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PROPERTIES AND BEHAVIOUR OF FOAMED BITUMEN MIXTURES FOR ROAD BUILDING*

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Foamed bitumen is finding increased acceptance in Australia as a means of stabilizing and strengthening marginal quality pavement materials. The paper summarizes the basic requirements for satisfactory performance of road pavement materials, with particular reference to the special requirements for bitumen-stabilized materials.

Development of a laboratory test system to adequately describe pavement materials produced by the incorporation of foamed bitumen was undertaken. This system was based on use of the Hveem stabilometer and aimed at clearly defining the effective range of binder content for significant improvement in the materials' performance. It also provides information to allow assessment of the optimum binder content both for the particular material, and for a given pavement service condition.

Results obtained using this system are given to show the different potential of various types of material used with the foamed bitumen process. The properties of the laboratory mixtures reported on are discussed against the performance of the resulting field mixtures observed to date.

Tentative test criteria are given based on the limited field performance observations available to date.

INTRODUCTION

1. The successful pavement has two basic needs: the ability to spread the effect of transitory and static vertical loads rapidly through the depth of the pavement structure so as to reduce the level of stress in the lower pavement layers, and the ability to survive limited local deflections under wheel loads, and hence strains, over a large number of repetitions without cracking. These two abilities must be maintained throughout the full range of service conditions anticipated for a specific design 'period' and location.

2. For gravel roads the level at which these abilities are maintained is relatively low, since a certain amount of cracking, ravelling, potholing and rutting under isolated critical combinations of the more extreme service conditions can be tolerated due to the low cost of surface maintenance. Once a pavement material is bound with a bituminous product the level at which these two abilities must be maintained becomes critical due to the relatively high cost involved in their repair.

3. In examining a material's ability to meet the two basic requirements, the requirements themselves are commonly considered to be provided for by two properties: interparticle friction and cohesion between particles (Ref. 1). These two properties are complementary to each other and are not generally measured separately. Tests such as CBR and unconfined compressive strength tests measure their combined effect. However, in the case of bituminous mixtures where the cohesion is dependent on the amount and type of bitumen added, a much greater control of this property is possible than with untreated soils. It is therefore logical to attempt to isolate and examine this particular property of 'cohesion' when dealing with bituminous mixtures. The lower types of bituminous mixtures may also be significantly affected in their properties by changes in temperature. Hence this aspect again requires more emphasis when considering tests for bituminous mixes.

4. In foamed bitumen/soil mixtures where only marginal improvement may be sought, the bitumen contents will generally be low. This, combined with the thorough dispersion and the extremely thin uniform films produced by the 'foam' process will tend to maintain, and in the case of the harsher materials improve, the wet cold mixtures' ability to be readily compacted by normal laboratory and field compactive efforts. Standard compactive efforts used in gravel testing can therefore be expected to be satisfactory for preparation of test specimens of these materials.

5. An evaluation system for bitumen-bound soil mixtures for use as pavement materials should then ideally measure the effect of the full range of, or the most detrimental, service temperature/loading condition/moisture content combinations on the compacted mixture's resistance to deformation under vertical load. It should also in particular measure the effect of temperature and moisture changes on 'cohesion' of the compacted mixture as a separate property.

DEVELOPMENT OF TEST PROCEDURES

6. A laboratory test system for the evaluation of foamed bitumen soil mixtures was developed along the above lines. It was aimed at allowing the range of bitumen contents yielding maximum benefits to be defined for any particular soil, and to provide readily obtainable standard test data for correlation with subsequent field performance of the treated materials. An essential part of this aim was to minimize both size of sample required, and, time from receipt of sample to reporting of results. The philosophy adopted was that the first design problem to be solved was that of defining the optimum foam binder content for the several significant mix properties. It was accepted that these optimum mixtures could then be assessed structurally for pavement design purposes by standard commonly used test procedures, which in themselves do not adequately reflect the effect of changes in foam bitumen content on the final service performance of the mixture.

7. Six tests were selected and modified to suit materials produced by the addition of foamed bitumen to soils.

(a) *The 'resistance value' test.* Carried out before and after a 4-day soak at room temperature. This reflects the ability of the material to resist vertical loading without significant lateral strain and is reported on a scale 0 to 100 where 0 represents this property in water, and 100 the performance of steel.

(b) *The relative stability test.* Carried out before and after exposure to moisture vapour at 140°F for 3 days. This measures the same property under more severe temperature and loading conditions and is reported on the same 0 to 100 scale.

(c) *The unconfined compressive strength test.* Carried out before and after a 4-day soak at room temperature (p.s.i.).

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*ACKNOWLEDGEMENT — The author wishes to thank the many associates in Mobil Oil Australia Limited and Stabilisers Australia Limited who helped in carrying out the work and analysis described in this paper.

(d) *The cohesion test.* Carried out before and after exposure to moisture vapour at 140°F for 3 days. This measures resistance to bending and is expressed as the weight of shot in grams required to break a 3 in. high by 1 in. wide specimen in the Hveem cohesiometer.

(e) *The Californian permeability test.* At room temperature. This is expressed in millilitres water lost into or through a 4 in. diameter 1000 gm specimen in 24 hours under 2.5 in. falling head of water.

(f) *The Californian swell test.* Loss of density and hence strength, by change in moisture. Direct free swell measurement in thousandths of an inch in 24 hours at room temperature.

The number of specimens required to establish 4-point curves for all six tests listed, excluding any CBR or Marshall specimens, was reduced to 16 by examining and adopting the principle of re-using specimens after non-failure tests. The whole test series thus requires 40 lb of soil (dry weight) and needs 10 days to carry out in its entirety.

8. A major reason for selecting this particular series of six tests was the ability of the Hveem stabilometer to handle the complete range of materials, ranging from subgrade materials right through to high quality asphalts. It was also considered that the stabilometer represented a realistic 'model' of the actual pavement conditions, by allowing limited deformation or stress development to occur laterally during the vertical loading tests.

9. Modifications to the original Californian test procedures, listed in Appendix 'A', consisted mainly of changing the method of preparation of the test specimens to parallel the construction method used to incorporate foamed bitumen into soils in the field. Specimen mixing and compaction procedure adopted was the same for all soil types and consisted of adding measured quantities of foamed bitumen to accurately batched samples of soil at room temperature and at optimum moisture content for mixing ('fluff point'*). Mixing was completed in a ½ HP Bryce dough mixer and the specimens were compacted in a Hveem kneading compactor at room temperature. The same maximum compactor foot pressure of 350 p.s.i. was used for all specimens. Actual measurement of the particular properties remained essentially as specified in the original California procedures for the tests. Only the condition of the specimens at the time of test was changed by the modifications made, e.g. the 'relative stability' specimen would still contain some water at time of test due to cold wet compaction and partial curing, in contrast to the moisture free specimens produced by the original procedure in which compaction is carried out dry at 140°F.

10. Foamed bitumen mixtures do not develop their full strength until they have lost a large percentage of the mixing water subsequent to compaction. It was therefore necessary to establish some standard accelerated curing system for laboratory use before the selected tests could be carried out. A series of mixtures using varying soil types and various bitumen contents were prepared and check weighed for loss of moisture daily during oven curing at 140°F. It was found that with the specimens in the moulds such curing resulted in a rapid initial drop in moisture content to a moisture level in the range zero to 4 per cent depending on type of soil and bitumen content. After three days this rapid drop had ceased in all cases and the moisture content appeared to have reached an equilibrium state. The actual levels of moisture content, zero to 4 per cent were thought to conveniently represent the fully cured or driest state of such field mixtures likely to be attained in service. This accelerated curing system was adopted as part of the standard specimen preparation procedure.

11. Ref. 2 provides a full record of the final procedures adopted as standard. It also describes the equipment constructed for the detailed examination of 'foam' and for its production on a laboratory scale.

12. In the absence of any field performance correlation data the optimum foamed bitumen content for a particular combination of material and service conditions was selected by considering all of the following factors:

(a) optimum values for specific properties measured,

(b) percentage retention of the individual properties after soaking or exposure to

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*Fluff point is defined as the moisture content at which a given weight of soil yields the greatest loose volume consistent with easy manipulation and was determined by observation of hand mixing incremental quantities of water into a sample of dry soil using a hand trowel.

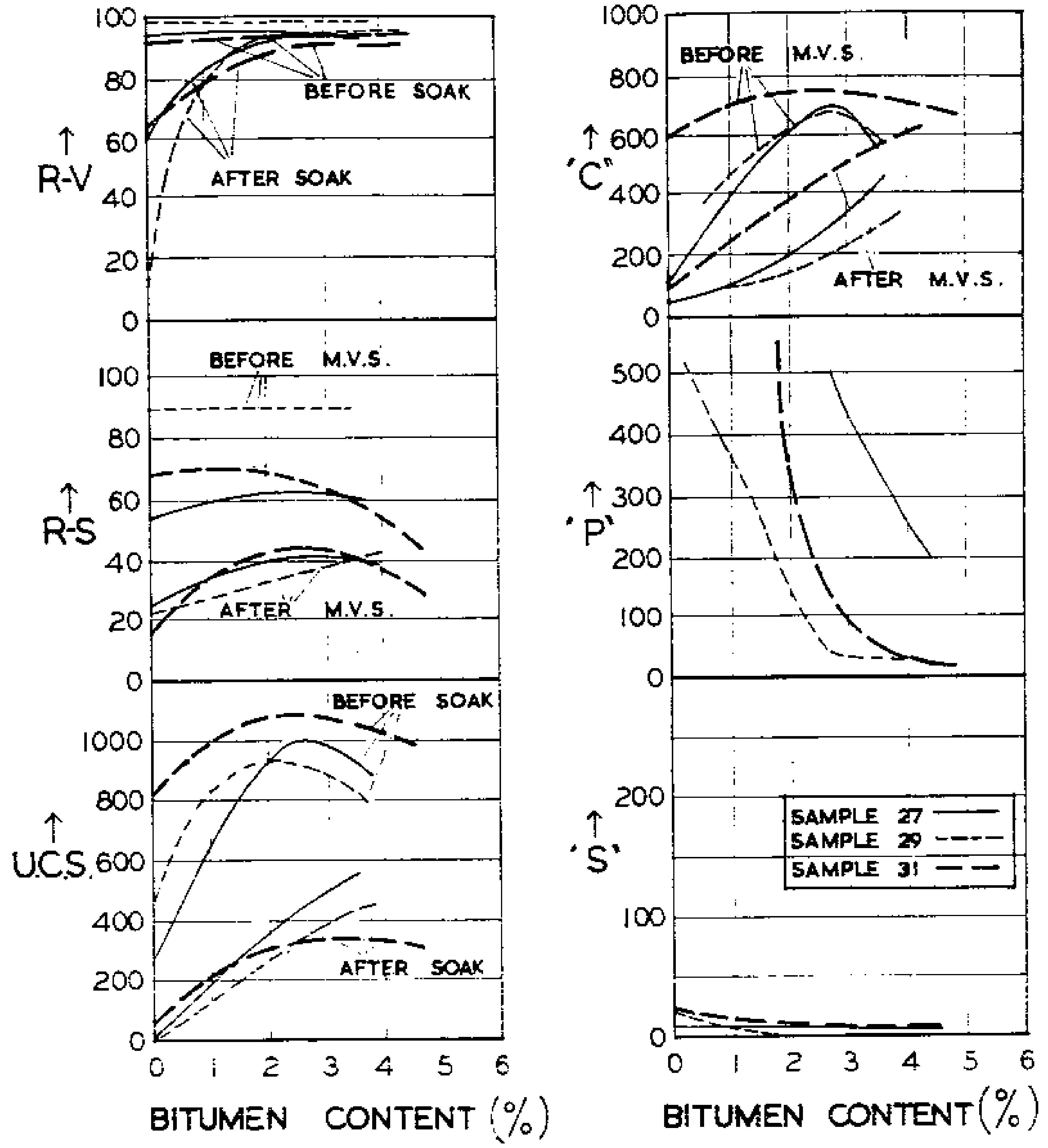

Fig 1 — Properties of second quality crushed materials with foamed bitumen

moisture vapour,

(c) user's structural requirements for the finished compacted mixture,

(d) in-service temperature conditions anticipated for the particular mixture at its actual level below pavement surface, and

(e) degree of permeability acceptable in material's working location.

LABORATORY TEST RESULTS

13. The results shown in *Fig. 1* and *2* are representative of some 22 material evaluations made during 1969 using the procedures discussed in this paper. They display properties of the mixtures obtained when foamed bitumen is incorporated into both strong materials (*Fig. 1*), and weak materials (*Fig. 2*). No figure is shown for the several natural gravels evaluated as these gave results intermediate between the two groups shown, and the graphs obtained followed the same general shape as those shown. Physical properties of the untreated soils, for which results of tests after incorporation of foam are given, are shown in TABLES I and II.

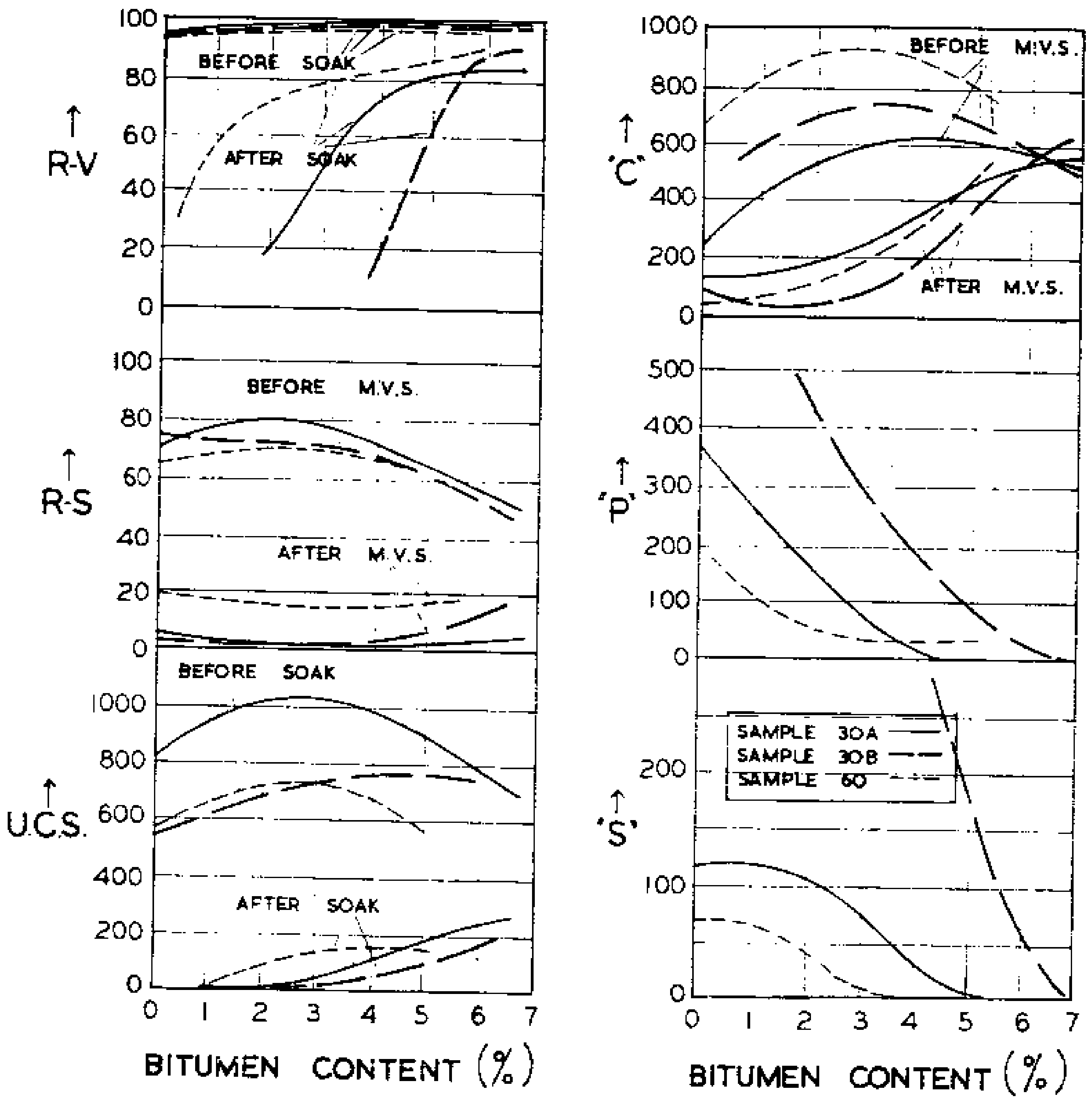

Fig. 2 — Properties of sandy loams with foamed bitumen

TABLE I

PHYSICAL PROPERTIES OF FIGURE 1 MATERIALS

Sample No.	Grading (% Passing BS Sieves)							Atterbergs			'Fluff Pt' Moisture (%)	Hveem Dry Density at 'Fluff Pt' Untreated (p.c.f.)
	3/4	3/8	3/16	7	36	100	200	LL	PL	PI		
27	100	70	46	36	13	7	4	19.6	15.6	4.0	4.8	131
29	100	74	50	37	16	7	4	20.0	18.0	2.0	5.2	129
31	100	78	54	38	20	13	8	29.5	16.5	13.0	4.3	130

14. *Fig. 1* and TABLE I show the effect of the addition of foamed bitumen to three second quality crusher products.

Sample 27 is a 'B' grade crushed dacite of low plasticity and lacking in fines.

Sample 29 is a quartzite quarry rubble of low plasticity and lacking in fines.

Sample 31 is a crushed breccia roadbase of medium plasticity.

15. The results for this type of material show a *rapid* increase in stability against soaking (R value curves) as the bitumen content is increased. The material becomes fully stabilized in this respect at low percentages of bitumen (1½ per cent to 2½ per cent by weight of dry soil). Relative stability in the cured state is not greatly influenced by the addition of bitumen until the bitumen content becomes so great that it begins to lubricate instead of bind the mix at the high test temperature. This drop-off begins to show at binder contents of 3½ to 4 per cent for this type of mixture, but some 6 per cent would be needed to reduce the result to 30 (the level accepted for hot mixes under the original procedure). At the 3½ to 4 per cent bitumen level the ability of the material to retain its relative stability after attack by moisture vapour at 140°F has been considerably improved. This is considered more significant than the slight drop shown in the cured specimen relative stability. The unconfined compressive strength results again reflect the marked increase in stability against weakening by water obtained with this type of soil at low bitumen contents. Cohesion for this group increases significantly at low bitumen percentages (1 to 3 per cent), with increased resistance to loss of cohesion on exposure to water vapour occurring at the same time. Swell is not a problem with this type of material. Addition of foamed bitumen rapidly decreases the permeability of these materials. Those

TABLE II

PHYSICAL PROPERTIES OF FIGURE 2 MATERIALS

Sample No.	Grading (% Passing BS Sieves)			Atterbergs			'Fluff Pt' Moisture (%)	Hveem Dry Density at 'Fluff Pt' Untreated (p.c.f.)
	7	36	200	LL	PL	PI		
30A	100	71	31	20	9	11	5.1	126
30B	100	81	39	16	9	7	4.6	124
60	100	67	28		Est.	4	8.2	117

shown have their permeability reduced to almost zero by the addition of 3 to 5 per cent bitumen. It is considered from the results that normal adequate strength and performance for use in road pavements would be obtainable from this type of material without making an impermeable mix and that the bitumen content necessary to protect such a material against the effect of water, and water vapour, at normal pavement service temperatures will lie in the range 1½ to 3½ per cent. Mixtures of this type have shown increases in soaked CBR values from 30 to 50 untreated to 80 to 100 treated.

MECHANICALLY WEAK SOILS

16. Table II and *Fig. 2* describe three sandy loams and the effect on their physical properties of the addition of foamed bitumen. As seen with the crushed materials in *Fig. 1*, the same basic patterns occur for each of the materials within this group. The patterns themselves however differ considerably from those shown in *Fig. 1*.

17. The R value curve after soaking shows a much greater sensitivity to grading for these high fines (−200) content materials, even at the low plasticity index recorded. There appears to be a definite amount of bitumen, varying widely with actual particle size distribution, below which no benefit is measurable by this test procedure. Once this amount is exceeded however the increase in R value (after soak) is marked and rapid. Stabilization of the resistance value against the effect of soaking is only achieved for this material group at bitumen contents in the 4 to 6 per cent range. This lack of measurable effect, after exposure to water or water vapour, until a certain bitumen content is reached, is also reflected in the relative stability, unconfined compressive strength and cohesion curves. The increase in level of these properties retained under adverse test conditions is slower and less marked than was shown with the crushed material. The addition of some 4 to 6 per cent bitumen is needed to give minimal values under adverse test conditions. Permeability is significant in this group because of these low results and because of the high swells recorded. The very low figures recorded for relative stability after moisture vapour susceptibility check would only be considered significant in the extreme service situation of high temperature, high water-table, heavy loading, where the mixture was located at the very top of the pavement, i.e. directly under the seal. This is a very severe test and may prove excessively stringent for general basecourse evaluation.

18. A similar series of test results for fine non-plastic sands again emphasized the importance of grading especially the grading of the −200 mesh material. Please and Mayer (Ref. 3) concluded that stability of coated gravel base courses was sensitive to content of fines (−⅛ in.), petrological nature of aggregate and viscosity of binder but not significantly to particle shape. The relative importance of grading, petrology and shape of the fine particles in foamed mixtures has not yet been determined. However, the results obtained to date confirm that the overall 'type' of fines does significantly affect the quality and strength of the finished mixture, especially in the finer gravel (−⅜ in.) and sand-sized materials.

19. For fine non-plastic sands, results for the various properties after soaking, or attack by moisture vapour are frequently higher than for the dry-cured specimens. This is believed to be a function of time rather than the effect of the water or vapour, since in the test procedures the dry-cured specimens are tested 3 or 4 days before the soaked or moisture vapour attacked specimens. A second peculiarity of the fine non-plastic sand group is the extremely poor relative stability results. These specimens are frequently too soft to handle, or so soft at the time of carrying out the test that it is impossible to achieve a valid stabilometer reading. Nevertheless, Table III shows that high, soaked CBR values can be achieved from these mixes.

GENERAL

20. From the results obtained and displayed it is apparent that the relative stability test, as currently described in this paper, is too severe for the lower types of mix being produced, and may need modification to the procedure to bring the actual strengths up to a more usable position on the scale. Possible modifications would consist of reducing the vertical stress used during this measurement or partial curing before compaction to allow use of full 350 p.s.i. compactor foot pressure for all mixes. The other tests have yielded data through the area of practical interest (0 to 6 per cent bitumen) of convenient magnitude and variation for display and interpretation. The 'fluff point' concept, used to establish mixing water content, has proved only partially successful with some soils in that, although allowing good initial dispersion to be achieved too little, total fluids may result thus preventing both completion of mixing and also adequate compaction.

LABORATORY CALIFORNIA BEARING RATIO VALUES

21. Tables III and IV summarize CBR data obtained on some sand/foamed bitumen mixtures designed, as described in this paper. The results fall in the 50 to 100+ range when full dispersion and mixing has been achieved. Such mixes have been used in sealed pavements. Table IV shows up the need for proper foaming and mixing water content with these weak sands. Where both dispersion and mixing have been fully achieved 50 to 80 soaked CBR was recorded. For the same materials, with improper foam and inadequate mixing water, only partial mixing was achieved. Although the bitumen was finely divided and quite well dispersed in this case, the characteristic uniform, thin films were not developed. The soaked CBR values recorded for these mixtures were only 1.5 to 6.0 per cent, i.e. less than the estimated untreated sand CBR of 11.0. The very low dry densities suggest that the small particles of bitumen have in fact prevented full compaction and, without the full thin films, the sand is acting simply as poorly compacted untreated sand. This again confirms the observations made during preparation of mixes that the 'fluff point' concept for mixing water content is not completely adequate. Consideration needs to be given to addition of 'post dispersion' stage water, still possibly within the mixing cycle. This refers only to certain types of fine materials where the 'fluff point' moisture content is in fact *far* below the optimum moisture content for compaction.

22. The importance of mixing water content when incorporating foamed bitumen into sands was stressed by Anderson, Haas and La Plant in their work on comparison of bitumen/sand mix properties for mixes produced by different methods (Ref. 4).

TABLE III

LABORATORY CBR VALUES ON LABORATORY MIXES

Non-plastic Fine Sands

Sample No.	Mix Data		Compaction Data			Cured out CBR Values			Moisture at Test		
	Bitumen 90 pen. (%)	Water (%)	Standard	MC (%)	Dry Density (p.c.f.)	MC (%)	Top (%)	Bottom (%)	Top (%)	Middle (%)	Bottom (%)
49F	3.1	9.1	Mod. A.A.S.H.O.	9.1	118	3.9	58	—	3.6	—	7.4
49C	3.0	6.7	Mod. A.A.S.H.O.	6.7	127	2.4	138	—	1.8	—	4.9
70	3.2	10.7	Mod. A.A.S.H.O.	11.2	111	0.4	85	—	1.0	—	3.0
71	3.2	10.7	Mod. A.A.S.H.O.	10.9	113	0.4	56	—	1.0	—	1.0

Specimens cured (49) 6 days, (70/71) 5 days, in oven at 140°F and cooled to room temperature before standard 4-day soak

TABLE IV

LABORATORY CBR VALUES FROM LABORATORY MIXES

Fine Plastic Sand

Sample No.	Mix Data		Compaction Data			Curing Data (before soak)		CBR			Moisture at Test		
	Bitumen 90 pen. (%)	Water (%)	Standard	MC (%)	Dry Density (p.c.f.)	140°F	Room Temp.	Top (%)	Bottom (%)	Swell (%)	Top (%)	Middle (%)	Bottom (%)
1104	4.0	8.6*	A.A.S.H.O.	7.7	114.6	3	1	80	100+	0.9	9.3	1.8	11.4
	4.0	8.6*	A.A.S.H.O.	7.7	112.3	1	1	50	50	1.0	11.9	4.7	10.6
	4.0	5.9†	A.A.S.H.O.	4.5	103.8	1	1	6.0	4.5	2.3	19.1	16.8	19.1
	4.0	5.9†	A.A.S.H.O.	4.7	104.1	3	1	6.0	3.5	3.4	17.7	18.2	20.2
	2.1	5.1†	A.A.S.H.O.	4.1	102.0	1	1	2.0	1.5	2.1	23.5	19.3	21.3
	2.1	5.1†	A.A.S.H.O.	4.2	102.6	3	1	2.0	1.5	3.2	18.4	20.0	25.3

* Good stable foam thoroughly dispersed yielding uniform colour mix with no segregation of bitumen.
† Mixes showed segregation of bitumen from sand. Inadequate foaming action resulting in partial dispersion without the characteristic thin uniform coating of the particles. Aggravated by low mixing water content.
All specimens cured 3 days in oven at 140°F and cooled to room temperature before standard 4-day soak. Compacted to 100 per cent modified A.A.S.H.O.

Acknowledgement. The author wishes to thank the Commissioner of Highways, South Australia for permission to reproduce the data used in TABLE IV.

TABLE V

LABORATORY CBR VALUES ON LABORATORY MIXES

Crusher Waste

Sample No.	Bitumen Content	Compaction Data		CBR Values		Moisture at Test		
	90 pen. (%)	MC (%)	Dry Density (p.c.f.)	Top (%)	Bottom (%)	Top (%)	Middle (%)	Bottom (%)
29	1.4	7.0	136	54	88		4.4 overall	
	1.5	6.0	139	83	137	5.1	4.0	3.7
	2.0	5.8	137.5	74	154	5.3	3.7	3.9
	2.0	6.0	137.5	108	164	5.3	3.8	3.1
	3.0	5.2	138	63	144	4.6	3.5	2.6
	3.0	5.9	136.6	82	130	4.0	1.7	2.5

23. TABLE V gives CBR results for one of the materials shown in *Fig. 1* (sample 29). The critical area around 1.5 per cent bitumen content, shown on the R-value graph is reflected in the CBR values obtained. The variance in CBR values at top and bottom of specimens is attributed to variations in finishing off the compacted specimens upper surfaces rather than the small differences in moisture content at test. Estimated soaked CBR for the untreated material was 35, and the strength gain measured 35 to 100+, is typical of the *Fig. 1* mixtures.

BEHAVIOUR OF FIELD MIXTURES

24. The triple rotor P.&H. in situ mixer has generally produced mixes superior to those produced in the Laboratory dough mixer. These mixes handle as though the soil had been merely wetted, i.e. cleanly, without packing or dragging on the metal working surfaces. Workability is good and compaction is a once only operation. Compaction has been carried out as soon after mixing as possible, to avoid further drying out of a mixture which may already be below normal fluid requirements for optimum compaction. Where such drying out has occurred, further amounts of water have been successfully added to aid compaction up to 24 hours after mixing. Compaction equipment used has included steel wheel 10-ton rollers; towed single drum vibrating rollers of 7-ton dead weight; and multi-wheel rubber-tyred rollers from 10-ton to 28-ton all up weight with tyre pressures from 50 p.s.i. to 90 p.s.i. Of these types the multi-tyre roller has proved most effective especially with the more tender sand mixes where the ability to start with low tyre pressures and progressively increase them has been useful. Two or three passes of the towed vibrating roller with vibration has proved to be the limit on sand mixes before loosening of the top 2 to 3 in. occurs.

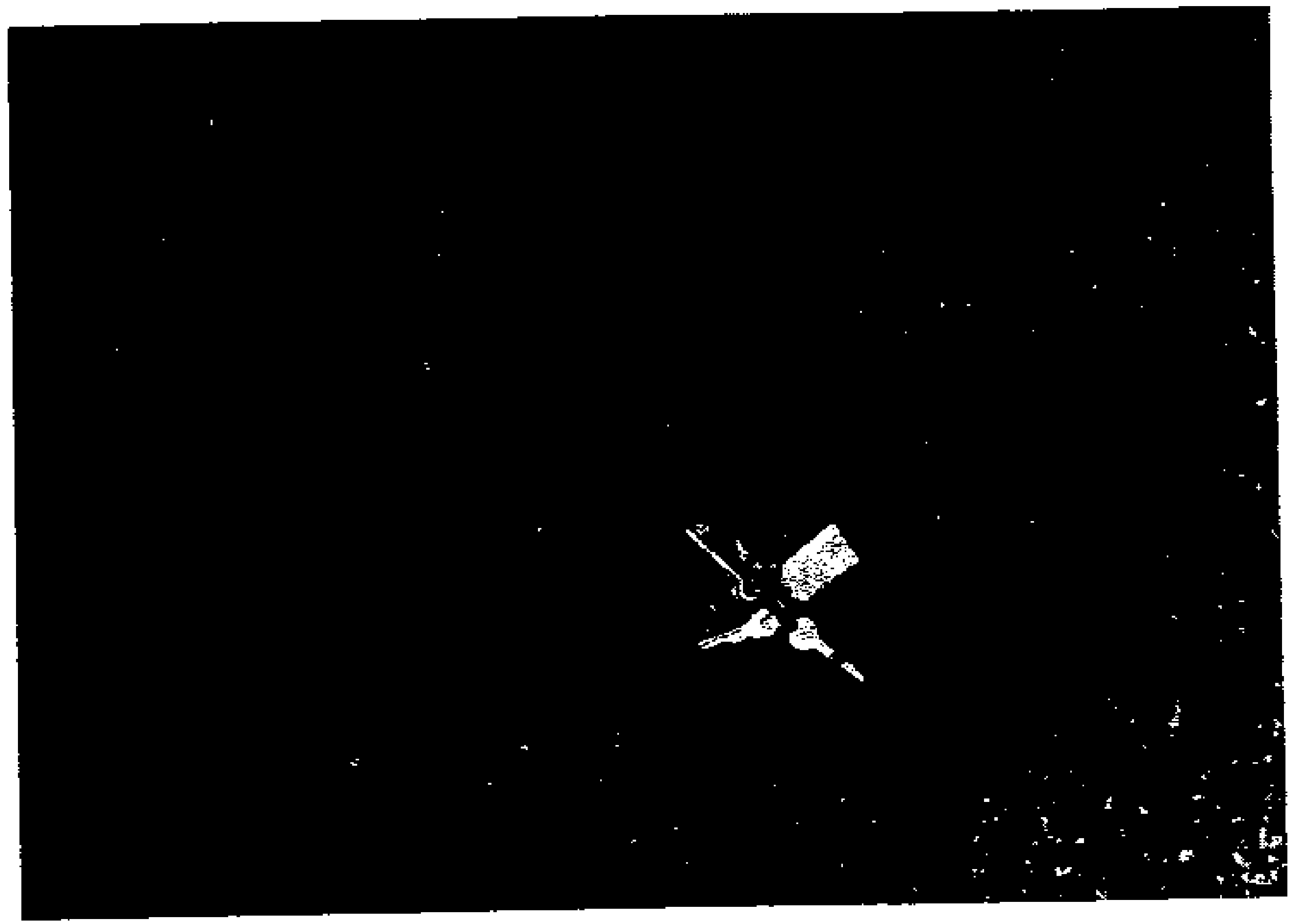

Fig. 3 — 3½ per cent foamed bitumen in 'A' grade FCR at 1 week (detail)

Fig. 4 — 3½ per cent foamed bitumen in 'A' grade FCR at 1 week (general)

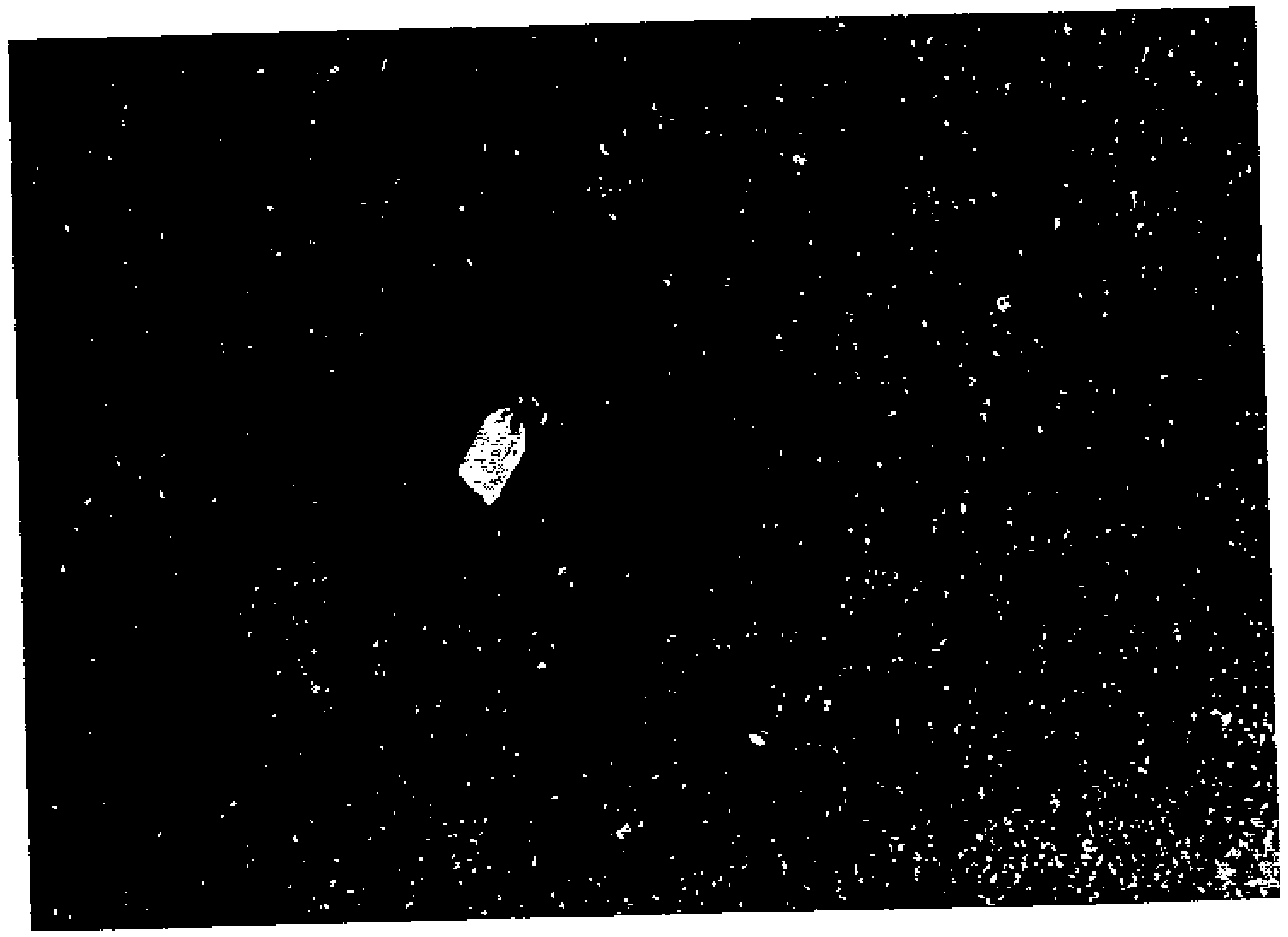

Fig. 5 — 5½ per cent foamed bitumen in bauxite sand mix at 3 days (detail)

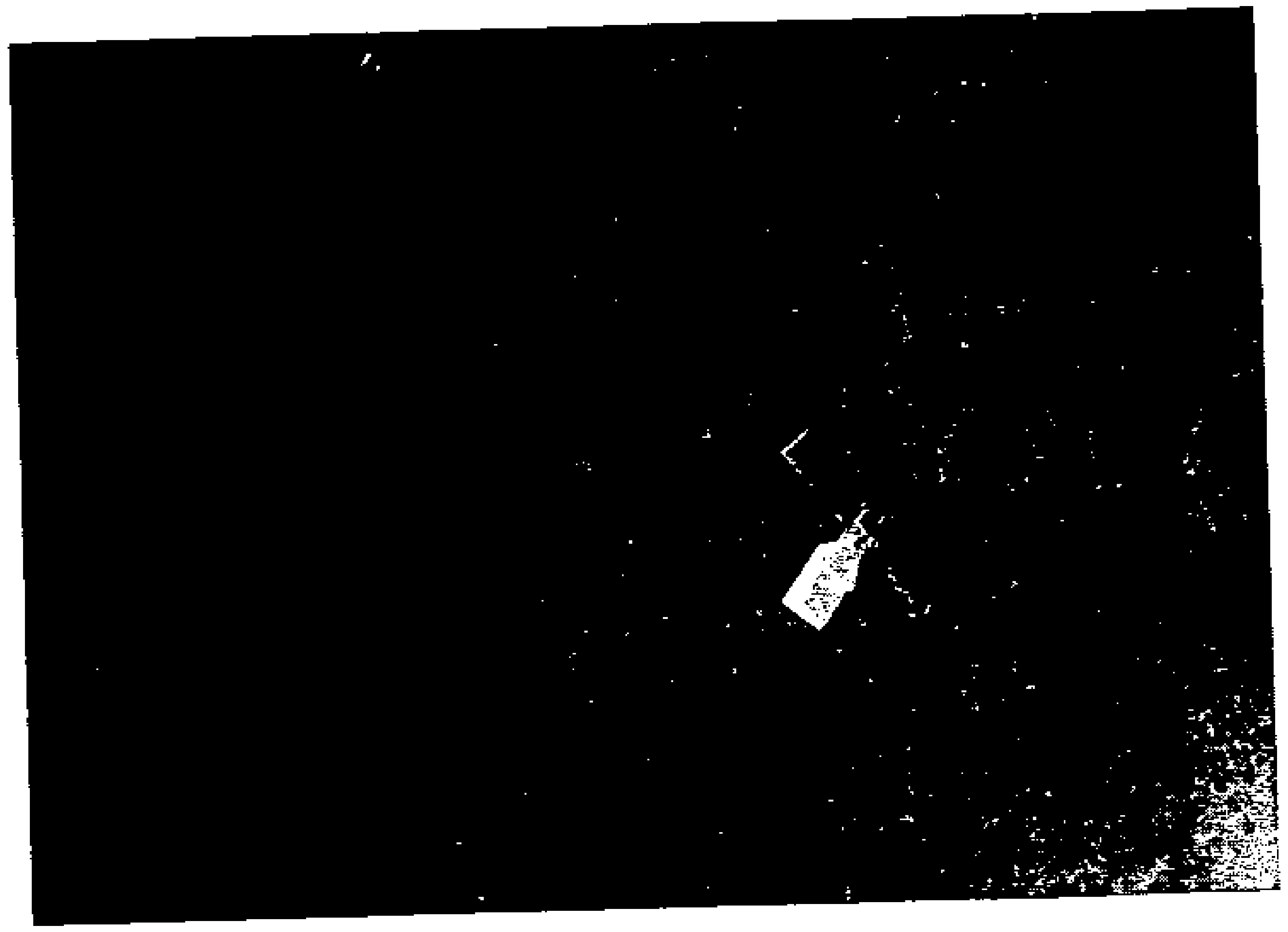

Fig. 6 — 6 per cent foamed bitumen in dune sand mix at 24 hours (detail)

25. *Fig. 3* and *4* show a 4 in. compacted thickness surface course of 'A' grade crushed basalt with 3 per cent of 90 pen. bitumen in it. The photos were taken one week after mixing and compacting, and the traffic had been using it throughout that period. The detail (*Fig. 3*) shows the typical partially coated coarse aggregates embedded in the bitumen bound 'mortar' of fines. In this type of mixture the initial traffic abrasion results in an enriching of the surface between these coarse aggregates as unsecured gravel and sand sized particles are stripped and removed leaving the film of binder to build up on the remaining surface and so stabilize it against further loss. The resulting texture is rough in detail whilst the surface retains its true overall geometry, thus giving a perfect key for asphalt wearing courses.

26. *Fig. 5* shows a 'local material' (bauxite pebbles and creek sand) foamed bitumen 2½ in. compacted thickness haul road wearing course. This mix was given 5½ per cent 60 to 70 pen. bitumen to give maximum permanent cohesion in the sand mortar part of the mix. It was mixed in situ on a pad off the road; loaded and transported in self-loading scrapers on the following day: spread by grader, and compacted by heavy rubber-tyred roller after replacing moisture lost by drying out in storing and handling. The compacted surface showed continual loss of individual pebbles under compaction equipment (*Fig. 5*). For this reason the compacted and cured surface was given a coat of cutback primer binder (field blend to MC-4 viscosity) covered with creek sand fully incorporated by rubber-tyred rolling.

27. *Fig. 6* shows a 6 in. compacted thickness sub-base for a heavy duty pavement at a container handling terminal, composed of non-plastic fine dune sand plus 6 per cent foamed 65 pen. bitumen. The photos were taken 24 hours after mixing and compacting. The degree of curing is indicated by the grader tyre tread impression. This particular mixture cured progressively from 20 CBR (cone) at compaction to 60+ after 3 weeks, at which time it was covered with a base course. The original sand had an estimated CBR of 13. The remainder of this 14,000 sq. yds was treated with 4 per cent of 65 pen. foamed bitumen with similar results.

28. The mixtures shown are all well over 12 months old (TABLE VI) and the pavements of which they form part are without visible deterioration under load. Uniformly graded sand mixes with low bitumen contents have proved difficult to cure under traffic, showing a loosening of the top inch, and formation of a false top on the undisturbed properly cured portion below. This effect has been successfully dealt with by rolling in an armour coat of fine crushed rock one nominal stone thick, to hold it during the early curing stages and so prevent progressive early loosening down into the main body of the mix. Prolonged rain caused local potholing of this type of mix under traffic during curing, but load carrying ability was retained right through from completion of mixing to addition of subsequent pavement layer or seal coat.

29. TABLE VI lists some of the foamed bitumen mixtures currently serving in pavements in Australia with construction dates. From early inspection of these pavements it is apparent that the test procedures adopted do adequately reflect the performance potential of foamed bitumen mixtures for pavement service conditions. Refinement of these procedures, and fixing of criteria for particular structural performance levels must await collection of actual performance data over several years.

30. The following tentative limits on property values obtained as discussed in this paper, are suggested as a guide in designing satisfactory foamed mixtures for use immediately under thin seal treatments.

TABLE VI

EXPERIMENTAL FOAMED BITUMEN WITH CONSTRUCTION DATES

No.	Location and Description	Area (sq. yd)	Compacted Thickness	Raw Material	% Bitumen as Foam	Date of Construction
1.	Freeman's Rd., Altona Base course for asphalt wearing course	6000	4"	'A' Grade FCR	3½% (90 pen.)	Feb. 1968
2.	Percy St., St. Albans Industrial area street base course for single seal treatment	8000	4"	3/8" crusher run shoulder material	3½% (90 pen.)	June 1968
3.	Hansen St., Altona Suburban St. base course for 2½" asphalt wearing course	4000 (See Fig. 3 and 4)	4"	'A' Grade FCR	3½% (90 pen.)	Aug. 1968
4.	Weipa Exptl. Haul Rds. Base Course Wearing Course	4000 8000 (See Fig. 5)	6" 2½"	1½" Bauxite as dug 3/8" - 3/16" Bauxite + sand	4% 5½% (65 pen.)	Oct. 1968
5.	Cross St., Footscray Car Park base course for 1" asphalt wearing course	12000	6"	'B' Grade FCR	3% (90 pen.)	Jan. 1969
6.	Summer Hill Hotel, Preston Car Park Base Course for 1" asphalt wearing course	14000	6"	'B' Grade FCR	3% (90 pen.)	June 1969
7.	Port Adelaide Sub-base for container terminal	14000 (See Fig. 6)	6"	Dune Sand fine non-plastic	4% (65 pen.)	March 1969
8.	Gold Coast Road shoulders for light seal	9000	6"	Beach sand Medium non-plastic	4½% (90 pen.)	April 1969
9.	Cranbourne S. Gippsland Highway Sub-base and base for light seal	24000	6"	Local sand Fine non-plastic	3% (65 pen.)	Aug. 1969
10.	Bendigo Subdivision Streets Base course for light seal	4000	6"	Battery sand Fine non-plastic	2½% 4% (90 pen.)	Sept. 1969
	Trafficked flanks of city streets for light seal	3000	6"	Local hill gravel	2½% (90 pen.)	Sept. 1969

Modified R value
  80 min (cured specimens)
  plus 80 per cent retention after 4-day soak
Modified relative stability
  20 min (cured specimens)
  15 min after moisture-vapour susceptibility
Cohesion
  50 min after moisture-vapour susceptibility
Free swell
  0.030 in. max.
UCS
  100 p.s.i. min (cured specimens)
  75 p.s.i. min after 4-day soak

The above limits to be considered with due regard to any special curing, environment, or loading conditions. When the mix is to be used in a position protected from extreme temperature and load stresses, e.g. below say 2 to 3 in. from the surface, then the relative stability test results should be given less weight in selecting an optimum content.

CONCLUSIONS

31. The Hveem stabilometer and cohesiometer can be used to positively rank foamed bitumen mixtures, by testing suitably prepared specimens before and after exposure to simulated extreme service conditions.

32. In fine grained soil mixtures the tests discussed tend to be pessimistic due to the compacted specimens continued increase in strength, which goes on even after the laboratory accelerated curing treatment has been completed.

33. Addition of foamed bitumen improves the physical properties of a wide range of engineering soils, from fine non-plastic sands and sandy loams through natural gravels to crushed products.

34. The presence of −200 mesh particles in a soil improves the ability of the foam to produce the essential uniform thin coatings on the finer fraction of the material. Dispersion of the binder alone is not enough to ensure the full benefits of the process.

35. Soils showing the greatest benefits from the addition of foamed bitumen are those showing dramatic loss of strength on exposure to water or water vapour, those lacking in natural cohesion, and those which degrade in service by movement and abrasion at inter-particle contact points.

36. The strength of foamed bitumen mixtures develops with loss of compaction water and with continued pressure between the coated particles during and after compaction. Without such inter-particle pressure, and with constant moisture content, the mixtures can be stored for several days without noticeable change in handling characteristics.

37. The time over which foamed bitumen mixtures can be re-worked in the field for adjustment of shape and/or compaction water content is consistent with current compaction techniques and plant capabilities.

APPENDIX A

CALIFORNIAN HIGHWAYS DEPARTMENT TEST PROCEDURES

38. These procedures were used in development of foam bitumen evaluation tests described in this paper.

201-B	soil and aggregate sample preparation
301-F	resistance 'R' value of treated and untreated bases
304E	stabilometer value of bituminous paving mixtures
305B	swell and permeability of bituminous mixtures
306B	cohesiometer values
307D	moisture vapour susceptibility of bituminous mixtures

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DISCUSSIONS

C. P. MARAIS
B.Sc., A.M.(S.A.)I.C.E., National Institute for Road Research, South Africa

39. An important characteristic of all bituminous materials is the effect temperature has on its physical properties, such as modulus and shear strength. Has the author any information on the temperature susceptibility of foamed asphalt mixtures within the working range of pavement temperatures?

40. The foamed asphalt process is an interesting application and the writer would be interested to know if any data is available on the 'before' and 'after' mixing properties of the bitumen used in the process. Also the long-term changes in the bitumen properties under actual in-service conditions would serve as an indication of the durability of foamed asphalt mixtures in practice.

O. G. INGLES
B.A., M.Sc., F.R.I.C., A.M.Inst.F., Principal Research Scientist, C.S.I.R.O., Victoria

41. Could Mr. Bowering comment on the durability of foamed bitumen treatments, especially in view of the thinness of the film and the greatly increased life which antiperoxidants can confer on straight bitumens, but which presumably cannot be used for foam bitumen work as the aeration process would destroy the antiperoxidant.

L. A. LARCOMBE
B.E., M.I.E.Aust., Manager Bituminous Pavements Pty. Ltd., New South Wales

42. The pavement detail shown in *Fig. 5* is very typical of a surface course mix with the uncoated larger stones held in a matrix of well coated fines. In most cases, with high bitumen contents, this condition will improve under traffic, providing weather conditions and traffic are not too severe, and the larger particles will become coated and firmly held in place.

43. The use of a light application surface treatment to protect the pavement in the initial stages should not be very expensive and appears to be a good insurance when conditions are at all doubtful.

44. Would the author advise:
(a) what was the application rate of binder and cover aggregate;
(b) has this treatment proved satisfactory in performance; and
(c) have the coarse particles now become coated and adequately held in the fine matrix?

AUTHOR'S CLOSURE

45. The author wishes to thank Professor Herzog and the delegates taking part in the discussion on this paper for their comments and questions. Some of the questions raised must still go unanswered, but the following paragraphs offer answers and further comments on those aspects raised for which measured or observed data are available.

To A. HERZOG
(See Introductory Remarks)

46. In reply to the discussion leader's comments, the vertical load used in the resistance value test is 160 p.s.i. This load is applied at a constant rate of vertical strain and is released immediately after the full load intensity of 160 p.s.i. has been reached. The application of this load to foamed bitumen mixture specimens of base course quality normally results in the development of horizontal pressures in the Hveem stabilometer of 5 to 30 p.s.i. Materials registering greater horizontal pressures than 30 p.s.i. generally are those needing further structural cover thickness to prevent deformation under traffic loading. However, the resistance value is also influenced by the 'turns displacement' figure measured in the stabilometer on completion of the test, and therefore the horizontal pressure developed is not, by itself, entirely accurate for use as a strength criterion. In practice, the influence of this 'turns displacement' figure is small when testing good quality base course mixtures at or near the optimum foamed bitumen content. Thus the horizontal pressure becomes a good guide to the mixture's strength.

47. Regarding the significant lateral strain value, it is impossible to measure lateral strain directly in the Hveem apparatus since the specimen is totally inaccessible throughout the test. However, repeated loading tests are currently being carried out by others on foamed bitumen/sand mixtures and the results of those tests will include further information on this aspect.

48. The environmental conditions simulated by the Hveem relative stability test are those of hot climate and heavy traffic situations, where the continued high temperatures at the pavement surface could possibly lead to surface deformation under high wheel loads. When this test is carried out after exposing the specimen to moisture vapour at 140°F, it is intended to simulate the conditions obtained in a sealed road where the stabilized soil is again under hot climate conditions, but also has pores of a suitable size and configuration to allow capillary movement of water or water vapour upwards from some accessible water table beneath the subgrade.

49. The relative stability test temperature of 140°F is assumed to represent the highest elevated temperature to be attained for a significant length of time, say periods of several hours duration, by the pavement surface. The vertical load is also increased in this test to 400 p.s.i. which is extremely severe and allows for impact loading and/or sustained application of heavy loads. Hence, the relative stability test results as described in the paper become a good indicator as to how well materials will cope with sustained static loads at elevated temperatures in the field. The response of foamed bitumen mixtures to repeated loading patterns is being studied at the moment as mentioned above. The size of the actual bubbles in the foamed bitumen has not been measured to the author's knowledge but laboratory work indicates that this bubble size is in fact an important factor in determining the suitability of the foam produced for use in the stabilization process. This 'quality' of foam is presently judged subjectively by observing and measuring the expansion achieved and the time taken for a standard volume of the foam to decrease to half of its original expanded volume. The void ratio of foamed bitumen of suitable consistency for good performance in this process varies between 90 and 95 per cent of the volume of the expanded foam.

To C. P. MARAIS

50. Mr. Marais' first point, on temperature susceptibility of foamed bitumen mixtures, is again related to the two basic tests selected in the investigation of the strength of particular mixtures, viz., the resistance value and the relative stability. These two tests cover the normal working range of pavement temperatures here in Australia but unfortunately the fact that the vertical pressure is also changed from one test to the other means that we have no precise comparison on changes

TABLE VII
EFFECT OF SERVICE TEMPERATURE ON PERFORMANCE OF FOAMED BITUMEN STABILIZED SOILS

Sample Reference No.	Foamed Bitumen Content (%wt.)	Horizontal Pressure Developed by Test Specimen under Vertical Load of 160 p.s.i.	
		At room temperature	At 140°F
127	2	6	6
	4	5	7
	6	7	15
149	2	6	8
	4	9	10
161	3	20	29
162	3	13	17
163	3	13	19
164	3	33	38
165	2	15	20
	4	15	16
	6	17	28

of strength caused purely by changes in temperature. However, TABLE VII gives the horizontal pressure developed in the stabilometer for a series of mixtures, under vertical loads of 160 p.s.i., both at room temperature and at 140°F. From this table it can be seen that the higher temperature does give a measurable but insignificant decrease in the resistance of the materials to deformation under vertical load.

51. It is notable that 'Turns Displacement' figures were recorded under the same partially unloaded conditions at each of the two temperatures but showed insufficient variation in results obtained at high and low temperatures to affect the resistance value calculation. Hence the particular figures in TABLE VII may be taken to indicate the extent of 'softening' of the mixtures due to change in service temperature alone. It can be seen that the temperature effect is only significant in mixtures containing excess (for this process) bitumen, or produced from very weak soils.

52. Both of these types of mixtures would automatically be excluded from use at the pavement surface (directly under a seal) by the test system described in the paper.

53. The author is unable to provide Mr. Marais with data on the properties of the bitumen used before and after processing in this way but would agree that the long term changes in the bitumen properties would serve as an indication of the durability of the foamed asphalt mixtures in service. It is intended to attempt to measure these properties when the initial pavements constructed here have been in service for a period of years.

To O. G. INGLES

54. The author is unable to confirm or refute Mr. Ingles' comment that the aeration process involved in foaming the bitumen could destroy any anti-peroxidant which may have been added to the bitumen in an attempt to extend its useful life. However, the addition of foamed bitumen to most of the materials stabilized in this manner to date, has drastically reduced their permeability and hence the possible movement of vapour or air in and out of the finished compacted mixture. This in itself could be expected to help preserve the physical properties of the bitumen during its service life in spite of its thin film condition.

To L. A. LARCOMBE

55. The pavement referred to by Mr. Larcombe and shown in *Fig. 5* of the paper was sealed with a field-manufactured cutback of MC4 consistency made from 60/70 penetration bitumen and power kerosene. This was sprayed at a rate of 0.18 gallons per sq. yd and covered with fine creek sand, the sand being applied in sufficient quantity to preclude picking up during subsequent rolling. The object was to cover the uncoated surfaces of the larger particles and fill the depressions where the larger particles had been lost from the surface. This treatment proved satisfactory in subsequent use and the reported performance from the site also indicates that the heavy ore hauling traffic proved beneficial in increasing densification of this particular material during the early months of its service life.