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TITLE Early performance of slurry seals used for paved road maintenance in Malaysia

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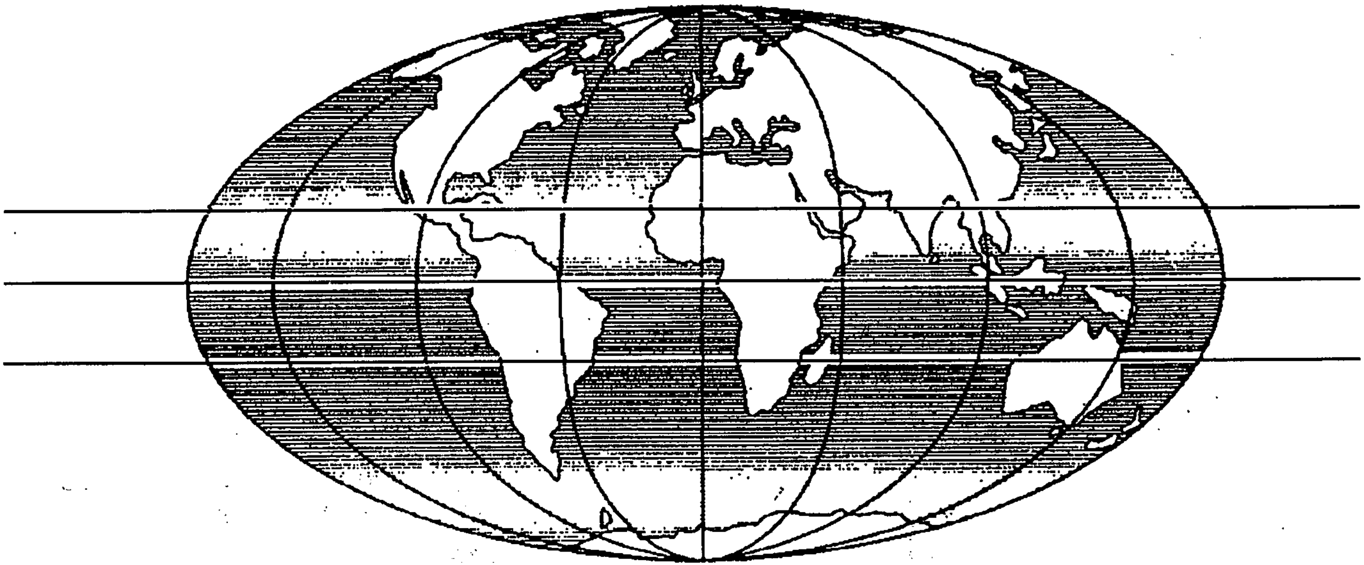

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EARLY PERFORMANCE OF SLURRY SEALS USED FOR PAVED ROAD MAINTENANCE IN MALAYSIA

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ABSTRACT

Following the introduction of slurry seals as a maintenance treatment for paved roads in Malaysia, it was found necessary to produce construction guidelines for their most cost effective use. To do this the Public Works Department embarked on a comprehensive study of the long term performance of different types of slurry seals under a range of pavement conditions and traffic levels. This paper describes the experimental design employed, the construction and the early performance of a general purpose slurry seal.The results show that this type of seal performs well when applied to uncracked asphaltic concrete surfacings but is ineffective in sealing even minor cracking at low traffic levels. The study has also shown that a general purpose seal reduces the rate of environmental ageing in the asphaltic concrete layer below the seal but that the bitumen in the seal itself ages rapidly despite its high bitumen content.

INTRODUCTION

1 A slurry seal is essentially a thin asphalt overlay. It is usually applied to an old surfacing to extend the life of the pavement by sealing the surface and thus preventing water penetration and more extensive pavement failures. A slurry can also improve the subsequent structural performance of the existing asphalt surfacing by decreasing the rate of oxidation of the binder and thereby preserving its fatigue properties. It can also improve the skid resistance properties of the existing surfacing.

2 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 thicknesses ranging from 3 - 11 mm.

3 Although slurries have been used extensively since the early 1960's it is only recently that the technique has been introduced to Malaysia as a potentially more cost effective alternative to the existing maintenance technique of thin asphaltic concrete overlays. The construction technique and guidelines for the use of slurries have been developed in regions of the world where the type and condition of road pavement, rainfall levels, ambient temperatures and humidity are different from those found in Malaysia. To establish the conditions under which slurry seals perform well and to draw up appropriate design guidelines it was therefore

necessary to carry out a research programme to study the performance of different types of slurry on roads having different levels of traffic, a range of surface conditions and a range of pavement strengths.

4 The research falls broadly into two parts. Firstly a study of the effectiveness of the general purpose slurry in sealing cracks of different intensities under varying traffic levels. Secondly a study of the ability of the general purpose seal to retard the oxidation of the binder in the top of the structural layer of the asphaltic concrete immediately beneath the seal.

5 The construction of the slurry seals began in March 1988 and is still underway. At the time of writing, the data available are from the performance study of one type of slurry, namely a general purpose seal.

OBJECTIVES

6 The objectives of the studies were as follows -

Study A -	To determine the effectiveness of Type 2 slurries in sealing cracking in road pavements of different strengths and varying traffic levels.
Study B -	To determine the effect of a Type 2 slurry in reducing the rate of oxidation of the binder of the existing asphaltic concrete surfacing.

SLURRY SEAL SPECIFICATION

7 There are three different types of slurries defined by the International Slurry Seal Association (ISSA). These are described in Table 1.

Table 1. Types of Slurry Seals

Sieve size		Per cent passing		
ins	mm	Type 1	Type 2	Type 3
3/8	9.5	100	100	100
No 4	4.75	100	90-100	70-90
No 8	2.40	90-100	65-90	45-70
No 16	1.18	65-90	45-70	28-50
No 30	0.600	40-60	30-50	19-34
No 50	0.300	25-42	18-30	12-25
No 100	0.150	15-30	10-21	7-18
No 200	0.075	10-20	5-20	5-15
Bitumen content*		10-16	7.5-13.5	6.5-12

* Per cent of dry aggregate

8 Each type of slurry has a particular function and should therefore only be used when the nature and the condition of the existing road pavement and the expected traffic level 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, and the results reported in this paper are confined to this type of seal.

SLURRY SEAL MIX DESIGN

9 The aggregate used in the Type 2 slurries was crushed granite, the filler was Portland cement and the binder was a cationic emulsion SSIK (CSS-1 equivalent). The emulsion had 61 per cent residual bitumen having a mean penetration of 96 at 25 deg C. The mix designs are shown in Table 2 and in Figure 1.

Table 2. Mix Design

Test	Spec.	Locations *	
		1	2
% Cement	-	0.5	0.5
% Emulsion	-	15.0	15.0
% Water	-	15.5	14.0
Consistency %	20-30	25-30	25
Wet Track Abrasion (gm/sq ft)	< 75	23.6	24.0
Sand Equiv. Test %	> 45	68	75

* 1. Bahau/Temerloh, Bahau/Keratong
2. Kuantan-by-pass, Pekan/Kuala Rompin

STUDY A

10 A factorial experimental design was employed in this study, the variables being pavement condition, pavement strength and traffic level.

SITE SELECTION AND LAYOUT

11 Twenty eight one kilometre experimental sites were selected from four lengths of road which were being sealed under an existing contract. These sites covered a wide range of traffic levels, pavement condition and strength (see Table 3).

12 In order to monitor the performance of the one kilometre sites it was found convenient to sub-divide them into 100 blocks, each 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

13 The existing condition of the road was quantified in terms of the characteristics of cracking, the extent and degree of rutting and the deflection of the pavement.

Cracking

14 The type and extent of cracking was recorded for each 10 metre block as follows:

Crack Intensity

0 - No cracks
1 - Single crack
2 - More than one crack - not connected
3 - More than one crack - interconnected
4 - Crocodile cracking
5 - Severe cracking with loose blocks

Crack Width

1 - Crack width < 1 mm
2 - 1 mm < Crack width < 3 mm
3 - Crack width > 3 mm
4 - Cracks with spalling

Extent of Cracking

1 - Total length of cracked area < 1 metre
2 - 1 metre < Total length < 5 metres
3 - Total length > 5 metres

The position of the cracks, whether they were in the wheelpath or across the whole carriageway, was also recorded.

15 Although the extent and severity 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.

16 In tropical climates cracks frequently start at the top of the surfacing (Rolt, Smith and Jones 1986) because of the embrittlement of the binder in the top few millimetres of the layer. 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. If the cracks are not treated they will eventually propagate downwards through the complete layer.

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

18 Cores were taken through cracks appearing in the slurries to determine whether the cracks completely penetrated the surfacing or were confined to the top few millimetres. Analysis of the cores helped to identify the likely causes of the cracks.

Rutting

19 Rutting was measured in the vergeside wheelpath using a 2 metre straight edge and wedge. The maximum value in each 10 metre block was used to categorise the block.

Other Surface Defects

20 Any other surface defects occurring in each block, such as bleeding, potholing, ravelling, patching or slippage were also recorded.

Deflection Measurements

21 Deflection tests were carried out at 40 metre chainages in the vergeside wheelpath using the Road Rater. These deflections were then corrected for an applied load of 2000 lbs (8.9 kN).

Traffic

22 The unidirectional average daily number of commercial vehicles (ADCV) was estimated from 16 hour traffic counts by multiplying by a factor of 1.3, this factor being derived from national 24 hour traffic counts. In this paper medium and heavy goods vehicles and buses are classified as commercial vehicles.

Table 3. Summary of Preconstruction Measurements

Site	Crack Intensity (%)					Rutting		Def. ins. .001	ADCV
	0	1	2	3	4	% (1)	mm (2)		
Bahau/ Keratong									
11/70/U	88	2	0	10	0	0	0	2.26	1141
11/70/D	96	3	0	1	0	0	0	2.21	1141
11/72/U	95	2	0	3	0	0	0	2.33	1141
11/72/D	98	0	0	2	0	2	12	2.21	1141
11/74/U	96	3	0	1	0	0	0	2.59	1141
11/74/D	92	7	0	1	0	5	7	2.37	1141
11/83/U	94	5	0	1	0	0	0	1.97	1141
11/83/D	96	2	0	2	0	6	7	1.84	1141
Bahau/ Temerloh									
10/39/U	89	11	0	0	0	3	6	2.17	1161
10/39/D	69	10	14	2	5	5	29	2.19	1161
10/49/U	79	5	11	2	3	0	0	2.04	364
10/49/D	62	15	10	10	3	0	0	2.26	364
10/52/U	97	0	0	1	2	6	6	2.01	364
10/52/D	83	2	0	8	7	41	8	2.16	364
10/58/U	75	0	1	2	22	1	8	1.92	364
10/58/D	62	1	1	6	30	25	8	1.87	364
Pekan/K. Rompin									
3/226/U	52	13	17	18	0	39	9	3.50	233
3/226/D	58	10	12	17	3	25	10	3.07	233
3/228/U	23	8	20	46	3	64	12	3.87	233
3/228/D*	7	0	27	64	1	63	12	4.86	233
Kuantan by-pass									
3/342/U	30	26	27	16	1	8	7	3.63	1547
3/342/D	53	19	16	12	0	10	8	3.76	1547
3/343/U	57	5	20	18	0	20	9	3.97	1547
3/343/D	76	6	11	7	0	4	7	3.31	1547
3/350/U	56	10	19	11	4	3	6	2.68	1547
3/350/D	61	4	18	13	4	9	7	2.88	1547
3/351/U	60	6	18	14	2	61	9	3.05	1547
3/351/D	65	10	10	15	0	22	8	2.88	1547

* 1 % of area had crack intensity 5

1) Percentage length of site with rut depth exceeding 5 mm.

2) Mean rutting of length of site where rutting exceeded 5 mm.

Skid Resistance

23 Skid resistance tests, using the Pendulum Tester (Road Research Laboratory, 1969), were carried out at 10 test chainages 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.

CONSTRUCTION MEASUREMENTS

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

Consistency Test

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

Thickness

26 The thickness of the newly laid slurry was measured using a simple mechanical depth gauge. The thickness of slurry on the sites ranged from 4.3 to 6.6 mm with a mean of 5.5 mm.

Material Sampling

27 During the construction of each site three bulk samples were taken from the delivery chute to measure binder content and grading. The results of these tests, given in Figure 2, show that the mean grading lies within the specified envelope and that the mean binder content was 9.8%, with a range of 7.8 to 12.1%.

Curing Time

28 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 completed, the slurry surface is damaged and another layer is required for repair.

29 The curing time recorded during the construction of the slurries was therefore the time from application of the slurry to reopening of the road to traffic. The mean curing time for the 28 sites was 3.8 hours with a range of 2.5 to 6.0 hours.

EARLY PERFORMANCE

30 The 28 sites described in Table 3 were constructed between April 1988 and April 1989 and their performance up to September 1989 is discussed in this paper.

Skid Resistance

31 The skid resistance measured soon after construction is shown in Table 4.

Table 4. Skid Resistance after Construction

Location	No. of sites	Months after Construction	Skid Resistance	
			Mean	Range
Bahau/ Keratong	8	4	60	51-65
Bahau/ Temerloh	8	3	58	49-67
Pekan/ Kuala Rompin	4	4	59	54-62
Kuantan By - Pass	8	2	68	65-71

32 The values of skid resistance have been corrected to a standard temperature of 35 deg 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 Type 2 slurry.

$$\text{SRV } 35 = \frac{(100 + t)}{135} . \text{SRV } t$$

t = Temperature at test
SRV t = Measured 'skid resistance' value
SRV 35 = Equivalent 'skid resistance' at 35 deg C

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

33 The mean values of skid resistance soon after construction ranged from 58-68 units, values that would be appropriate for class 1 roads in the UK (Road Research Laboratory, 1969). Monitoring will continue to identify the change in skid resistance with time.

Crack Sealing

34 It is claimed that slurries can fill minor cracking in an asphaltic concrete surfacing thus preventing water penetration and further rapid deterioration.

35 The crack intensity prior to the application of the slurry was recorded for each block, as described above, and then regular surveys carried out after construction to measure the effectiveness of the Type 2 slurry in sealing cracks of different intensities. The results are shown in Figure 3.

36 Figure 3 shows, as a function of time, the percentage of the blocks displaying a given initial level of cracking prior to sealing which have subsequently cracked. For example, at the Bahau/Temerloh sites 62 per cent of those blocks with intensity 2 prior to the slurry had cracked 15 months after resealing.

37 Figure 3 shows that the time to cracking of the slurry is dependent on the intensity of cracking prior to sealing. This implies that the mode of failure is most likely to be reflection cracking in the slurry above cracks in the existing surface. This was confirmed by coring investigations both on the Bahau/Temerloh and Bahau/ Keratong roads. The cores taken from the Bahau/Temerloh sites showed that all cracks that had reflected through the seal were ones that had penetrated the full depth of the underlying surface whereas the cores from the Bahau/Keratong sites showed that 60 per cent of the reflection cracks were above cracks that were confined to the top 30 mm of the old 70 mm thick surface.

38 It might be expected that for any particular width of crack in the existing surface, the time taken to reflect through the new slurry surfacing would depend not only on the crack intensity, as shown in Figure 3, but also on the pavement deflection and traffic level. At present there is insufficient data to verify this hypothesis but early results indicate that this is not the case. Figure 4 compares the rate of cracking for those blocks with intensity 3 prior to sealing for all the four locations. The results show that the rate of increase in the number of cracked blocks does not seem to depend on traffic level despite wide differences between the sites, from 233 to 1661 commercial vehicles per day (Table 3).

39 It might also be expected that the width of the cracks, in addition to their intensity, would affect the rate of propagation through the new slurry. Figure 5 shows the relationship between time to cracking and width of the crack prior to sealing for cracks of intensity 4, at the Bahau/Temerloh sites. The figure shows that it took longer for cracks having width 1 (ie < 1 mm) to propagate through the seal than for wider cracks. However, after 15 months, approximately 95% of all cracks with intensity 4 prior to sealing had reflected through, independent of their width.

40 It can also be seen from Figure 3 that a small percentage of those blocks that had no cracking (intensity 0) before sealing have subsequently cracked. A coring investigation again showed these to be reflection cracks appearing above cracks that have either started in the existing asphaltic surfacing since sealing or were so fine that they were difficult to see and not recorded during the surface condition survey carried out prior to construction.

41 In general the slurry surfacing laid on uncracked blocks has performed adequately for 15 months, with no slipping or loss of aggregate. However, because control sections could not be included at the test sites described in this paper, it is not possible to say at this stage whether the slurry seal has increased the life of the existing road pavement.

STUDY B

42 Work done elsewhere (Dickinson, 1984) has shown that as the bitumen in an asphaltic concrete oxidises with time, its viscosity increases rapidly, making the mix more brittle. The oxidation of the binder is usually more severe in the top few millimetres of the surfacing. Thus treatments, such as slurry seals, that are claimed to retard the rate of oxidation of the binder in the underlying structural layer, could be a means of preventing premature failures due to age hardening.

43 It is important to note here that although the slurry may prevent rapid oxidation of the surface of the asphaltic concrete layer itself, the degradation of the binder in the slurry, and subsequent embrittlement of the seal, may lead to cracking that will eventually propagate downwards through the asphaltic concrete layer.

SITE SELECTION

44 A 600 metre site was selected which had an existing cracked surface of semi-grouted stone prior to overlay. The overlay was a nominal 20 mm asphaltic concrete wearing course material laid to an average thickness of 70 mm. One month after overlay, 300 metres of the site were sealed using a Type 2 slurry having an average thickness of 6 mm. The remaining 300 metres were left unsealed to act as a control section.

SAMPLING AND LABORATORY TESTING

45 Samples of the asphaltic concrete overlay material were taken at the plant to determine the Marshall properties, binder content and grading. These results are summarised in Figure 6.

46 Samples were also obtained from the paver during construction. These were taken at six locations from both the sealed and the control sections at 100 metres chainages in both directions.

47 To monitor the behaviour of the material after construction 100 mm cores were cut from the finished surface at regular intervals of time, the first series of cores being taken immediately prior to the application of the slurry.

48 The cores were placed in an oven at 80 deg. C for 30 minutes and then the slurry surfacing was sliced off with a spatula. The binder from the slurry was recovered using the rotary evaporator and its viscosity measured using a sliding plate microviscometer at a temperature of 45 deg. C and a shear rate of 0.05 per second.

49 After the slurry was sliced off, any remaining fines were removed using a soft wire brush and the last remaining traces of bitumen emulsion removed using a cloth soaked in methylene chloride. The top 3 mm of the asphaltic concrete surfacing was then cut off using a diamond saw and the viscosity of the recovered binder tested as described above.

EARLY RESULTS

50 Results are presently available up to 10 months after the construction of the asphaltic concrete overlay, that is 9 months since the application of the slurry.

Binder hardening in the slurry seal

51 The viscosity of the binder recovered from the slurry is shown in Figure 7. The samples from all six test locations follow a similar trend of rapid ageing to a mean value of 5.73 log poise after 9 months. This increase in viscosity represents a change of penetration value from 71 to 25 (Hasnur, 1990).

Binder hardening in the asphaltic concrete overlay

52 Figure 8 shows how the viscosity of the binder recovered from the top 3 mm of the asphaltic concrete overlay has changed with time for both the control and the sealed sections. In the figure the two directions of traffic have been separated and the tests from 3 points aggregated for the sake of clarity.

53 The results from both directions show similar trends. The 4 mm layer of slurry seal has reduced the rate of hardening of the binder in the top layer of the asphaltic concrete. After sealing, the viscosity of the bitumen in the asphaltic concrete has increased by a factor of between 1.5 and 4.0 during a ten month period whereas the viscosity of the bitumen recovered from the control section has increased by a factor of about 6.5.

54 A comparison of the results obtained by Hasnur (1990) shows that the increase in viscosity of the bitumen in the top of the asphalt layer beneath the slurry seal was very similar to the increase in viscosity observed at a depth of between 4 and 7 mm in an unsealed asphalt surface. In other words the protection afforded by the 4 mm slurry was the same as that of 4 mm of asphaltic concrete.

55 Measurement of the viscosity of binder recovered from the slurry seal itself indicated that the rate of increase was very similar to that of the top 3 mm of the asphalt layer in the control section. Thus, in this example, the ageing of the binder appears to depend only on time and the depth of the bitumen sample below the exposed surface. It does not depend on whether the top surface is asphaltic concrete or slurry seal and therefore seems to be independent of mix properties.

56 It is not known at this stage in the research, whether this result applies to all types of slurry and asphaltic concrete. For asphaltic concrete with higher voids, the rate of ageing is known to be greater and it might be expected that the application of a slurry will have more effect on the ageing of such a mix.

57 The degree of bitumen ageing which can be tolerated before cracking becomes likely depends on the strain level in the bitumen itself and this, in turn, depends on the mix properties and binder content. The tolerable level of ageing in a mix with low binder content will be much less than for a richer mix, assuming nothing else changes, because the strain in the bitumen film will be greater.

58 The most tolerant surface will be a continuous film of bitumen, ie. a surface dressing. Dickinson (1984) has shown that the critical level of viscosity for a surface dressing is approximately 7.5 log Poise, a value which is much greater than the viscosity measured during this study. It is expected that both the slurries and asphaltic concrete surfacings will crack before this level of viscosity is reached. The results of the study will indicate the critical levels for both slurries and asphaltic concrete and should also demonstrate whether slurries are more effective than asphaltic concrete in resisting this form of deterioration.

CONCLUSIONS

59 The mean curing time of nearly four hours restricts the use of these slurries to low traffic roads or to roads where suitable deviations for traffic can be provided.

60 Type 2 slurries applied to structurally sound roads with no rutting or cracking have performed well with no slippage or loss of aggregate.

61 The skid resistance of newly constructed Type 2 slurries was in the range of 58 to 68. This is appropriate for class 1 roads in the UK but suitable specifications for Malaysia have not been derived to date.

62 The Type 2 slurries have been ineffective in sealing cracks in asphaltic concrete surfacings. Almost 100 per cent of those areas of roads displaying crack intensity 4 before sealing have cracked again within 15 months. The slurries have been slightly more effective at sealing the lowest intensity of cracking but almost half of these cracks have also reflected through the slurry within 15 months.

63 The viscosity of binder recovered from a 4 mm thick layer of Type 2 slurry increased by a factor of about 15 in nine months (4.5 to 5.7 log Poise). This increase is similar to that observed in the top 3 mm of an asphaltic concrete control section.

64 The viscosity of binder recovered from the experimental sites depended on time and the depth of the sample below the exposed surface. It did not depend on whether the surface was a slurry seal or asphaltic concrete, implying that mix proportions and binder content are relatively unimportant over the range of values studied.

65 Provided slurries are applied before cracking begins, Type 2 slurries appear to be a more economic method of providing a fresh, crack resistant surface than the alternative of applying a 40 mm asphaltic concrete overlay. However the critical strains at which cracking becomes probable have not been determined for either the slurry seals or for asphaltic concrete. All results are therefore preliminary.

ACKNOWLEDGEMENTS

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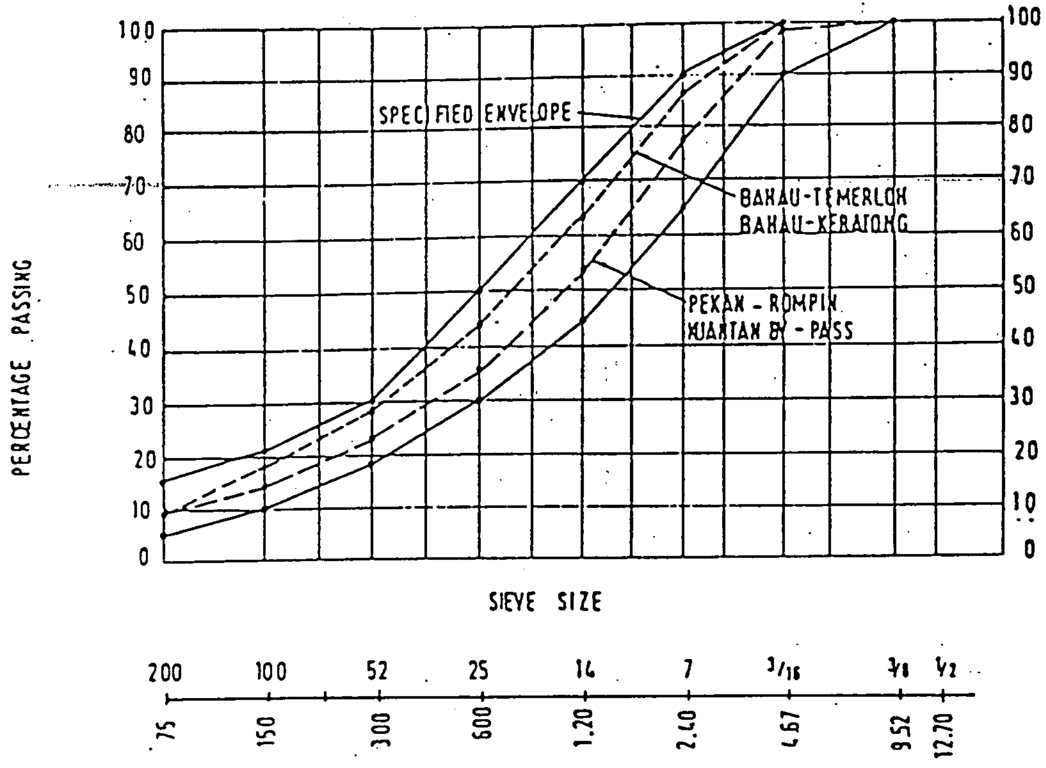

FIGURE 1. MIX DESIGN GRADINGS – TYPE 2 SLURRY

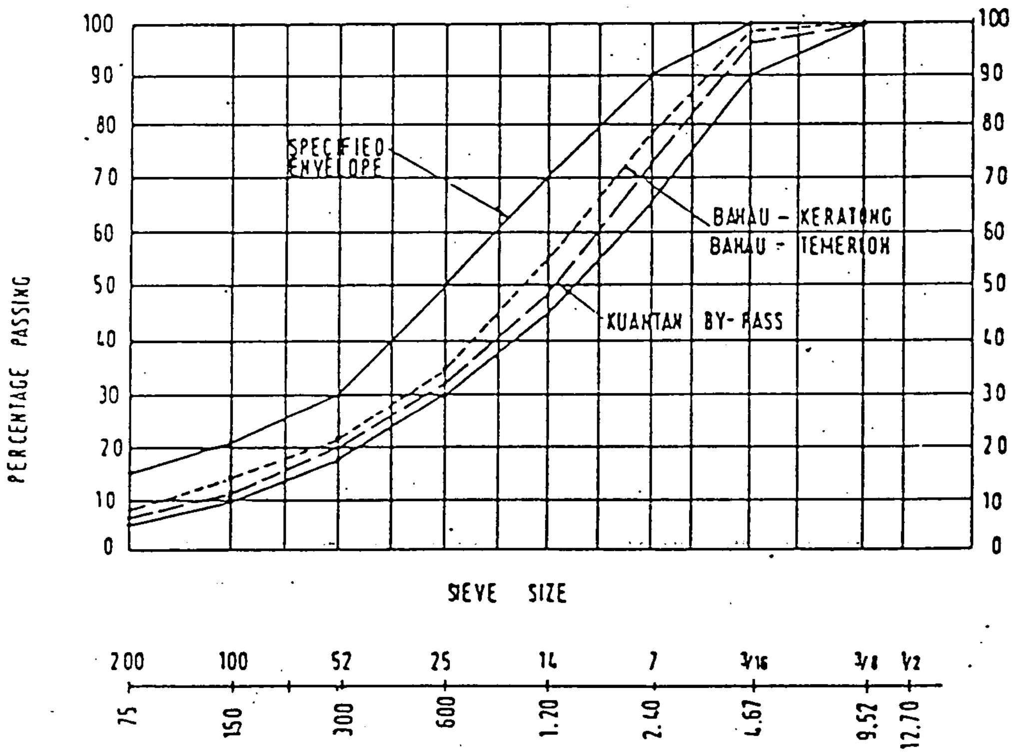

FIGURE 2. MEAN AGGREGATE GRADINGS – TYPE 2 SLURRY

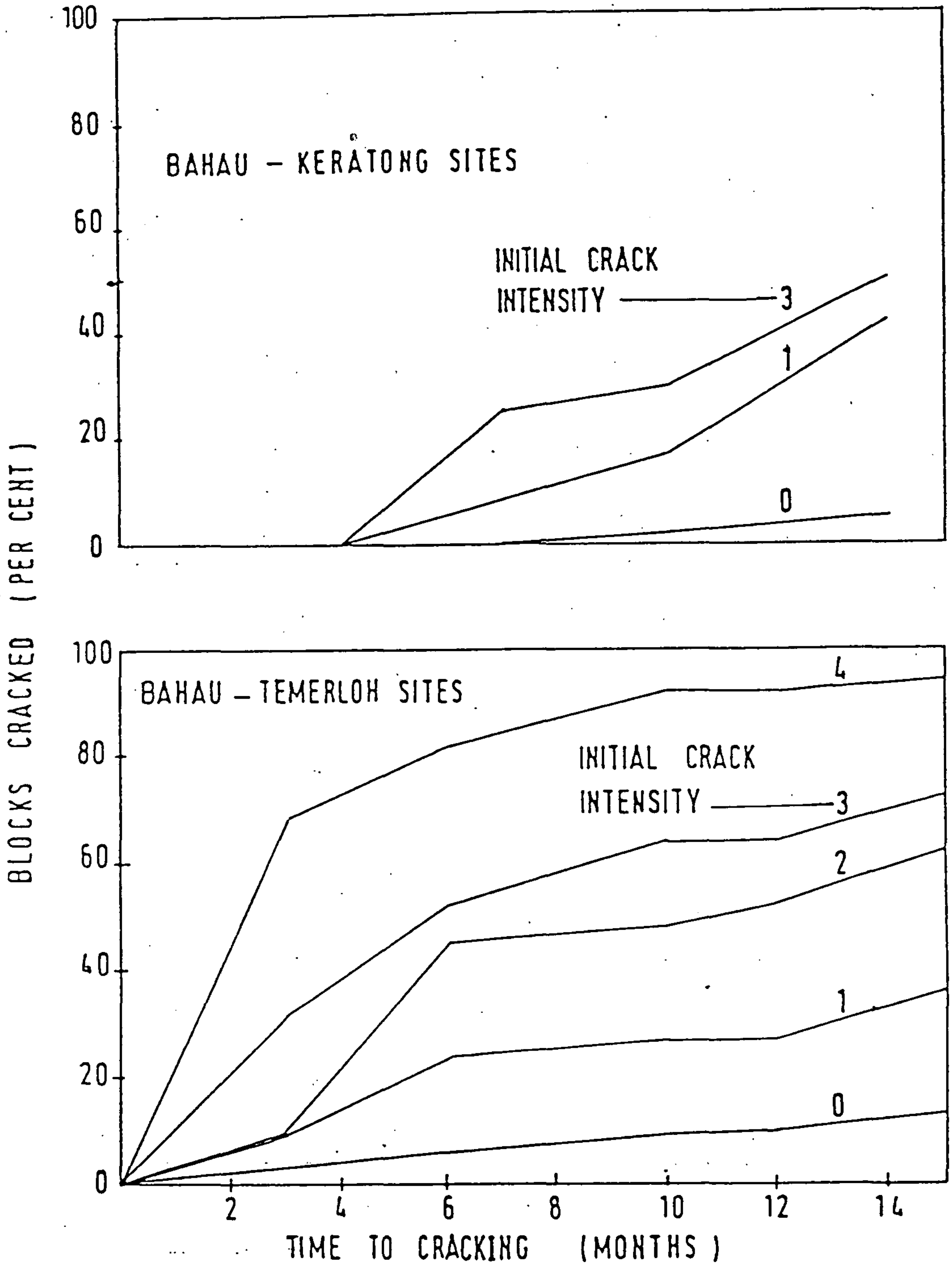

FIGURE 3. RELATION BETWEEN NUMBER OF BLOCKS CRACKED AND TIME TO CRACKING FOR DIFFERENT INITIAL CRACK INTENSITY

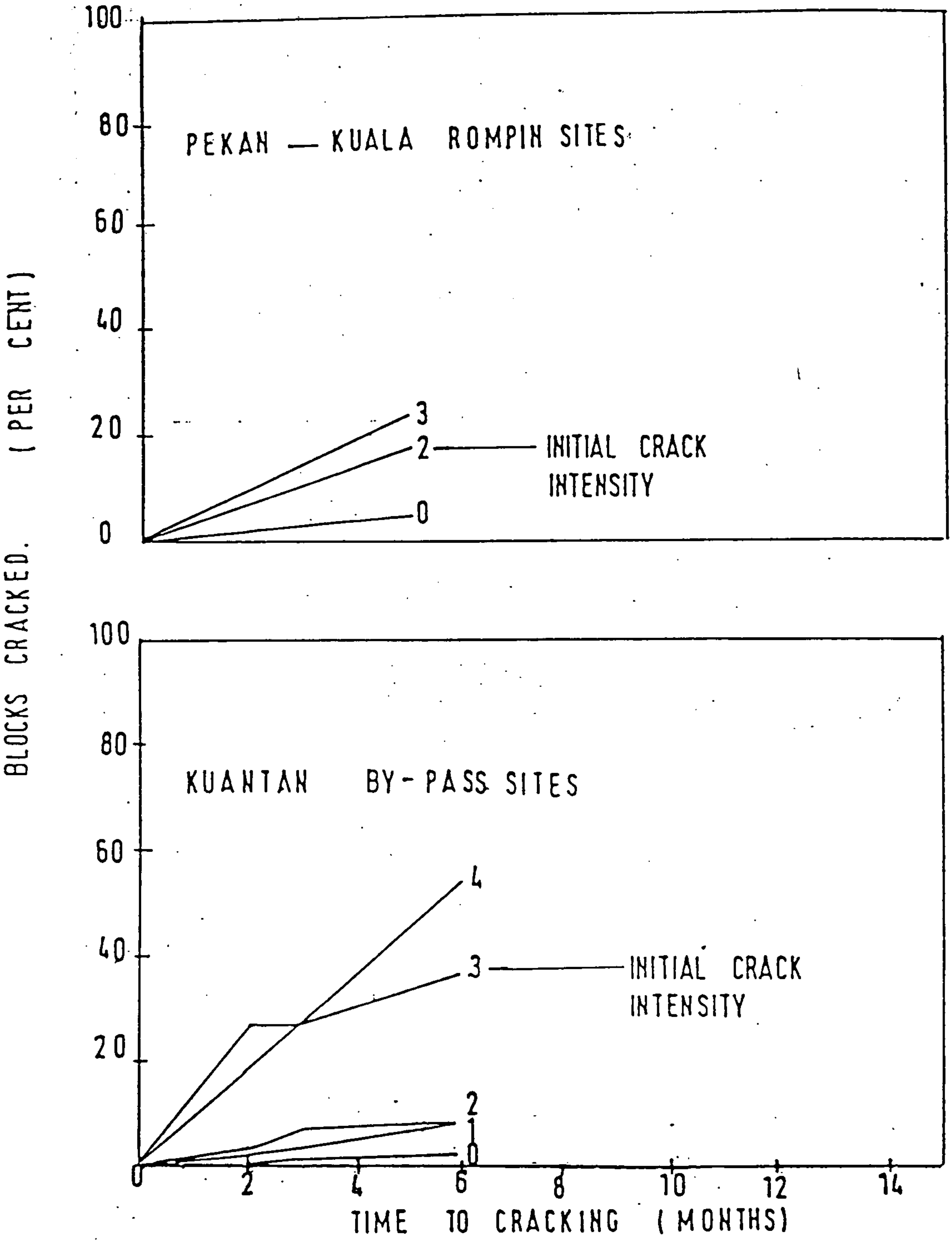

FIGURE 3. CONTINUED

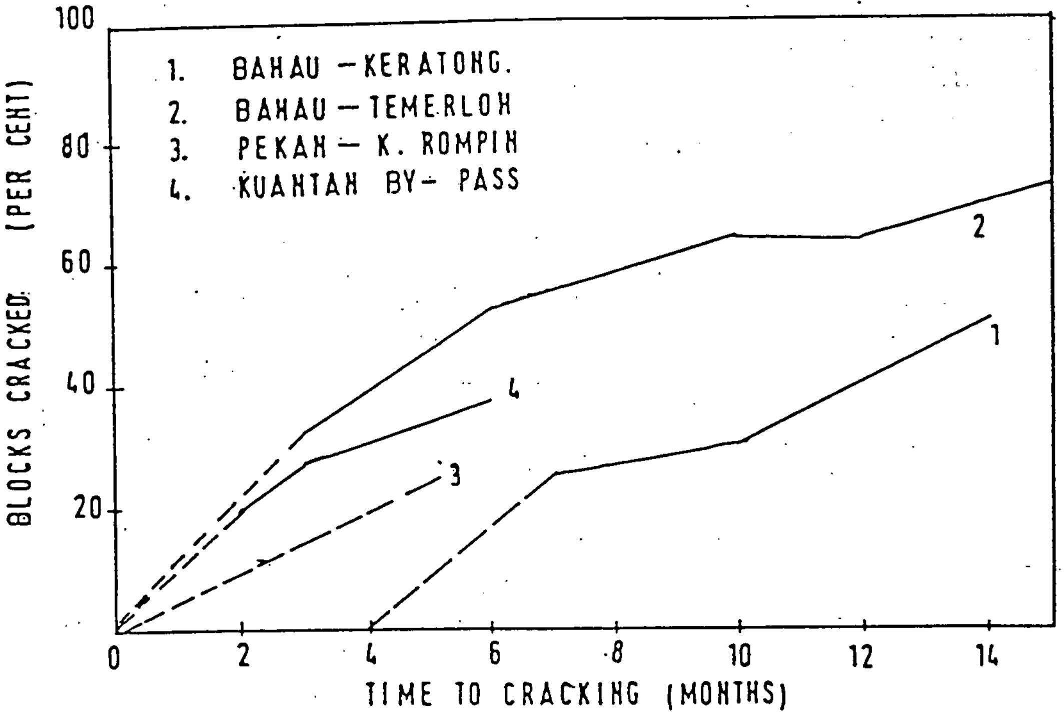

FIGURE 4. RELATION BETWEEN NUMBER OF BLOCKS CRACKED AND TIME TO CRACKING FOR INITIAL CRACK INTENSITY 3

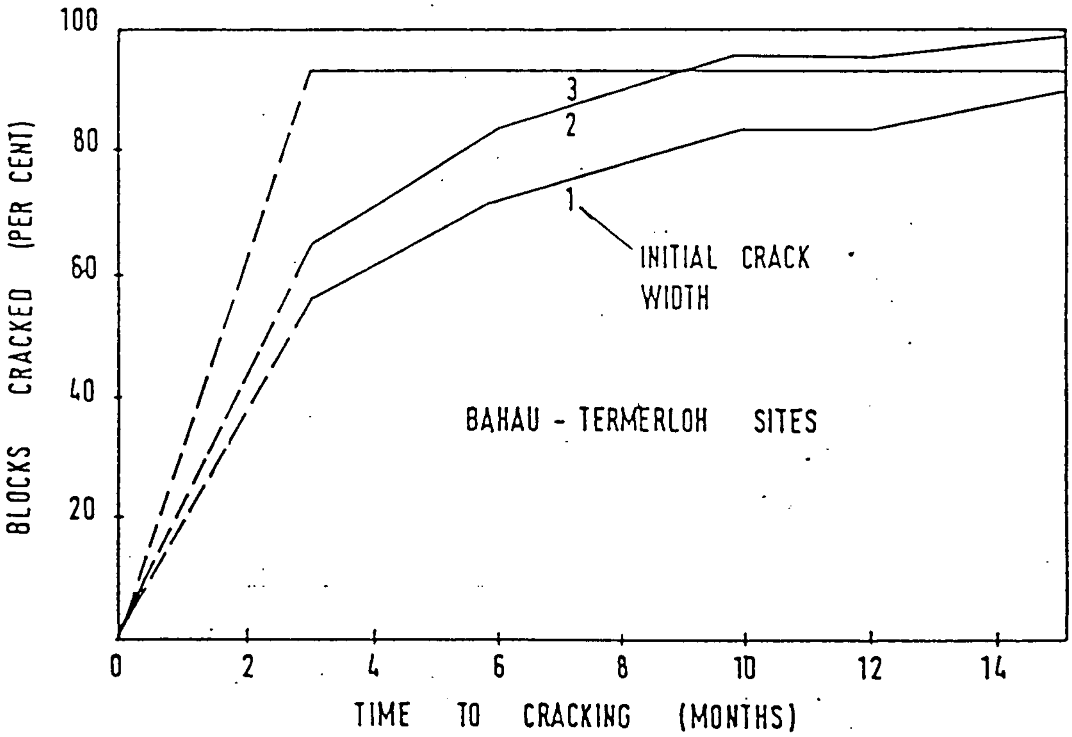

FIGURE 5. RELATION BETWEEN NUMBER OF BLOCKS CRACKED AND TIME TO CRACKING FOR DIFFERENT INITIAL CRACK WIDTHS

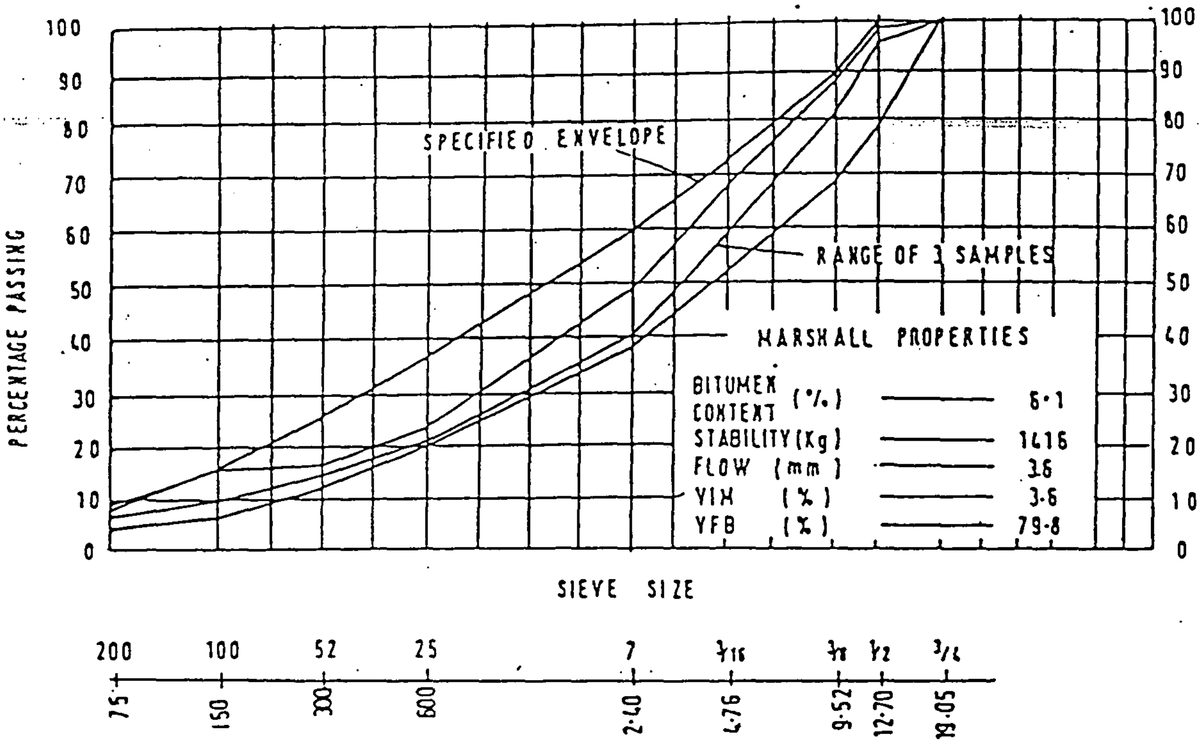

FIGURE 6. MIX PROPERTIES — 20 mm ASPHALTIC CONCRETE WEARING COURSE

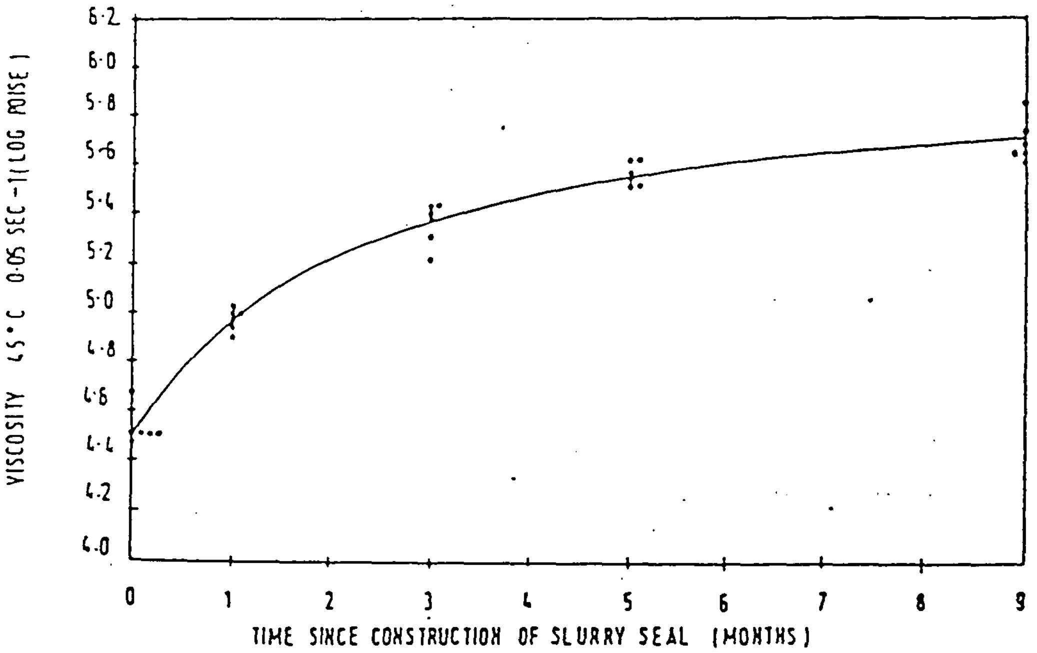

FIGURE 7. RELATION BETWEEN VISCOSITY AND TIME — TYPE 2 SLURRY

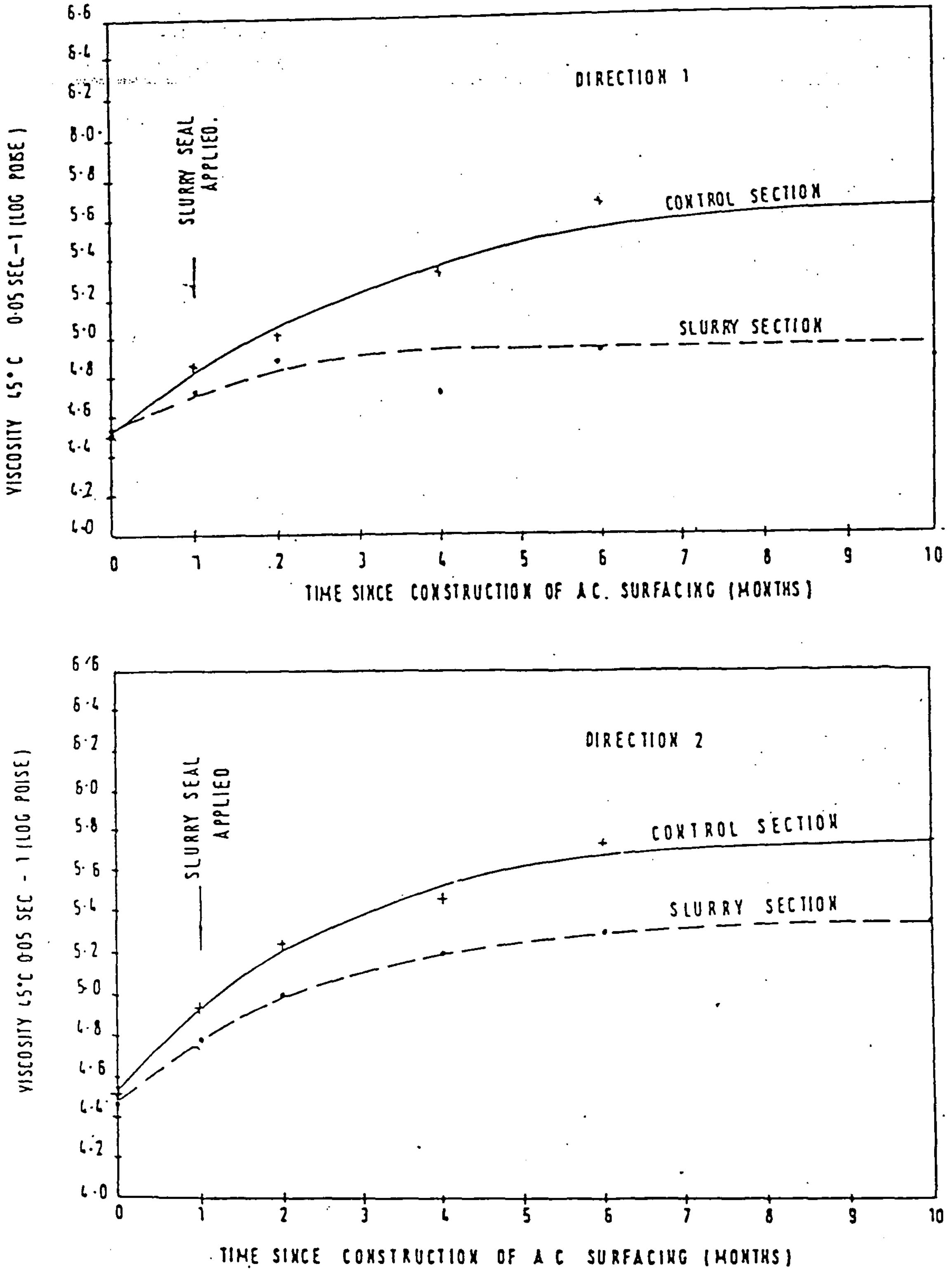

FIGURE 8. RELATION BETWEEN VISCOSITY AND TIME-A C SURFACING.