# Evaluation of Emulsified, Asphalt-Treated Sand for Low-Volume Roads and Road Bases

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**The objective of this study was to evaluate, in the laboratory, the feasibility of using blends of dune sand-crusher fines that were stabilized with CSS-1h emulsified asphalt in the construction of low-volume roads in the Kingdom of Saudi Arabia. Marshall stability, water sensitivity, split tensile strength, resilient modulus, fatigue life, and rutting tests were conducted on cured Marshall specimens. Factorial design was used in this study in which crusher fines percentages were varied between 0 percent and 50 percent of the total aggregate weight and the Portland cement content was varied between 0 percent and 3 percent of dry aggregate weight. Results indicated that dune sand mix properties were drastically changed by the inclusion of crusher fines in the mix. The stability, resilient modulus, fatigue, and rutting characteristics of such mixes were improved significantly. Thickness design charts were developed for the designed mixes, which proved to be suitable for use in hot, arid areas. Pavement thickness was significantly reduced when crusher fines, cement, and dune sand blends were treated with emulsified asphalt.**

## INTRODUCTION

In many of the arid and semi-arid countries of the world, such as the Kingdom of Saudi Arabia, treated dune sand is a potential source of road building material. This is particularly significant in areas that lack good quality aggregate because the cost of importing aggregate is high. The small amount of good quality aggregate that does exist is used for other construction purposes, which is a prime concern in an area in which low-volume roads carry up to 2,400 vpd.

The Kingdom of Saudi Arabia has nearly completed the construction of main highways and expressways that join main city centers. However, a large number of settlements and agricultural land remain to be connected to the main highways by rural or agricultural roads. The Kingdom has already constructed about 42,000 km of agricultural roads, and about 32,000 km are expected to be constructed in the current 5-year plan, which was started in 1986. Most of the existing low-volume roads are dirt tracks that are hazardous and require continuous maintenance. The construction of an asphalt concrete layer was suggested to improve and upgrade the quality of these roads. Because a high percentage of these roads run through dune sand areas, the use of conventional mixes would be very expensive. Attempts should be made to use the locally available sands and emulsified asphalts for such road construction.

The objective of this research was to evaluate the feasibility of using locally available dune sand that is blended with various percentages of crusher fines and cement content and treated with CSS-1h emulsified asphalt to construct low-volume roads.

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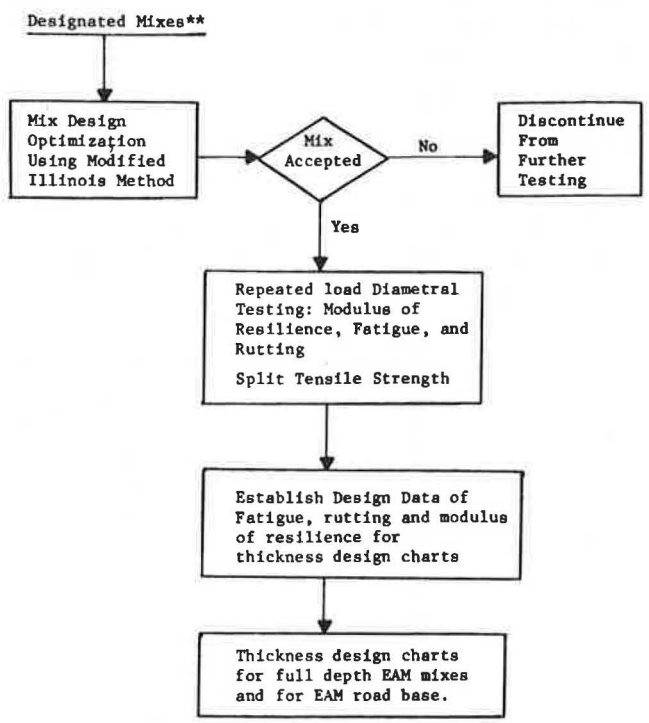
## RESEARCH APPROACH

An approach was adopted to select different combinations of mixes, optimize the design of these mixes, and evaluate their performance through laboratory tests. The evaluation process was entirely experimental. The design parameters needed for thickness design were evaluated and then incorporated into a computer-aided design program to develop design charts for the selected mix combinations. The research approach and testing program are outlined in Figure 1.




**Designated Mixes

| Cement Content % | Crusher Fines % of Total Agg. Dry Weight | | |
|---|---|---|---|
| | 0 | 25 | 50 |
| 0.0 | A-0 | B-0 | C-0 |
| 1.5 | A-1.5 | B-1.5 | C-1.5 |
| 3.0 | A-3 | B-3 | C-3 |

**FIGURE 1 Research approach and designated mixes.**

## MATERIALS

### Aggregate

Two types of aggregates were selected for this study: dune sand and crusher fines (CF). These materials were selected on the basis of their availability in abundant quantities at low cost. Dune sand was collected from the Dhahran area. The dune sand is uniformly graded and has a hard, smooth surface. Emulsified asphalt may not have adequately stabilized the sand; it was therefore blended with crusher fines (*1, 2*).

The crusher fines were also collected from the Dhahran area. Crusher fines, which are a by-product of aggregate crushing, are produced in large quantities because of the weak nature of the limestone in the Kingdom. This material is produced in greater quantities than are needed, which creates a disposal problem because it needs to be transported to dumping areas.

Three different percentages of crusher fines were blended with sand: 0, 25, and 50 percent of crusher fines by total weight of the combined dry aggregates. These blends are hereafter designated as blends A, B, and C, respectively. The selection of percentages was based on the available gradation of dune sand. The gradations are shown in Figure 2.

Based on the literature, three levels of cement percentages were selected to be added to the blends: 0.0, 1.5, and 3.0 percent of dry aggregate weight of CF/sand blend (*1-4*). In the mix designation, the percentage of cement appears after the blend type. For example, if 50 percent crusher fines (Blend C) were used in the mix preparation and 3 percent of cement was added, the mix is abbreviated as EAM-C-3, in which EAM stands for emulsified asphalt mixture.

### Emulsified Asphalt

Cationic, slow-setting emulsified asphalt (CSS-1h), which is produced locally for sand stabilization, was used in this study. Various tests were performed to evaluate the selected emulsified asphalt, and the results are shown in Table 1. The test results were compared to ASTM specifications D-2397. Results of the comparison indicated that the selected emulsified asphalt was within the specified limits with the exception of the stability test, which yielded a value of 1.9 percent against a recommended maximum of 1 percent. This emulsion should not be stored for a long time to avoid settlement. The emulsified asphalt was stored in closed, 3-litre containers and was shaken continuously to ensure uniformity.

**TABLE 1 EMULSIFIED ASPHALT TEST RESULTS, WITH THE ASTM D2397 SPECIFICATIONS**

| | Test Results | ASTM Specifications | |
|---|---|---|---|
| | | Minimum | Maximum |
| Viscosity at 77° F | 23 | 20 | 100 |
| Storage stability (%) | 1.9 | - | 1 |
| Sieve test (%) | 0.1 | - | 0.1 |
| Residue (%) | 59 | 57 | - |
| Penetration for residue at 77° F | 46 | 40 | 90 |
| Cement mixing test (%) | 0.9 | - | 2 |

## MIX DESIGN OPTIMIZATION

The modified Illinois method was adopted for the design of emulsified asphalt mixtures (EAMs) (*5*). A Marshall compactor was used to prepare specimens, which were compacted with 75 blows on each side. To achieve the optimum proportion for the mix, the following points were followed for each mixture design:

- Determination of optimum premixing water required to wet aggregate surface,

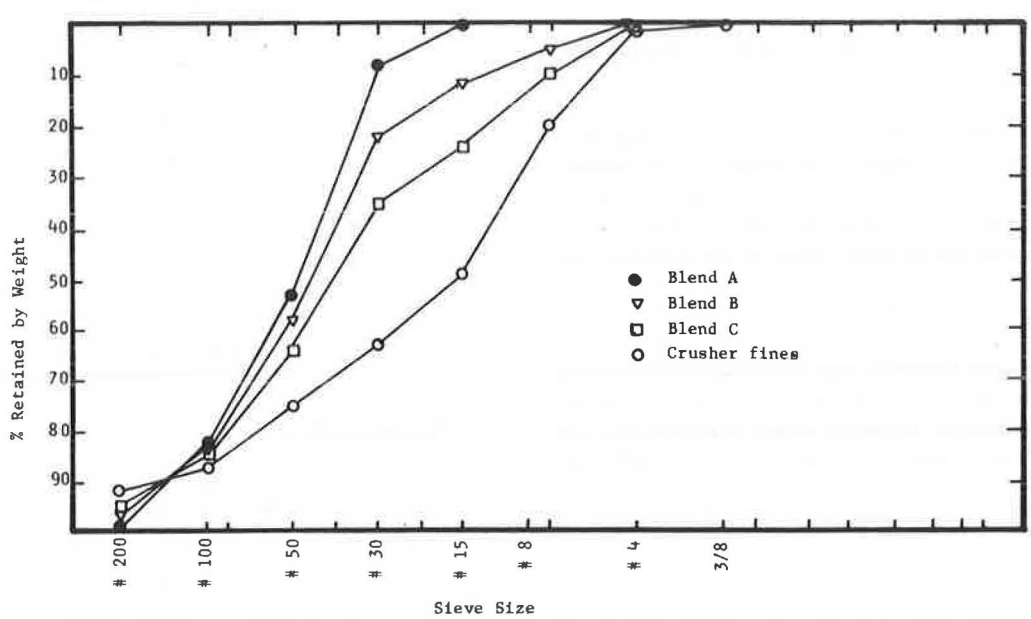



**FIGURE 2 Gradation of aggregates evaluated (ASTM C-136).**

- Determination of optimum total fluids that would produce maximum stability when varying the emulsified asphalt content and fixing premixing water, and
- Determination of asphalt residue required to achieve optimum properties when total water content is fixed.

This procedure was used to design the nine mixes considered. Portland cement was added after water but prior to the emulsified asphalt. Mixes were then compacted and cured in an oven for 12 hrs at 100° F inside the mold, and cured outside the mold for 12 more hrs. Finally, the specimens were vacuum-desiccated at 3.9 in/Hg for 48 hrs to accelerate curing and to eliminate any aging effect on the specimens.

Five specimens were prepared for each given set of variables. Three specimens were tested for Marshall stability and two were subjected to vacuum soaking to test for water sensitivity. A mix was accepted if it met the following criteria:

- Maximum stability (should not be less than 500 lbs),
- Minimum stability loss (retained stability index should not be less than 50 percent), and
- Good aggregate coating (more than 50 percent).

If any mix failed to meet these conditions, it was rejected.

A presentation of the optimization results for the nine mixes would be lengthy. A typical mix design result for mix EAM-C-1.5 is shown in Figure 3. The effects of the variation of crusher fines and the Portland cement content on the stability and water sensitivity of the mixes are shown in Figures 4 and 5.

The results of mix design optimization were analyzed and are summarized in Table 2, which identifies the parameters of each mix design. It has been observed that, although mix stability increased with an increase in the percentage of crusher fines, the water damage effect increased. However, this negative effect retarded as the cement content increased. For instance, the retained stability for mix type A (no crusher fines) was 60, 70, and 68.60 percent for 0, 1.5, and 3 percent cement content, respectively; the retained stability for mix type C (50 percent crusher fines included) was 32.9, 85.2, and 75.5 percent for 0, 1.5, and 3 percent cement content, respectively. Those mixes that showed low retained stability were omitted from further testing because they did not satisfy the criteria for water sensitivity.

The results generally indicated that stability tends to increase when the Portland cement content is increased or when the percentage of crusher fines in the blend is increased (Figure 4). The percent-retained stability tends to increase when the cement content is increased and to decrease when the crusher fines content is increased, as shown in Figure 5.

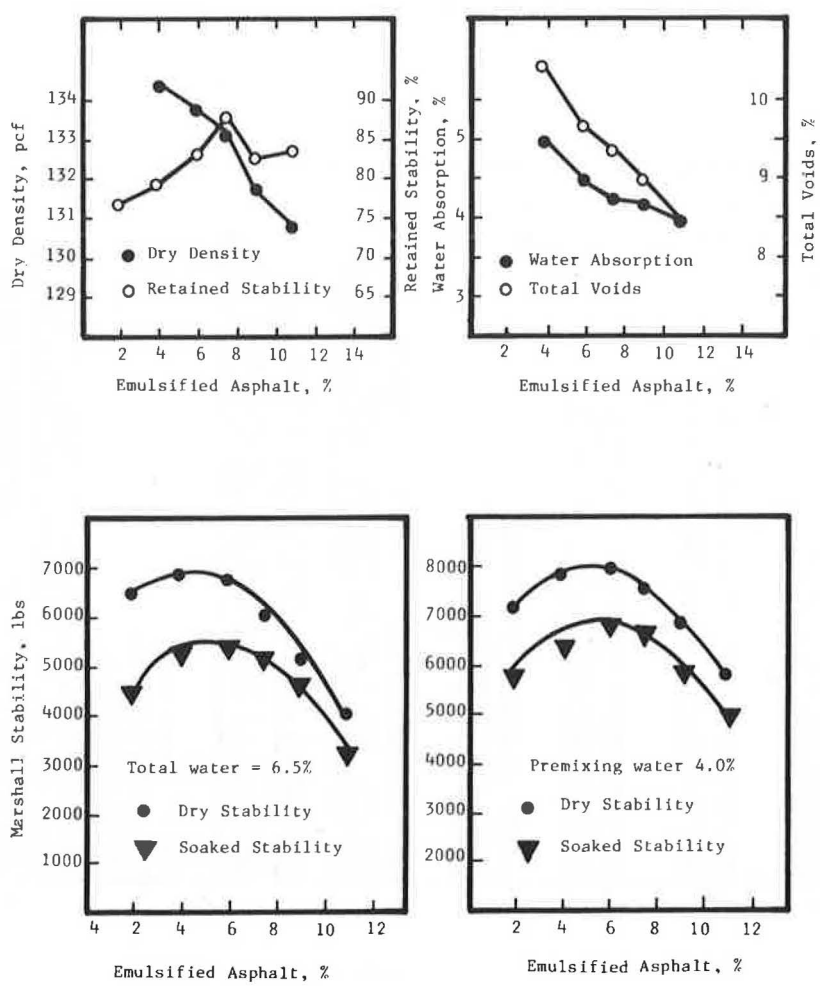



**FIGURE 3 Results of Marshall mix design for EAM-C-1.5.**

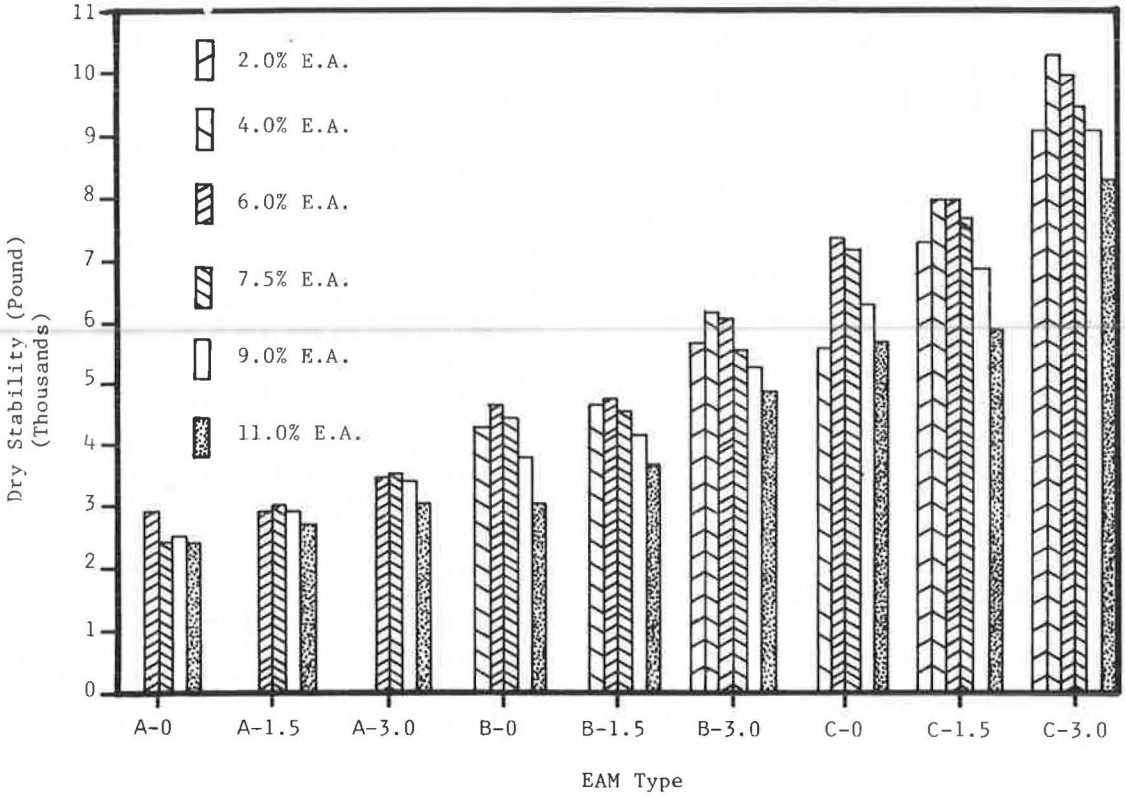



**FIGURE 4 Relation between EAM type and dry Marshall stability.**

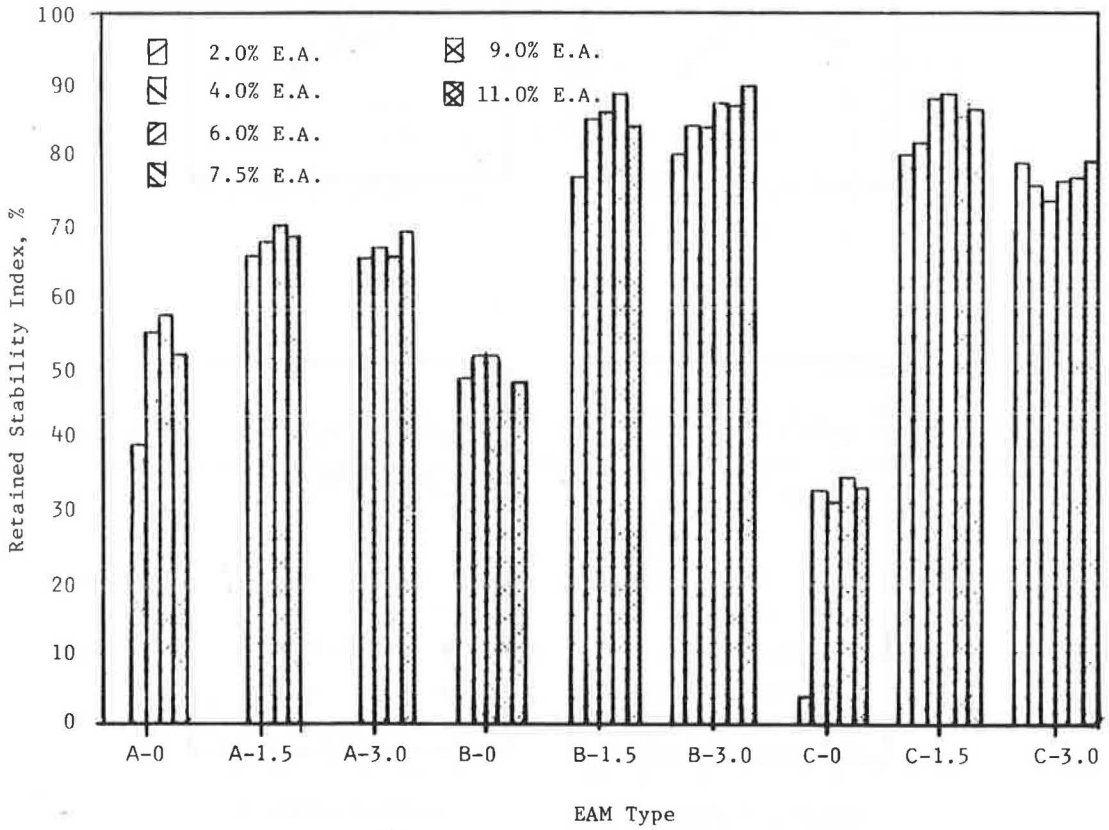



**FIGURE 5 Relation between EAM type and soaked Marshall stability.**

**TABLE 2 PROPERTIES OF THE DESIGNED MIXES**

| Designated Mix | EAM A-0 | EAM A-1.5 | EAM A-3 | EAM B-0 | EAM B-1.5 | EAM B-3 | EAM C-0 | EAM C-1.5 | EAM C-3 |
|---|---|---|---|---|---|---|---|---|---|
| Crusher fines (%) | 0.0 | 0.0 | 0.0 | 25 | 25 | 25 | 50 | 50 | 50 |
| Cement (%) | 0.0 | 1.5 | 3.0 | 0.0 | 1.5 | 3.0 | 0.0 | 1.5 | 3.0 |
| Dry stability (lb) | 2,500 | 3,000 | 3,500 | 4,400 | 4,700 | 6,200 | 7,300 | 8,100 | 10,200 |
| Soaked stability (lb) | 1,500 | 2,100 | 2,400 | 2,300 | 4,000 | 5,000 | 2,400 | 6,900 | 7,700 |
| Total water (%) | 6.69 | 6.58 | 6.08 | 6.58 | 6.58 | 6.05 | 6.58 | 6.05 | 5.73 |
| Emulsified asphalt content (%) | 9.00 | 8.00 | 7.50 | 7.50 | 6.00 | 5.00 | 6.00 | 5.00 | 4.00 |
| Dry density (pcf) | 115.20 | 117.10 | 117.60 | 121.90 | 123.50 | 126.00 | 131.30 | 134.00 | 134.60 |
| Retained stability (%) | 60.00 | 70.00 | 68.60 | 52.30 | 85.10 | 80.60 | 32.90 | 85.20 | 75.50 |
| Water absorption (%) | 12.20 | 10.2 | 10.20 | 4.40 | 4.90 | 4.80 | 4.80 | 4.60 | 4.80 |
| Total voids (%) | 26.60 | 24.40 | 24.00 | 17.30 | 17.50 | 16.30 | 9.70 | 10.00 | 10.10 |
| Coating (%) | 95 | 90 | 85 | 90 | 85 | 80 | 80 | 70 | 65 |

### Mix Design Equations

A series of curves similar to those of Figure 3 was developed and used to optimize each mix design. Optimum total water content and emulsified asphalt content were determined based on the criteria adopted earlier. To simplify the design process of blends of dune sand and crusher fines when treated with Portland cement, the multilinear regression analysis was carried out to fit the relation between total water (TW) and emulsified asphalt (EA) content versus crusher fines (CF) and cement (C) contents. The analysis resulted in the following two relations:

$$TW = 6.8211 - 0.0066\,(CF) - 0.2211\,(C) \quad \text{.....} \quad (1)$$

$$EA = 9.0278 - 0.063\,(CF) - 0.667\,(C) \quad \text{.....} \quad (2)$$

where

$TW$ = total water content in percentage of dry aggregate weight,
$EA$ = emulsified asphalt content in percentage of dry aggregate weight,
$CF$ = crusher fines percentage of dry aggregate weight, and
$C$ = cement percentage of dry aggregate weight.

The above equations were fitted with $R^2$ = 0.86 and 0.97, respectively. The F-tests were found to be significant at less than a 0.05 significance level. The above equations indicate that the addition of cement or crusher fines would decrease the total water and emulsified asphalt content required to achieve an optimum mix.

## LABORATORY EVALUATION OF OPTIMIZED MIXES

The developed mixes were evaluated by testing their behavior under dynamic loading to measure their fatigue and rutting susceptibility. A repeated load diametral test was used because it is simple and has been reported to be adequate for comparable studies (*6, 7*). Tests for all mixes were run on 4-in-diameter Marshall-size specimens fabricated at the optimum asphalt and water content as shown in Table 2.

Two groups of tests were made: Group 1 included static testing to determine the indirect tensile strength of the mixes at different temperatures. In this group, mixes EAM-B-0 and EAM-C-0 were excluded because of their low retained stability. Three samples for each mix were prepared and maintained at the designated temperature for 2 hrs to ensure all samples had a constant temperature. Samples were then tested at a 2 in/min stroke rate until failure. The ultimate load was recorded to determine the indirect tensile strength. For this test group, three temperatures were considered: 77, 104, and 131°F.

Group 2 included dynamic testing to determine resilient modulus, fatigue, and rutting characteristics. In this group of test mixes, EAM-A-0, B-0, and C-0 were excluded. The mix EAM-A-0 was excluded because of its low split tensile strength, as will be explained later in the analysis of Group 1, while mixes EAM-B-0 and C-0 were excluded because of their low retained stability, as mentioned earlier. Mixes with 1.5 and 3.0 cement content were continued for dynamic testing. Three identical samples were tested at each testing point, as was performed for Group 1. The procedures for the dynamic, repeated load diametral test can be found in the literature (*1, 2, 6, 7*). A test was performed on each sample by applying the vertical dynamic load and measuring the corresponding horizontal elastic strain. The dynamic load was increased until the designated initial strain value was obtained. The load was then kept constant for about 50 to 100 cycles, after which the horizontal elastic strain was measured for modulus of resilience calculations. Horizontal strain transducers were then removed and aluminum foil was attached to the specimen to disengage testing equipment when the specimen fails. The repeated load was kept constant and the vertical plastic deformation was measured by a vertical LVDT device at a various number of load repetitions until failure occurred. For all test samples, the following conditions were maintained to obtain uniform results:

- A static load of 10 lbs was applied to prevent a hammering action and to hold the specimen in place.

- The dynamic repeated load was a sinusoidal of 1 Hz frequency and a load period of 0.1 sec.
- The test temperature was kept constant at 104° F, which was found to be the most prevailing temperature during the summer in Saudi Arabia (*1, 2*).
- The load applied varied for each mix depending on the ultimate tensile strength. For all cases, the load range was between 0.1 and 0.4, which was the ultimate load at failure in the split load test. At least three levels of load were considered in the development of the fatigue curves. However, the tests were performed under constant load control. The load was adjusted to reach a predesignated initial tensile strain value. The range of the initial tensile strain was 20-100 $\times$ $10^{-6}$ in/in.
- Resilient modulus, fatigue life, and permanent deformation (rutting) were simultaneously evaluated for each tested sample.

## PRESENTATION AND ANALYSIS OF RESULTS

### Group 1: Split Tensile Test Results

In this test, the split tensile strength was evaluated at each temperature by the following equation:

$$S_t = 2\,P_{max}/\pi \cdot t \cdot d \qquad (3)$$

where

$S_t$ = split tensile strength (psi),
$P_{max}$ = the maximum load at failure (lbs), and
$t, d$ = sample thickness and diameter respectively (in).

For each mix, the average $S_t$ value for each set of three samples at each designated temperature was calculated. The results for all mixes are presented in Figure 6. It is shown that strength decreased as the temperature increased. All mixes behaved similarly in that aspect. A dune sand mix without any improvement of crusher fines or cement (curve A-0) had very weak strength. The strength was improved by adding cement (curves A-1.5 and A-3).

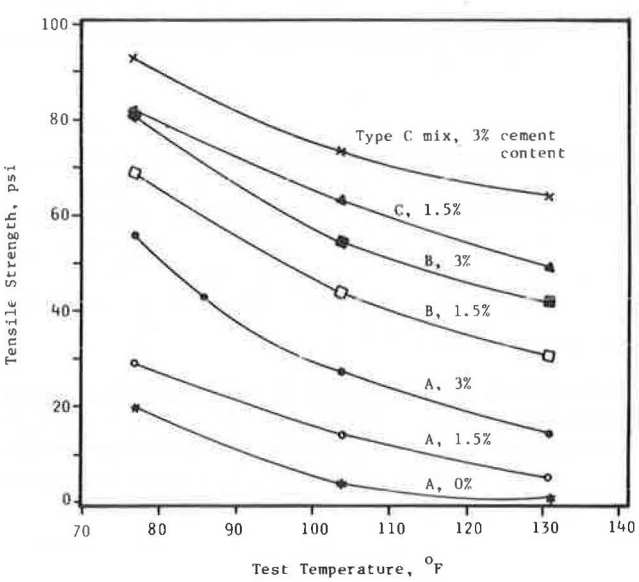



**FIGURE 6 Split tensile strength for EAM types at different temperatures.**

Mixes with 25 and 50 percent crusher fines (B and C mixes) had greater strength. The addition of cement similarly improved the strength significantly. Split tensile strength was generally greatly improved by the addition of crusher fines and Portland cement, especially at a high temperature. It is noted that at low temperatures (77° F), mix B-3 behaved similarly to mix C-1.5; that is, adding 25 percent crusher fines and 3 percent cement was almost equivalent to adding 50 percent crusher fines and 1.5 percent cement. However, this was not verified at higher temperatures. Pure dune sand mixes (A-0) had very weak strength and were therefore not tested further.

### Group 2: Dynamic Test Results

#### *Resilient Modulus*

The modulus of resilience $M_r$ for each mix was evaluated at three initial tensile strain levels. The initial tensile strain value was calculated by the following equation:

$$\varepsilon_t = (\Delta h) \times 0.52 \qquad (4)$$

and $M_r$ values were calculated by the following equation:

$$M_r = P(\mu + 0.2734)/t \cdot \Delta h \qquad (5)$$

where

$\varepsilon_t$ = horizontal elastic strain,
$\Delta h$ = total horizontal elastic deformation (in),
$P$ = applied dynamic repeated load (lbs),
$\mu$ = Poisson's ratio (0.35), and
$t$ = sample thickness (in).

Results of $M_r$ values for the designated mixes EAM-A-1.5, A-3, B-1.5, B-3, C-1.5, and C-3 are presented in Figure 7. Values of $M_r$ at some selected initial strain values are also listed in Table 3. Results indicate that the modulus tends to decrease as the initial tensile strain increases for all mixes. Mixes varied differently for a selected strain level. For example, at 60 $\times$ $10^{-6}$ in/in initial tensile strain, moduli values were 2, 9, and 12.5 $\times$ $10^5$ psi for mixes EAM-A-1.5, B-1.5, and C-1.5, respectively. Similarly, for 3 percent cement content, the moduli values were 4.2, 11.5, and 18.5 $\times$ $10^5$ psi for mixes EAM-A-3, B-3, and C-3, respectively. The effect of cement addition on $M_r$ is obviously significant, as shown in Figure 7. For example, the $M_r$ value of mix type A increased from 2 $\times$ $10^5$ to 4.2 $\times$ $10^5$ psi at 60 $\times$ $10^{-6}$ in/in initial strain rate when the cement content was increased from 1.5 to 3 percent.

The general conclusion that can be drawn from these results is that as the cement content increases, the modulus increases. This can be attributed to the increase in stiffness due to the cohesive effect of the cement in the mixes. Moduli values also increased as the crusher fine content increased.

#### *Fatigue Life*

Fatigue life was determined by the number of load repetitions at failure for a constant applied load for all designated mixes. The

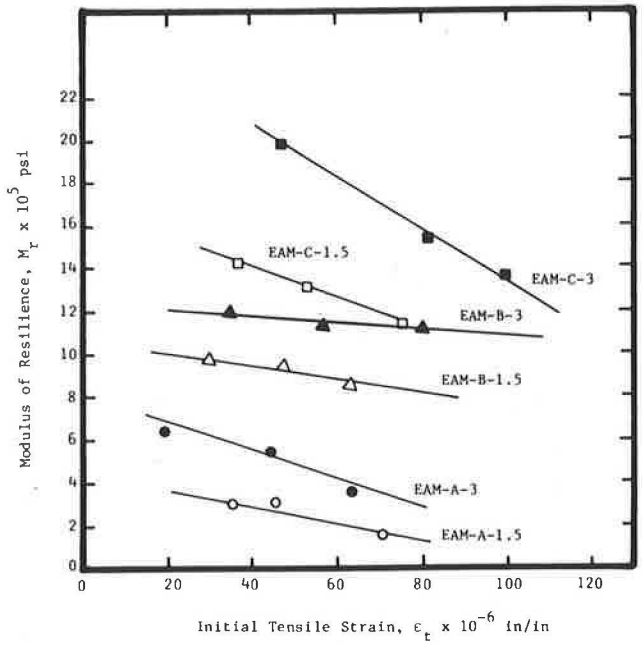



**FIGURE 7 Effect of initial tensile strain on modulus of EAM types.**

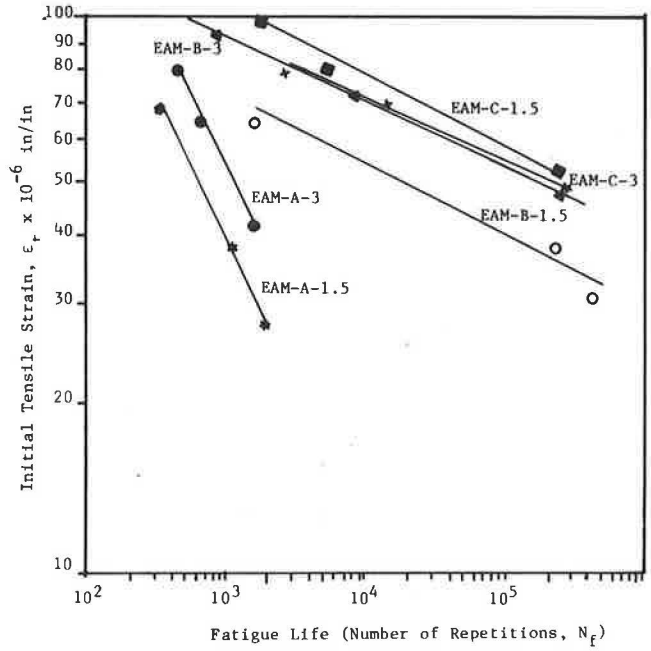



**FIGURE 8 Fatigue test results for EAM types.**

**TABLE 3 SUMMARY OF DYNAMIC TEST RESULTS**

| Designated Mix | Fatigue Test: Fatigue Parameter $a$ x $10^{-3}$ | Fatigue Test: Exponent $c$ | Modulus of Resilience Test: Applied Stress (psi) | Modulus of Resilience Test: Initial Tensile Strain $\varepsilon_t$ x $10^{-6}$ | Modulus of Resilience Test: $M_r$ x $10^3$ (psi) | Rutting Test: $A$ x $10^{-3}$ in./in. | Rutting Test: $b$ |
|---|---|---|---|---|---|---|---|
| EAM-A-1.5 | 0.925 | 0.455 | 14.75 | 68.8 | 300 | 4.21 | 0.289 |
| | | | 8.36 | 37.1 | 180 | 2.37 | 0.257 |
| A-3 | 1.91 | 0.518 | 31.49 | 63.5 | 380 | 3.36 | 0.191 |
| | | | 30.91 | 44.5 | 530 | 2.74 | 0.209 |
| EAM-B-1.5 | 0.161 | 0.113 | 33.64 | 47.6 | 950 | 3.90 | 0.101 |
| | | | 21.00 | 29.1 | 970 | 3.80 | 0.071 |
| B-3 | 0.170 | 0.101 | 35.30 | 57.1 | 1,130 | 2.68 | 0.135 |
| | | | 33.70 | 35.0 | 1,200 | 2.62 | 0.099 |
| EAM-C-1.5 | 0.252 | 0.138 | 52.51 | 52.9 | 1,280 | 3.61 | 0.057 |
| | | | 40.12 | 37.1 | 1,420 | 3.57 | 0.025 |
| C-3 | 0.182 | 0.118 | 94.95 | 82.1 | 1,540 | 2.81 | 0.282 |
| | | | 70.94 | 47.6 | 1,980 | 1.65 | 0.117 |

results of fatigue life $N_f$ were plotted against the initial strain for each test, as shown in Figure 8. A straight line relation on a log to log scale fit the results for each mix. The relationship can be presented by the following equation (*8*):

$$N_f = a\ (1/\varepsilon_t)^c \qquad (6)$$

where

$N_f$ = number of load repetitions at failure,
$\varepsilon_t$ = initial tensile strain,
$a$ = fatigue parameter that is a function of stress level applied (which was determined experimentally), and
$c$ = fatigue exponent (slope of the log $N_f$ - log $\varepsilon_t$ relationship).

An analysis of the results presented in Figure 8 shows that the fatigue exponent ($c$) was smaller for mixes EAM-A than for that of EAM-B and C. The exponent for mix A was about 0.5, whereas it was 0.12 for mixes B and C. This means that the tendency to fracture in the mixes with crusher fines was higher than that of dune sand mixes. However, the fatigue life of mixes B and C was much greater than that of mix A, which indicates that the addition of crusher fines would increase fatigue life as long as the induced tensile strain was maintained at a certain level. Results show that if the induced elastic strain was greater than 100 × $10^{-6}$ in/in, the fatigue life of mixes with crusher fines would be shorter than that of mixes with dune sand only. The addition of cement significantly improved fatigue characteristics. However, when 3 percent cement was added to the mix with 50 percent crusher fines (mix C-3), the fatigue life was shortened, which can be attributed to the high increase in the stiffness of the mix. On the other hand, mix B-3 (25 percent

crusher fine and 3 percent cement) behaved similarly to mix C-1.5 (50 percent crusher fines and 1.5 percent cement). This result coincided with that of the analysis of resilient modulus. It was generally concluded that emulsified asphalt sand mixes tended to be stiffer when the content of cement and crusher fines was increased.

*Rutting (Permanent Deformation)*

The vertical permanent strain during the repeated load test was obtained by measuring the vertical permanent deformation and was calculated by the following equation (*9*):

$$\varepsilon_p = Y_T(-0.1185 - \mu(0.03896))/(-0.8954 - \mu(0.0156)) \quad (7)$$

where

$\varepsilon_p$ = accumulated vertical strain (in),
$Y_T$ = total vertical deformation (in), and
$\mu$ = Poisson's ratio (0.35).

Permanent deformation results were plotted against corresponding load repetitions. The results were found to fit a linear relationship when drawn on a log to log scale, which can be represented by the following equation (*10*):

$$\varepsilon_p = AN^b$$

where

$A$ = intercept with $\varepsilon_p$ axis (log to log plot),
$b$ = slope of the straight line, and
$N$ = number of load applications (cycles).

Typical test results are presented in Figure 9. The results indicate that rutting decreased when cement content or the crusher fines percentage were increased, or both. This indicates that rutting in a desert-like environment can be controlled, or decreased, for sand mixes by adding Portland cement, crusher fines (or weathered limestone such as marl), or lime to the mix. It may be possible to achieve a balance between stiffness and tenderness by carefully controlling these components.

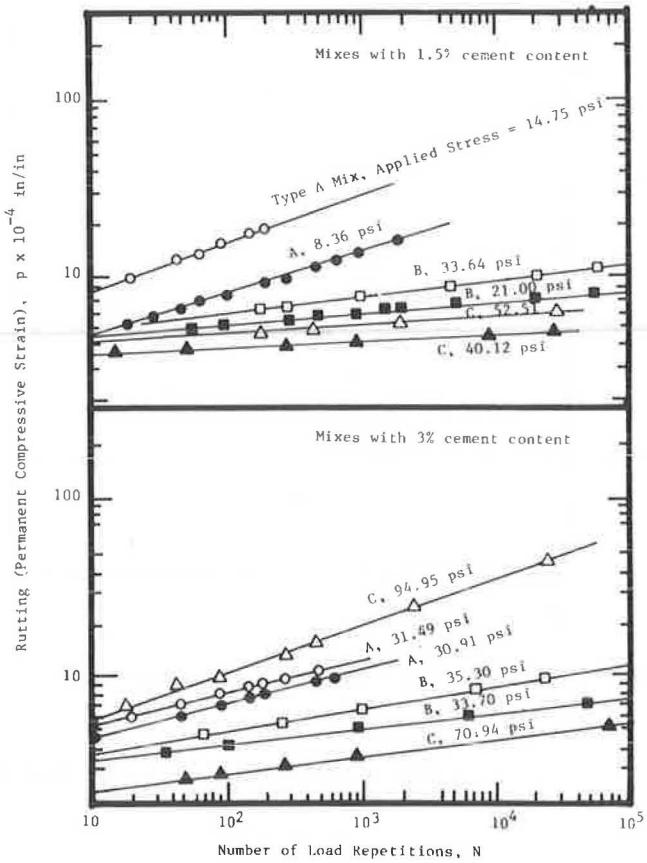



**FIGURE 9 Rutting test results for EAM types.**

## DESIGN APPLICATION

Design charts that were based on these test results were prepared for two cases that might be suitable for low-volume roads. Case 1 is for a full-depth EAM cold mix laid directly on subgrade and Case 2 is for an EAM road base overlaid by 2 in of hot asphalt concrete mix. Charts were also prepared for three types of mixes based on their ability to resist rutting, fatigue, and stability loss. The mixes EAM-A-3, EAM-B-3, and EAM-C-1.5 were selected and assigned moduli values of $3.5 \times 10^5$, $11 \times 10^5$, and $12 \times 10^5$, respectively. These values were obtained at $70 \times 10^{-6}$ in/in initial tensile strain. The subgrade was assigned CBR values of 3 to 15 and was assumed to have rutting behavior similar to that described by Shell (*11*). Lab fatigue curves in Figure 8 were shifted with a factor of 100 to suit field conditions as recommended by a number of researchers and were used to predict stabilized layer behavior (*12-15*). Shell's BISAR program was used to calculate critical stresses and strains under a standard, 18-kip single axle load (*11*). Fatigue and rutting life were then predicted, and the critical value was used in the design charts. Typical examples of the design charts for each material at 104° F are shown in Figures 10 to 12. It is shown in these charts that an increase in the percentage of crusher fines yielded a great decrease in the pavement thickness for the same traffic volume.

## CONCLUSIONS

1. Dune sand treated with emulsified asphalt alone was weak and unstable, and did not resist rutting under traffic loads, especially in a hot climate. The addition of crusher fines and Portland cement improved the mix properties significantly.
2. Two equations were developed to determine the optimum emulsified asphalt content for the cold mixes in regard to the percentage of crusher fines and cement added.
3. Thickness design charts were developed using the obtained results. The charts show that pavement thickness was reduced significantly if modified emulsified asphalt sand mixes were used.
4. The modified sand mixes that were developed have a great potential for use in low-volume roads, especially desert roads for which dune sands are available and hot asphalt mixes are uneconomical.

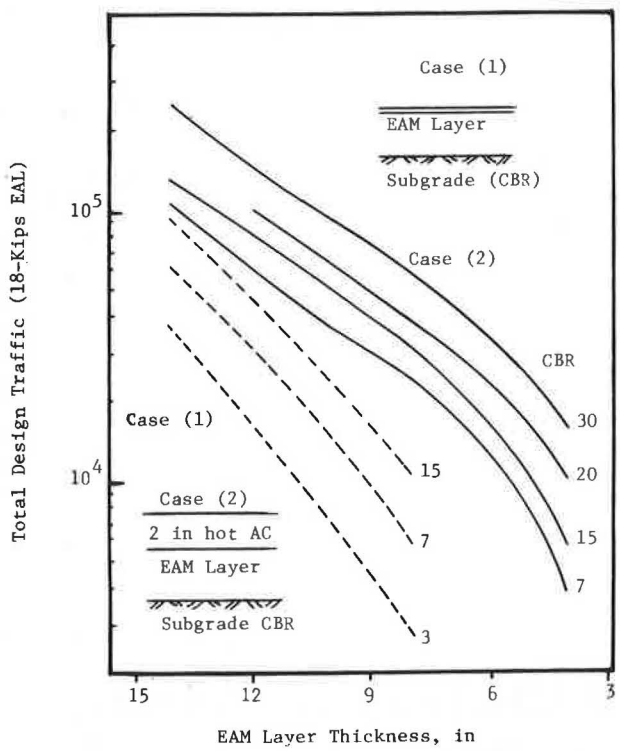



**FIGURE 10 Relation between EAM pavement thickness and total traffic for EAM-A-3 for low-volume roads.**

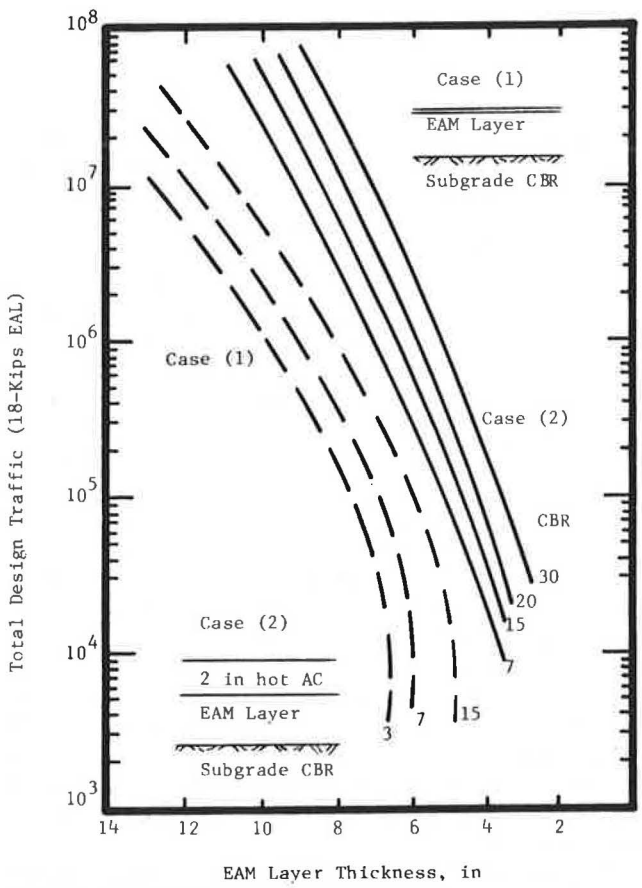



**FIGURE 11 Relation between EAM pavement thickness and total traffic for EAM-B-3 for low-volume roads.**

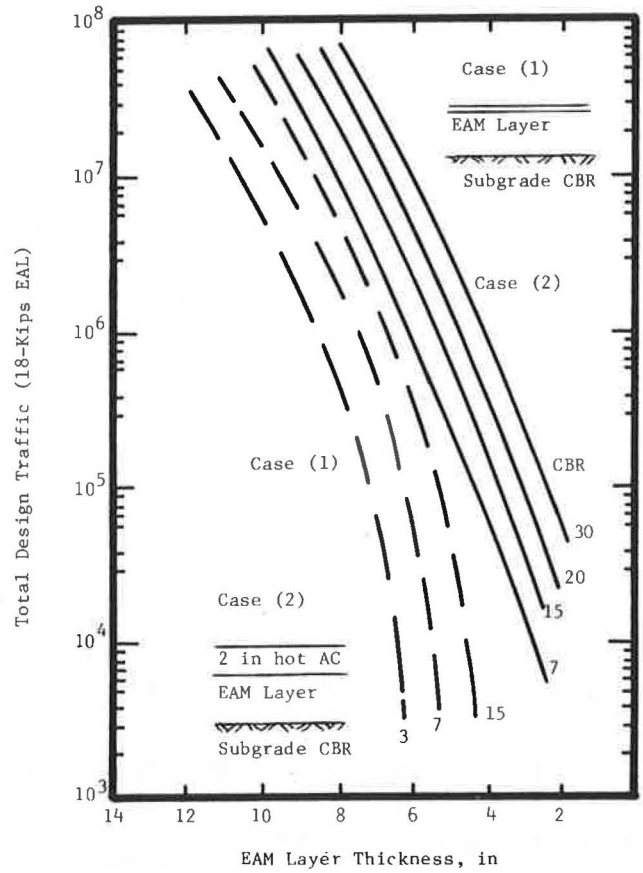



**FIGURE 12 Relation between EAM pavement thickness and total traffic for EAM-C-1.5 for low-volume roads.**

## ACKNOWLEDGMENT

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# Recent Investigations Into the Use of Plastic Laterites as Bases for Bituminous-Surfaced Low-Volume Roads

H. GRACE AND D. G. TOLL

**The development of specifications for bases for bituminous-surfaced roads in temperate zones is described in this paper. These specifications were developed in the 1920s and 1930s when compaction plant was light compared with that available today. These specifications have been adopted with limited modifications by developing countries in tropical zones for low-volume roads. The majority of lateritic gravels do not comply with the requirements of these specifications and bases of crushed stone or stabilized materials are normally used. A description is provided of full-scale, trial sections of road in Kenya and Malawi in which plastic lateritic gravel bases were used and the test results of site investigations gathered over a number of years. These trial sections have performed satisfactorily. A 3-year laboratory study of the Kenya laterite has been undertaken at Imperial College London to ascertain the reasons for their satisfactory performance. The construction procedures used and the relative densities found in the subgrade are also described. It is concluded that the satisfactory performance of the plastic laterite bases was a result of their high degree of compaction, the grading that resulted in low permeability and high stiffness, the construction procedures adopted, and the well-drained subgrade.**

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The construction of an all-weather access road is a vital step in the evolution of a subsistence economy to a trading economy. This evolution is necessary if the standard of living is to be raised and would help solve the many problems associated with education, health, transportation, and famines.

A network of all-weather roads ensures that the communities in its vicinity can benefit from and contribute to the development process through all the seasons of the year. An all-weather road network normally requires the provision of a bituminous surface, at least on the steeper grades.

The currently accepted specifications for bases beneath a bituminous surface impose limitations on grading, plasticity, and bearing capacity. In the majority of cases, the requirements of these specifications eliminate the use of locally occurring "as dug" materials. Processed materials such as crushed and graded stone or stabilized materials are therefore required. Both materials are expensive and cost much more than locally occurring as-dug materials.

When an earth or gravel road is upgraded to bituminous standards, the provision of the base course with a bituminous surface constitutes the greatest proportion of the cost. The savings that can be realized by using as-dug, locally occurring gravels as base material instead of crushed stone are substantial and often amount to between 20 percent and 60 percent of the total cost.

Lateritic gravels are widespread in developing countries. These gravels do not generally comply with accepted base specifications but they have often been used for economic