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Design and Performance Study of Sand Bases Treated with Foamed Asphalt

S.M. ACOTT AND P.A. MYBURGH

The objective was to provide guidelines on the design of sands treated with foamed asphalt. The study included an evaluation of foam properties and a range of sand types. The foam-treated mixtures were characterized by index-type tests and by more fundamental procedures. The design asphalt content was selected as the lowest level at which the mix complied with a minimum Rt value of 70 at 40°C. All other engineering tests were conducted at the design asphalt content. To complement the laboratory work, two roads were constructed and then monitored over a five-year period by various field test procedures. Emphasis was placed on upgrading locally available materials by using low asphalt contents and selecting relatively light pavement designs. All experimental sections consisted of a thin surfacing and a 150-mm foam-treated layer on natural subgrade. From the field investigations, vane-shear and dynamic-cone-penetrometer values were found to be good indicators of shear strength, and limiting values are proposed to prevent distortion. For low-strength mixtures the critical parameter was the time period to develop this minimum required stability. From an analysis of deflection data, the foam-treated layer was considered adequate to protect the natural subgrade for the relatively light design traffic. In conclusion, this study has shown that properly designed sands treated with foamed asphalt can be used with confidence for low-volume roads provided that attention is given to the use of appropriate curing techniques, engineering test procedures, and the adoption of realistic limiting strength values.

An essential requirement for the construction of a low-cost, low-volume road is the need to make greater use of local available construction materials. In areas where sand forms the existing bush track or where there are nearby reserves, foamed-asphalt stabilization becomes a very attractive proposition since small quantities of asphalt can significantly increase the shear strength.

This paper is a summary of a field and laboratory investigation, conducted over a five-year period, in which the overall objective was to provide information on construction techniques and material specification and to formulate mix and structural design guidelines for foam-treated materials. The research approach was to determine the properties of the foamed asphalt and a wide range of natural sands and to then characterize the treated mix by using both index-type values and more-fundamental parameters. From a literature review and from discussion with various engineers, the stabilometer and vane-shear tests were selected as methods that would be most suited for evaluating these mix types in a routine laboratory environment. The stabilometer had also been used previously by Bowering and Martin (1), among others, for the evaluation of foam-treated materials. To complement these tests, the laboratory was equipped with a repeated-load indirect-tensile apparatus to measure the resilient modulus. Indirect tensile strength and static elastic modulus were evaluated by equipment at the National Institute for Transport and Road Research, and data are also reported on a short triaxial study conducted by the Roads Department of the Cape Provincial Administration.

To establish performance data, two full-scale field experiments were constructed and then monitored over a five-year period. Various field test procedures were used to evaluate the structural response of the test roads and to characterize the in-place materials. These included vane-shear and dynamic-cone-penetrometer (DCP) tests as shear-strength indicators and deflection (Benkelman and Lacroix) and curvature to evaluate load response. To quantify the condition of the test pavements, regular condition surveys were made by an experienced inspection panel. The visual observations were complemented by rut depth, crack index, and axle-weight analyzer surveys.

MATERIALS CHARACTERIZATION

Foamed Asphalt

For mix design purposes, a laboratory foam dispenser was constructed to provide foamed asphalt under controlled conditions. An air-rectified 60/70 penetration grade asphalt was heated to 160°C and combined with atomized water in the spray nozzle of the dispenser. To establish foaming moisture levels, the foamed asphalt was directed into a 5-L container, and the foam expansion ratio and half-life were determined at various moisture contents. Consistent with previous studies, foam expansion increased and half-life stability decreased with added moisture. For design purposes, a bitumen-water ratio of 1:50 was selected according to minimum desirable expansion and half-life criteria of 8 ml/g and 20, respectively (2).

Aggregate Properties

Fine aggregates evaluated for foam treatment included aeolian, alluvial, and mine-tailing sands, sand blends, and mixtures of sand and quarry overburden. A summary of the aggregate properties used in the test roads is given in Table 1.

Engineering Properties of Foam-Treated Sand

Specimen fabrication essentially followed the procedures originally developed by Mobil Oil Australia (3). Water was first added to the sand until the fluff point was reached (i.e., maximum loose bulk volume). The required quantity of foam was then directed into the aggregate and mixing was carried out in a planetary mixer until the foamed asphalt was evenly dispersed. An improved procedure for determining optimum aggregate moisture content, which is based on determining the moisture content at maximum dry density, was recommended by Ruckel, Acott, and Bowering (2).

Specimens for stabilometer and cohesiometer tests were compacted by the kneading compactor according to the procedures described in the Asphalt Institute's Basic Asphalt Emulsion Manual (4). The tensile strength and static modulus of these briquettes were also determined. The test method followed the procedure described by Kennedy (5). The resilient modulus of the samples was determined by the repeated-load indirect-tensile apparatus developed by Schmidt (6).

Specimens for the triaxial test study were 48 mm in diameter and 58 mm high. These were prepared by securing the cured briquette between two platens and then trimming it to size by using a wire and saw frame.

For vane-shear test specimens, the treated sand was compacted in a California bearing ratio (CBR) mold by using modified AASHO compaction. The mold was then placed in an upright position in an oven and cured for three days at 60°C.

After curing, the mold and three legs of the vane-shear apparatus were then secured on a base plate and a vane was driven vertically into the mix surface with a mallet. The maximum torque required to shear the sample was then determined and related to the shear strength of the sample according to the dimensions of the vane (7).

It is not the intention of this paper to give a detailed commentary on the mix characteristics but rather to summarize the major conclusions arising from the study (8). These were as follows:

1. All clean sands responded poorly to foam treatment, and the presence of at least 6.5 percent of 75-μm material was desirable.
2. There was good correlation between the Hveem Rt-value and vane-shear strength. The relationship was of the following form:

$$\text{Hveem Rt-value} = 0.0658 \text{ vane-shear strength (kPa)} + 55.2 \qquad (1)$$

where the test temperature is 40°C and the correlation coefficient is 0.85 for 25 pairs of test results.

3. The tensile strengths of the foam-treated sands (range, 108-518 kPa) were lower than the reported tensile strengths of asphalt concrete, sulfur asphalt, and recycled asphalt (range, 490-2200 kPa).
4. For the higher-tensile-strength foam-treated sands, peak failure load and deformation were well defined, whereas for the low-strength mixtures the peak tensile stress remained constant for a considerable increase in horizontal deformation.
5. The foam-treated sands exhibited a wide range of static-elastic moduli (50-850 MPa). This was due mainly to the differences in horizontal deformation at failure.
6. From a short triaxial compression study on the blend of aeolian coastal dune sand and filler, the addition of 3.0 percent foamed asphalt increased the cohesion intercept component of the mix from 31 to 110 kPa. There was also a small decrease in angle of shearing resistance from 32.7 to 30.3.

For the mixtures evaluated on the two test roads, the design asphalt content was selected as the lowest asphalt content at which the mix complied with a minimum resistance Rt-value of 70 after subjection to the moisture vapor susceptibility (MVS) test. All other engineering tests were carried out on specimens at the design asphalt content. A summary of the test data is given in Table 2. The temperature of the specimens for the stabilometer, cohesiometer, and vane-shear tests was 40°C. The tensile-strength, static-elastic-modulus, resilient-modulus, and triaxial evaluations were conducted on specimens at ambient temperature.

CONSTRUCTION OF TEST ROADS

In 1977, two road experiments were constructed to provide information on the field performance of the foam-treated mixtures described above. Emphasis was placed on the use of mixtures of marginal, low bitumen content and the selection of relatively light pavement designs.

Kleinvlei Road

The Kleinvlei experiment forms 0.6 km of a township collector road near Cape Town in the Cape Province

Table 1. Aggregate characteristics.

Mix Description	Unified Soil Classification System	AASHTO System	Uniformity Coefficient	Gradation Coefficient	Percent Passing 75-μm Sieve
River sand	SW/SM	Gravel sand A-1-b	8.7	2.0	6.5
Mine-tailing sand	SP/SM	Silty sand A-2-4	4.1	1.8	13.5
River or mine-tailing sand blend	SP/SM	Gravel sand A-1-b	8.5	1.2	10.0
Aeolian coastal deposit plus 10 percent filler	SP/SM	Fine sand A-3	3.2	1.3	10.0
Quarry overburden	GM-GC	Clayey gravel A-2-5	-	-	14.0

Table 2. Engineering characteristics of design mixtures.

	Test Temperature 40°C				Test Temperature 23°C		
		Rt-Value					
Mix Description	Design Asphalt Content (%)	Before MVS Test	After MVS Test	Vane-Shear Strength (kPa)	Tensile Strength (kPa)	Static Elastic Moduli (MPa)	Resilient Moduli, 0.1 s (MPa)
River sand	4.0	89	75	-	518	844	5000-6600
Mine-tailing sand	4.0	79	75	193	108	37	800-880
River or mine-tailing sand blend	4.0	91	74	522	339	501	2200-3100
Aeolian coastal deposit plus 10 percent filler	3.0	82	80	255	156	47	1000-1600
Aeolian coastal deposit and quarry overburden blend (50/50)	3.0	98	83	-	586	-	5100

of South Africa. The test sections were as follows:

Section	Mix Description
A	Aeolian coastal deposit plus 10 percent filler
B	Aeolian sand and quarry overburden blend (67/33)
C	Aeolian sand and quarry overburden blend (50/50)
D	Aeolian sand and quarry overburden blend (25/75)
E	Crushed-rock base (100 mm) plus gravel subbase (150 mm)

After shaping, mixtures A-D were stabilized in place with 3.0 percent foamed 60/70 penetration asphalt to form a 150-mm base layer on the aeolian sand subgrade.

The in situ treatment was carried out by a stabilization train, which consisted of a crawler tractor, single-shaft pulvimixer, and an asphalt tanker with 10 000-L capacity. The tractor was required to prevent traction problems and ensure a constant forward speed of the train. The foamed asphalt was applied via a spray bar, which was located directly above the tines of the pulvimixer.

For comparison purposes, a granular pavement was also monitored. This included a 100-mm crushed-rock base plus a 150-mm gravel subbase and was designated section E.

The foam-treated sand mix (section A) was tender during the compaction phase. The base layer could not support the pneumatic roller until a stable working platform had been formed by the steel wheel roller. For the blends of treated sand and overburden (sections B-D) the layers were all stable under the pneumatic roller.

The mean asphalt content extracted from the 25 samples was 2.9 percent and the standard deviation was 0.97 percent. The soaked laboratory CBR of the sand subgrade at 100 percent mofified AASHO compaction was in the range of 15-20, and the cohesion intercept value and angle of shearing resistance were 13.0 kPa and 31.3°, respectively.

Two months after construction, the experimental sections were surfaced with a chip and spray plus slurry application (known locally as a Cape seal). Apart from isolated weak spots, there were no signs of chip embedment under the rollers. Prior to surfacing, the sections had been primed and subjected to construction vehicles and local residential traffic.

Chamdor Experiment

In October 1977, three sands were treated with 4.0 percent foamed 60/70 penetration asphalt in a 50-tonne/h drum mix plant. The 150-mm foam-treated base mixtures were constructed directly over the natural subgrade to form a 200-m roadway at an industrial site at Chamdor near Johannesburg.

The three mixtures consisted of a foam-treated mine-tailing sand, a river sand, and a mine and river blend. Aggregate properties and mix characteristics were given in Tables 1 and 2.

After being mixed in the drum plant, the foam-treated sand was hauled to the site, tipped, and then graded to the required shape. The 150-mm base was compacted by three passes of a 10-tonne steel wheel roller and 15 passes of a 22-tonne roller.

All three sands were easy to work, the foamed asphalt was well distributed, and there were no signs of instability during compaction.

Sand-replacement densities of the foam-treated sections varied from 98 to 104 percent moderate AASHO compaction. The mean asphalt content, extracted from 10 samples, was 4.1 percent and the standard deviation was 0.23 percent. Sand-replacement density of the subgrade material varied from 89.0 to 94.0 percent modified AASHO compaction and laboratory CBR varied from 25 to 68 over this density range.

ROAD PERFORMANCE

Over the five-year postconstruction period, the following procedures were used to monitor the condition and performance of the test sections:

1. Traffic analysis by axle weight analyzer (AWA) survey;
2. Benkelman-beam, Lacroix-deflection, and curvature surveys;
3. In situ vane-shear strength;
4. In situ DCP values; and
5. Road-condition surveys.

Traffic Analysis

In September 1979 (20 months after construction), an AWA survey was conducted in both lanes of the Kleinvlei road over a seven-day period. From an analysis of the AWA data, the average daily traffic in the northbound and southbound lanes was 40 and 25 equivalent single 80-kN axle loads, respectively.

The Kleinvlei road forms part of a bus route and is a collector road for an expanding residential area. In 1978, the township consisted of 1300 houses with an anticipated increase to 4000 over a 10-year period. The higher traffic axle loading in the northbound lane entering the township was associated with the movement of construction materials required for this development.

At Chamdor, the foam-treated sand base was initially used as an all-weather roadway for trucks associated with the construction of a manufacturing plant. Under these variable conditions, no attempt was made to estimate traffic. By November 1978, much of the heavy construction engineering had ceased and the sand-stabilized base was surfaced with a 50-mm layer of asphaltic concrete.

Deflection and Radius of Curvature

Benkelman-beam deflection and radius-of-curvature tests were carried out on the Kleinvlei road 6, 16, and 51 months after construction. Measurements were made in the four wheel paths and on the road centerline. As shown in Figure 1, apart from the higher deflection in section D after 6 months, the mean deflections of each section were similar for the three time periods, and in all cases deflection reduced with time.

A similar uniformity in the data is also re-

Figure 1. Deflection and curvature history of Kleinvlei test sections.

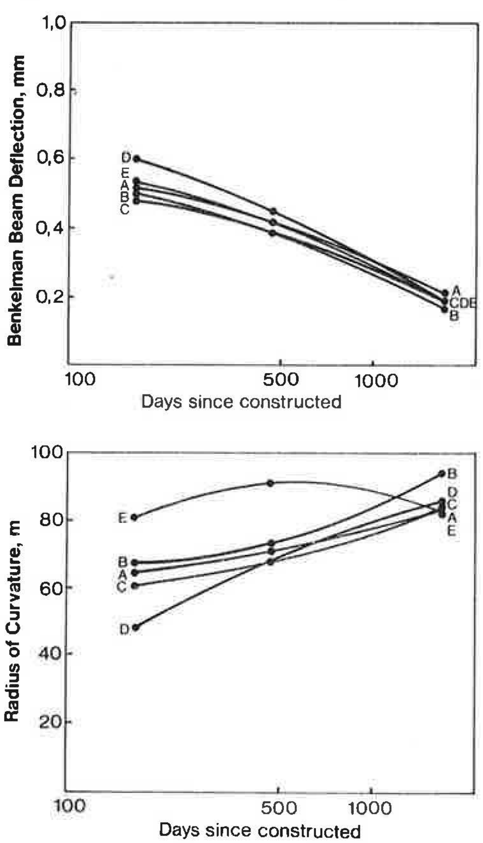


Figure 2. Increase in vane-shear strength with time.

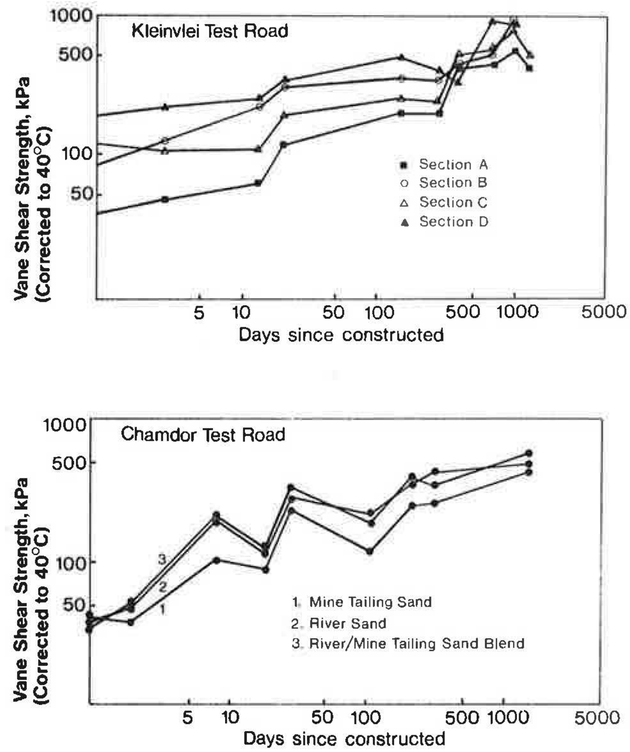
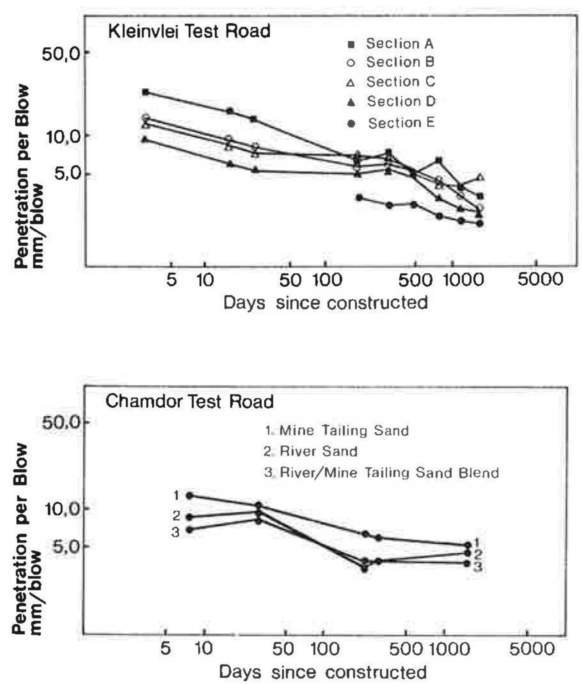


Figure 3. Reduction in DCP value with time.



flected in the results from a Lacroix deflectograph survey conducted nearly three years after construction. Mean Lacroix deflection range between sections varied from 0.26 to 0.29 mm and the standard deviation was typically 0.05 mm.

As shown in Figure 1, the radius of curvature of the granular structure (section E) was initially 20 m higher than that of the foam-treated sections, but after 51 months the radius of curvature was similar for all sections.

At the Chamdor experiment, test sections displayed a relatively high deflection (0.68-0.85 mm) and low curvature (25-29 m) one day after construction. After seven months, the radius of curvature had increased only 5 m for the foam-treated mine-sand base and a further 24 m for the section with river and mine sand. The deflection of the base with river and mine sand had dropped from 0.85 mm to 0.59 mm, but there was no significant change for the mine-sand base.

Vane-Shear Strength

The field vane-shear apparatus developed by Marais (7) was used to monitor the setting up of the treated mixtures. The mean vane-shear strength of each section was corrected to a standard test temperature of 40°C by employing curves of vane-shear strength and temperature previously developed in the laboratory (8).

As demonstrated in Figure 2, the mean vane-shear strength of the Kleinvlei and Chamdor sections increased significantly over the five-year evaluation period. Although all sand mixtures exhibited a relatively low vane-shear strength (35-40 kPa) immediately after compaction, a 10-fold increase in strength was recorded after some two years. In comparison, the mixtures of sand and overburden (sections B, C, and D) displayed high vane-shear strengths in early life (90-200 kPa) but increased only fivefold over a two-year period.

DCP Tests

The DCP apparatus, as described by Van Vuuren (9), consisted of a 16-mm diameter steel rod with a 20-mm hardened 30° cone at one end. An 8-kg sliding hammer strikes an anvil and the penetration of the rod into the foam-stabilized base is recorded. The DCP value, expressed in millimeters per blow, is the gradient of the penetration-per-blow curve. The slope of the curve over the 150-mm thick layer was determined by regression analysis and was used as an index of strength. Test results were not corrected to a standard test temperature but are reported at the base temperature at the time of test.

In line with the increase in vane-shear strength with time, the DCP values also indicated a strength improvement for all mixtures. As shown in Figure 3, the DCP value for the foam-treated mixtures decreased from a range of 7.0-24.0 mm/blow after construction to a range of 4.0-5.00 mm/blow after 4.5 years.

Pavement Condition Rating

Members of an inspection panel rated each pavement section of the Kleinvlei test road according to the degree and intensity of the various distress modes, i.e., fracture, deformation, loss of surface texture, loss of stone, and potholing. The degree and intensity of distress were expressed on a scale from 1 to 5 according to a procedure reported by Curtayne and Walker (10).

First the rating procedure was described and each panel member independently assessed the condition of the pavement. A summary of the group observations is given in Table 3.

To complement the condition surveys, the maximum permanent deformation under a 1.8-m straight edge was measured in the four wheel paths. Throughout the five-year evaluation period there were only small differences in the mean rut depth of sections B, C, D, and E (typical rut depth, 7.0 mm), whereas the permanent deformation of section A ranged from 10.0 to 12.0 mm for this period. This was due to a consistently higher deformation (typically 16 mm) in the outer wheel path of the southbound lane. This higher value was ascribed to the poor asphalt dispersion in the mix in that lane. This was improved in the center and northbound lanes by varying the tine speed, tailboard opening, and forward speed of the pulvimixer.

At the Chamdor road, the performance was not monitored so rigorously as at Kleinvlei due to the variable service conditions. After five years of service, each section was performing satisfactorily and the mean rut depths of the mine, river, and mine-and-river sand sections were 8.3, 6.7, and 8.5 mm, respectively.

CORRELATION OF DATA

Permanent Deformation

In general, permanent deformation increases with the number of axle repetitions, but at a decreasing rate. For the Kleinvlei road, a terminal rut depth of 15 mm has been assumed. As shown in Table 4, apart from the outer wheel path of the southbound lane of section A, indications are that for the design traffic the rut depth of all sections will remain acceptable. In the southbound lane, deformation initially developed in the first year, after which rut depth became relatively constant. This rutting was also associated with faint longitudinal cracking in the surface treatment (see Table 3).

To determine whether the vane-shear and the DCP tests could provide good indices of shear strength, the rut depths and corresponding vane-shear strength and DCP values in each lane were analyzed in more detail (8). This analysis showed that the initial deformation (up to 11.0 mm) in section A took place when the vane-shear strength and DCP values of the base layer were in the range of 102-130 kPa and 10.0-14.5 mm/blow, respectively. Despite an increase in vane-shear strength from 130 to 155 kPa and DCP reduction from 10.0 to 9.1 mm/blow, the average rut depth in the outer wheel path increased from 11.0 to 15.0 mm. In the northbound lane of section A, minor rutting (10.0 mm) took place while the vane-shear strength of the treated sand increased from 100 to 200 kPa and the DCP value reduced from 14.5 to 5.6 mm/blow. For sections B, C, and D, deformation was minimal. For these mixtures, vane-shear strengths were greater than 200 kPa and DCP values were less than 8.4 mm/blow throughout the postconstruction period (while trafficked).

At Chamdor, a 50-mm hot-mix asphalt surface was applied to the foam-treated sand sections one year after base construction. As shown in Figures 2 and 3, vane-shear strengths and DCP values at the time of surfacing were in the range of 270-430 kPa and 4.0-6.0 mm/blow, respectively. Although lower strengths were initially recorded, the surfacing layer also acted as a leveling layer and the minor rutting recorded after five years of service confirms that under relatively light traffic, the base is stable when the vane-shear strength exceeds 270 kPa and the DCP value is less than 6.0 mm/blow.

From the above discussion, indications are that distortion will occur when the vane-shear strength

Table 3. Summary of Kleinvlei condition surveys.

Description	Section A Northbound Lane	Section A Southbound Lane	Section B	Section C	Section D	Section E
Fraction	No cracking	Faint or distinct longitudinal cracking observed in outer wheel path 9/19/78; no significant change over period 9/19/78-7/1/82; area affected <10 percent of road surface	Faint longitudinal cracking observed on 1/21/81 <10 percent of road length	No cracking	Faint random cracks observed in wheel paths at end of May 1978; crocodile cracking by mid-June 1978; distinct cracks 10 percent of area	No cracking
Deformation	Distortion 10-20 mm for <10 percent of road length; no significant change since 5/16/78; depressions in road surface for <10 percent of area	On 5/16/78 distortion in wheel path 10-20 mm for 40 percent of road length; depressions <10 mm for <10 percent of road length; no significant change in distortion since 5/16/78 but depressions now 40 percent of road area	Distortion 10-20 mm for <10 percent of road length, no significant change since 5/16/78; depression in road surface for <10 percent of area	Distortion <10 mm for 80 percent of road length; no change since 5/16/78; depressions in road surface for <10 percent of area	No visible distortion; <10 mm for >80 percent of road length	No visible distortion; <10 mm for >80 percent of road length
Loss of surface texture	Stones generally well proud of binder or rough surface texture; some evidence of slurry wear and bleeding for <10 percent of area		Stones well proud of binder or rough surface texture; minor bleeding in northbound lane for <10 percent of road length; some evidence of slurry wear; some fatty areas left-hand lane on bend	Stones well proud of binder or rough surface texture; some fatty areas and evidence of slurry wear	Stones well proud of binder or rough surface texture; some evidence of slurry wear; fatty areas <10 percent	Stones well proud of binder or rough surface texture; some evidence of slurry wear
Loss of stone	No loss of stone; some evidence of loss of slurry aggregate		No loss of stone; some evidence of loss of slurry aggregate	No loss of stone; some evidence of slurry aggregate	No loss of stone; some evidence of slurry aggregate	No loss of stone
Potholing	Two isolated potholes observed 12/3/79 and 1/21/81		No sign of spalling	One small pothole observed 12/3/79	Two 600x300-mm patches required to repair cracked area	One small pothole observed 5/16/78
Is this pavement of acceptable quality?	Yes	Yes	Yes	Yes	Yes	Yes

Table 4. Vertical deformation under 1.8-m straight edge, Kleinvlei test road.

Days Since Construction	Deformation (mm) by Section A	A'	B	C	D	E
170	9.7	11.2	7.6	6.7	6.3	7.4
318	9.8	14.9	7.6	8.1	5.2	7.6
457	8.9	15.6	5.7	7.3	6.5	5.5
748	10.2	15.1	7.8	7.5	7.2	7.3
1111	10.4	15.1	7.1	8.3	8.0	8.7
1528	10.4	16.1	6.7	7.9	4.7	6.9

Note: A refers to northbound lane and southbound inner wheel path; A' refers to southbound outer wheel path.

of the base is less than 155 kPa at 40°C. Because DCP tests were not corrected to a standard test temperature, a relationship was sought between the vane-shear strength and the DCP value. Individual test results from the sand sections at Kleinvlei and Chamdor and the mean value of the test results for the sand-overburden sections were used in the correlation. As shown in Figure 4, a highly significant correlation was found between the logarithms of vane-shear strength and penetration per blow.

The equation of the straight line was as follows (correlation coefficient, 0.85; 78 pairs of results):

$$\text{Log vane shear (kPa)} = -1.05 \log \text{penetration/blow} + 3.38 \quad (2)$$

This relationship is independent of mix type, test temperature, and binder content over the range of materials and conditions encountered at the two test roads.

From these data, the limiting vane-shear strengths and corresponding DCP values (at 40°C) that would be required to prevent distortion are 155 kPa and 13.5 mm/blow, respectively. The field vane-shear strength compares well with the laboratory vane-shear strength proposed by Marais and Freeme (11). In their studies, vane-shear strength between 130 and 200 kPa was regarded as critical, above 200 kPa as satisfactory, and below 130 kPa as unsatisfactory.

From the limiting field vane-shear strength criteria and from the good correlation found between Hveem Rt-values and laboratory vane-shear strength, the proposed minimum-strength values for laboratory design and field control at 40°C are vane-shear strength, 155 kPa; Hveem Rt-value, 65; and DCP value, 13.5 mm/blow.

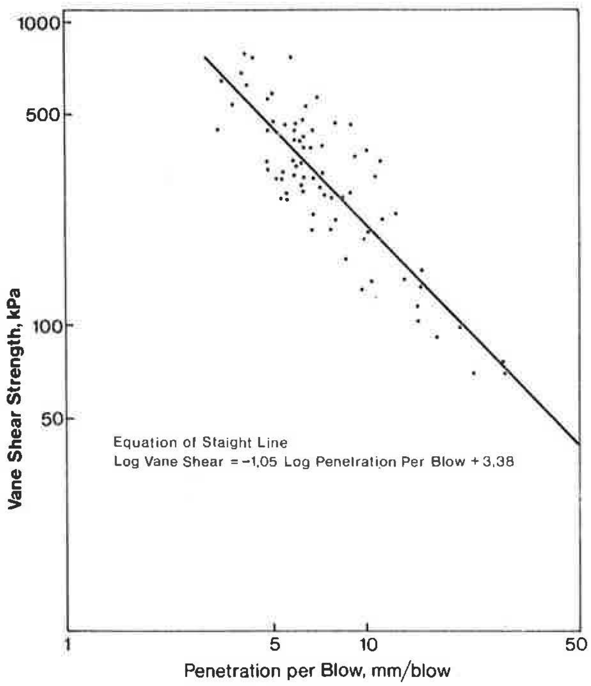
Structural Considerations

For the Kleinvlei test road the deflection values of the foam-treated sections and the granular pavement decreased significantly over the five-year evaluation period (typically from 0.5 to 0.2 mm). The causes of this reduction were not quantified, but it is reasonable to assume that this was due to a combination of factors such as an increase in foam-treated base stiffness and layer consolidation.

There is evidence to show that the performance of a pavement can be related to pavement deflection. From the information presented by Kingham (12) and by Lister and Kennedy (13), the low levels of deflection measured at Kleinvlei throughout the evaluation period indicate that the 150-mm foam-treated base will be adequate to protect the sand subgrade for the estimated design traffic of 0.3×10^6 standard axles.

It is of interest to note that although the foam-treated mixtures at Kleinvlei had widely differing

Figure 4. Vane-shear strength versus DCP value.



mix properties, the mean deflections of each section were similar. This low variability both between and within sections reflects the uniformity of the sand subgrade with respect to particle shape, grading, and density.

Although the early-life Benkelman-beam deflections at both Chamdor and Kleinvlei also showed that the subgrade was adequately protected, the more critical design consideration is associated with the initial low radii of curvature. Dehlen (14) observed that a radius of curvature of less than 38 m can be associated with flexural cracking of the surfacings. The radii of curvature at Chamdor (25-29 m) measured one day after construction indicate that for low-strength mixtures sufficient curing must take place before the base is surfaced. The localized flexural cracking of the surface treatment in section D at Kleinvlei and the associated low radius of curvature confirm this finding.

CONCLUSIONS

The study showed that poor-quality sands can be successfully treated with foamed asphalt in a central mix plant or by in-place stabilization. For low-stability mixtures the critical factor was the time factor for the mix to cure so that the treated sand base was stable under traffic. From the laboratory and field performance study the minimum strength values that were found to limit permanent deformation in the treated base to less than 15 mm at 40°C were vane-shear strength, 155 kPa; Hveem Rt-value, 65; and DCP value, 13.5 mm/blow. These values apply for traffic levels of less than 40 standard axles per day.

For laboratory design purposes, proposals have been made previously for standardizing specimen conditioning, which will replicate short, intermediate, and long-term cure periods (2). The evaluation of laboratory vane-shear strength and Hveem Rt-values at these cure states and the use of the above criteria can be used to indicate how soon these mixtures can be subjected to traffic. The field vane-shear strength can also provide a useful link with the laboratory design values and can be used for field-control purposes.

The deflection surveys showed that a 150-mm-thick foam-treated sand base was adequate to protect the sand subgrade. The deflection of all experimental sections decreased significantly over the five-year evaluation period. This was attributed to increases in foam-treated base stiffness and possibly layer consolidation. In view of the low initial curvature of the treated sand base, we suggest that, in addition to mix stability, the resilient modulus of the foam mixtures should also be determined for the short, intermediate, and long-term cure conditions. The minimum base moduli required to limit the tensile strain in the surfacing to an acceptable level can then be related to the minimum desirable curing period (2).

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