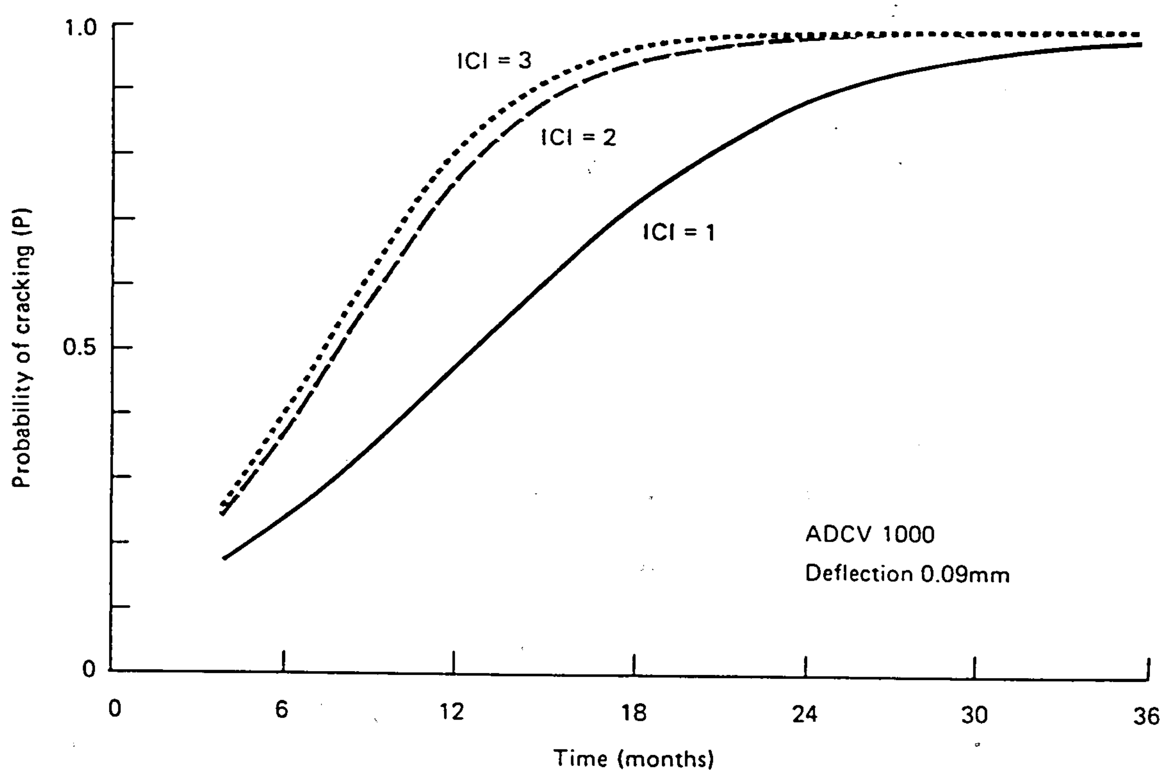

Fig.3 Probability of cracking

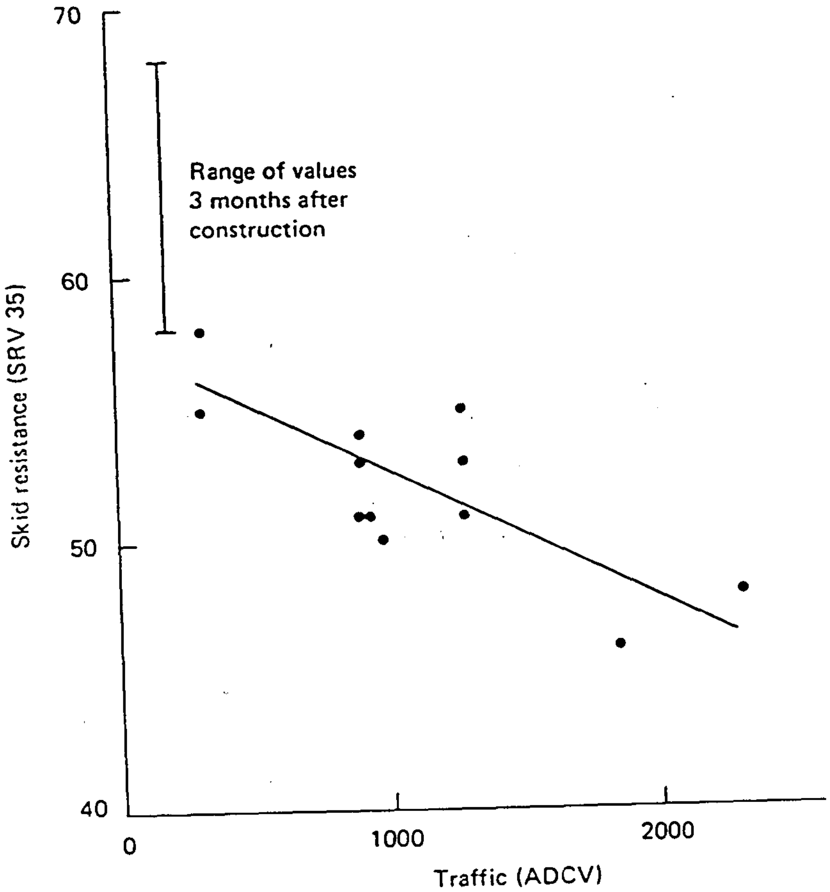

Fig.4 Relation between skid resistance and traffic volume

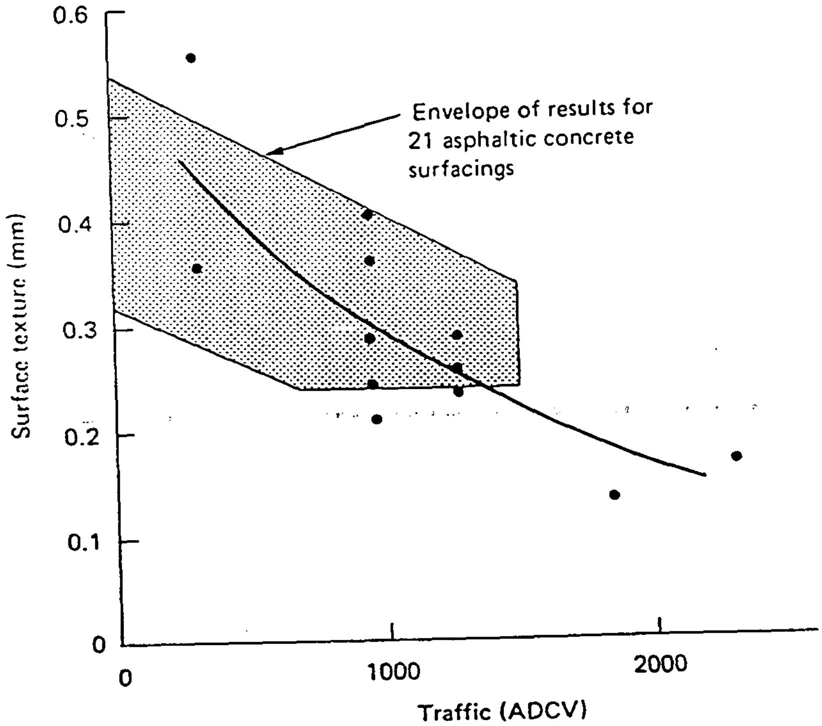

Fig.5 Relation between texture depth and traffic volume