shoulders; to discuss laboratory investigations and field research; and to report current practices and recommendations for aggregate requirements, mix design, and construction methods for econocrete pavements.

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Construction and Performance of Sand-Asphalt Bases

Richard D. Barksdale

Sand-asphalt base construction practices and field performance are described based on extensive field inspections and interviews with state transportation personnel in Florida, Georgia, Maryland, and South Carolina. The results are also summarized of laboratory fatigue and rutting tests performed on both sand-asphalt and sand-stone asphalt mixes. Laboratory studies indicate that the fatigue characteristics of a sand-asphalt mix can be generally controlled by (a) limiting the void content to 12-15 percent, (b) using asphalt contents greater than 5.5-6.5 percent, and (c) designing the mix with a Marshall stability as high as practical. Important variables that affect rutting in a sand-asphalt mix are asphalt content, Marshall stability (or air void content that appears to be related to Marshall stability), and the characteristics for the aggregate. The specific effects of these variables are presented for selected mixes. Sand-asphalt and sand-stone blend asphalt mixes can be successfully used as bases on primary and Interstate highways. Rutting in pavements constructed by using 150- to 200-mm (6- to 8-in) sand-asphalt base is typically between 8 and 15 mm (0.3 and 0.6 in). An allowable rut depth for design purposes of 10 mm (0.4 in) is recommended for primary and Interstate pavements. The 50-blow Marshall mix design method can be used for sand-asphalt bases, provided rutting and fatigue resistance of the mix is taken into account. The blending of up to 75 percent crushed aggregate with sand offers an excellent way to decrease rutting and increase fatigue life of the mix while still using local sand.

Due to rising energy costs, construction of pavements by use of local materials, often of low quality, has become a necessity. Pavements constructed by using sand-asphalt mixes, if not properly designed, may undergo excessive rutting or premature fatigue distress. The purpose of this paper is to investigate the use of sand-asphalt in base-course construction. The findings presented are the result of field inspections and interviews with personnel of four selected state transportation organizations and a comprehensive laboratory investigation of fatigue and rutting characteristics of sand-asphalt mixes.

SELECTED CONSTRUCTION PRACTICES AND FIELD PERFORMANCE

Sand-asphalt mixes are used in the southeastern portion of the United States, primarily in the coastal plain areas. The construction practices and field performance of sand-asphalt bases in Florida, Georgia, Maryland, and South Carolina are summarized in this section. Other southern coastal plain states also use sand-asphalt bases.

Florida

The Florida Department of Transportation has used sand-asphalt bases extensively throughout Florida and has used, to a much lesser extent, sand-stone-asphalt blends. Pavements in Florida that have sand-asphalt bases were found to show good performance and surface rutting usually less than 12 mm (0.5 in). A cross slope of 2 percent is used in Florida and no problems of ponding water were reported. The surface cracking that develops is typically longitudinal. Because of the favorable climate and good subgrade conditions that occur throughout most of the state [usually a California bearing ratio (CBR) of 15-25], relatively light structural sections are used in Florida. For pavements subjected to high volumes of traffic, a 75- to 130-mm (3- to 5-in) thick asphalt-concrete (AC) surfacing mix is placed over approximately 250 mm (10 in) of sand-asphalt base. A 300-mm (12-in) prepared subgrade is used below the base. For low-volume roads, a 40-mm (1.5-in) thick sand-asphalt surfacing is placed over 150-200 mm (6-8 in) of unstabilized limerock base.

In metropolitan areas that have concentrated traffic that require relatively high stability, a sand-asphalt base that has a stability of 3.3 kN (750 lbf) is sometimes specified. Usually, however, a sand-stone blend AC mix is used to meet higher stability requirements. This

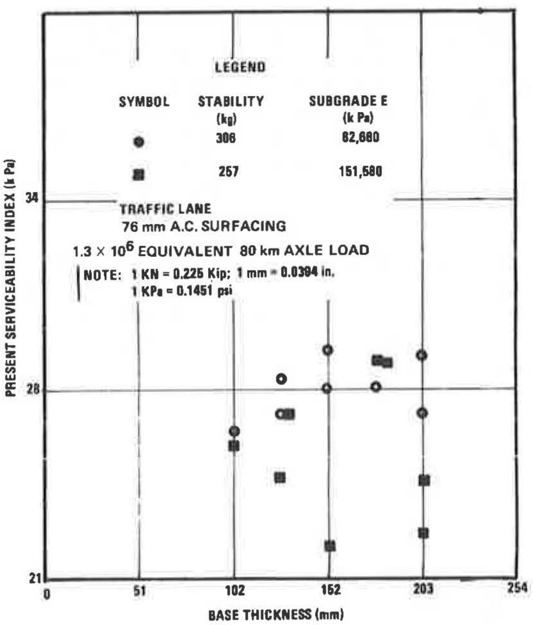


Figure 1. Variation of pavement performance with sand-asphalt base thickness and base stability—Marianna test road.

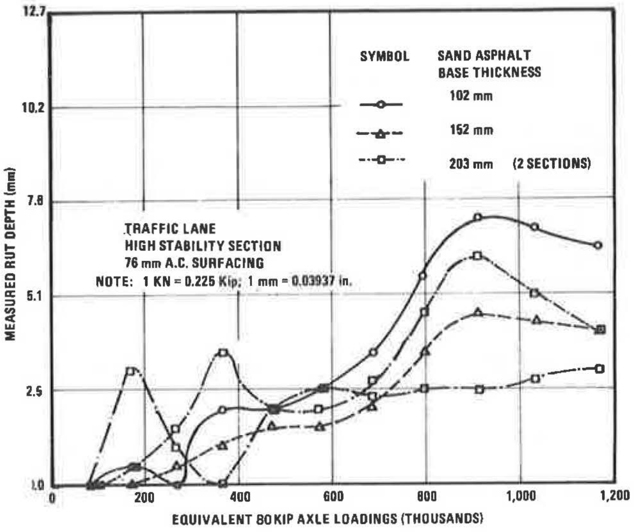


Figure 2. Effect of traffic loading and sand-asphalt base stability on rut depth at Marianna test road—traffic lane.

type mix has been used on about eight jobs. Sand-stone blend AC mixes can be placed in lifts up to 130-150 mm (5-6 in) in thickness and can have up to 25 percent sand. Natural sands are frequently used in the surface (up to 15-20 percent) and in binder courses. A 2-kN (500-lbf), 50-blow Marshall stability mix is generally used for sand-asphalt bases, although in some areas, such as West Palm Beach, mixes are sometimes used that have stabilities as low as 0.45-0.9 kN (100-200 lbf).

The air voids in sand-asphalt mixes are limited to 12 percent. For sand-asphalt bases, two sands or crushed-stone screenings are frequently blended to meet stability and gradation requirements. When possible, a well-graded sand that has angular grains is used. The rounded blow sands found in the Lake Wales area are typically blended with 50 percent screenings for stability. Specifications allow up to 12 percent fines, but experience shows that 6-7 percent fines are usually required to meet stability requirements. Up to 7 percent clay can now be used in the sand.

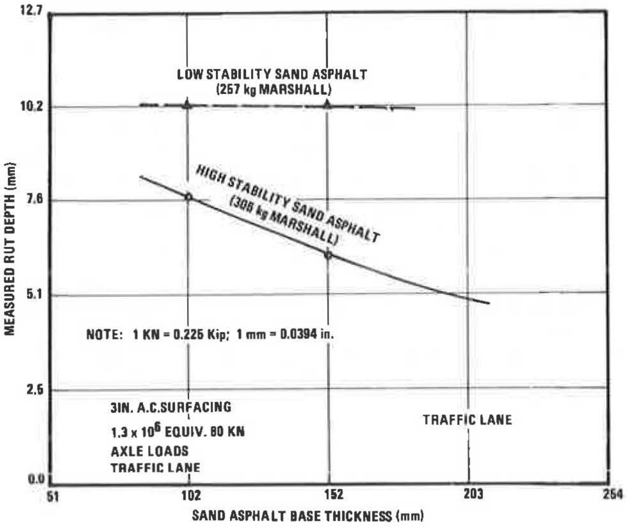


Figure 3. Rut depth as affected by sand-asphalt base thickness, base stability, and traffic lane—Marianna test road.

In sand-asphalt bases, Florida typically uses 6.5-7.5 percent of an AC-20 viscosity grade asphalt cement that has a viscosity at 60°C (140°F) between 160 and 240 Pa·s (1600 and 2400 poises). Field experience indicates, however, that asphalt cements that have viscosities in the range of 200-240 Pa·s (2000-2400 poises) at 60°C have fewer problems during laying than asphalt cements that have lower viscosities. Silicone, which has been found effective in keeping the mix from tearing during laying and for use with adsorptive aggregates, is added at the rate of 1.5 parts/1 000 000 to the asphalt cement. The addition of more than 2 parts/1 000 000 silicone has been found to cause problems with the mix. The Maryland and Georgia transportation departments also add silicone to sand-asphalt mixes, although South Carolina does not.

Sand-asphalts are mixed at approximately 121°C (250°F) and placed at about 92 or 93 percent of the 50-blow Marshall maximum density. Even this density is sometimes relatively difficult to obtain in the field. Also, sand-asphalt lift thickness greater than 75 mm (3 in) has been found to result in rolling of the layer during compaction. If the sand-asphalt hangs under the screed of the paving machine, the stability of the mix is reduced by adjusting the cold gate at the plant, changing the blend, or increasing the asphalt content of the mix. Florida is considering the use of 1.5-2 percent crushed stone screenings in all mixes, which is similar to the practice followed in Louisiana.

Test Roads

The Marianna test sections inspected were in excellent condition after 1.2 million equivalent 80-kN (18-kip) axle loadings and had values of 22-29 kPa (3.2-4.2 lbf/in^2) (Figure 1), as reported elsewhere (1). Only minor longitudinal cracking was observed locally in some sections. The section used consisted of a 75-mm (3-in) thick AC surface and binder overlaying a sand-asphalt base 100-200 mm (4-8 in) in thickness. The test sections rested on an excellent prepared sand subgrade 0.6 m (2 ft)

Table 1. Paractice usually followed by the Georgia Department of Transportation for the use of surfacing and leveling or patching sand-asphalt mixes.

Vehicles per Day	Truck Traffic (%)	Allowable Mixes
0-499	<7	SA-1 for surface and leveling or patching[a]
0-499	>7	SA-2 for surface and patching[b]
500-999	<7	SA-2 for surface and leveling or patching
500-999	>7	Sand-asphalt surface not permissible; use G or H mix for leveling and patching
1000-1999	Any	Sand asphalt not permissible; use G or H mix for leveling and patching
2000	Any	Use H, F, E, modified B, or D mix

[a] Sand-asphalt mix 1 (SA-1) = 5.5-7.0 percent AC, 5-16 flow, 50-blow Marshall stability of 1.56 kN (350 lbf).

[b] Sand-asphalt mix 2 (SA-2) = 5.5-7.5 percent AC, 5-16 flow, 50-blow Marshall stability of 3.11 kN (700 lbf).

thick. Rut depths in the sections were typically 6-8 mm (0.25-0.3 in) at the time of the field inspection; maximum observed rut depths were 12 mm (0.5 in). The sand-asphalt base was constructed by using an excellent local sand that has a small amount of clay. The average Marshall stability of the sand-asphalt base varied from 2.5 to 3.0 kN (566 to 675 lbf).

Rutting in the Marianna test sections was found to gradually increase with the number of wheel load repetitions (Figure 2). The 3.0-kN (674-lbf) Marshall stability sections had an average rut depth of 6 mm (0.25 in) in the traffic lane compared to 11 mm (0.43 in) for the 2.5-kN (566-lbf) Marshall stability sections (Figure 3). Therefore, for conditions existing at the Marianna test road, increasing the Marshall stability from 2.5 kN to 3.0 kN resulted in a significant reduction in rut depth in the traffic lane. This large difference in observed rut depths between the low- and high-stability sections was not reflected in measured present serviceability index (PSI) values.

The Marianna test road was constructed over a very stiff subgrade that had a modulus of elasticity that was greater than the reported modulus of the sand-asphalt base (1). The presence of the stiff subgrade undoubtedly influenced the observed results and must be considered in extrapolating these results to other pavements. Rutting in the high-stability sections was inversely proportional to base thickness; however, in low-stability sections it was constant (Figure 3) or else increased with base thickness.

The performance of sand-asphalt and limerock bases has been compared at the Lake Wales test road (2,3). The sand-asphalt and limerock base sections both had a 40-mm (1.5-in) and 75-mm (3-in) AC surfacing and a 75- to 250-mm (3- to 10-in) thick base. After approximately 1.75 million equivalent 80-kN (18-kip) axle loads, the sections that had limerock bases all were in good condition, although some longitudinal cracking was observed in the thinner sections. The sand-asphalt base sections that had a 75-mm surfacing and 200-mm (8-in) surfacing were not cracked, whereas the sections that had a 40-mm surfacing were cracked. Moderate transverse cracking was observed in the sand-asphalt sections that had 100- to 150-mm (4- to 6-in) bases for both 40- and 75-mm AC surfaces.

In the Lake Wales test road, after 1.75 million 80-kN axle loadings, the limerock base sections were performing better structurally than those constructed with sand-asphalt. Perhaps one factor that partially accounted for the performance difference was the use of blow sand in the sand-asphalt. These blow sands are considered inferior to the more angular sands found in the northern part of the state. These sands were, however, blended with equal amounts of crushed-stone screenings, which resulted in mean Marshall stabilities that varied from 1.5 to 2.3 kN (340 to 528 lbf).

Georgia

The Georgia Department of Transportation has used sand-asphalt for surfacing, leveling, and base courses since about 1974. Therefore, extensive histories of the performance of sand-asphalt construction have not been developed. In the 4th district, sand-asphalt is used most often for leveling and thin overlay surfacing work. Sand-asphalt surfacing and leveling mixes are now generally used for the levels of traffic summarized in Table 1. Sand can be used in AC surface, binder, and base mixes as long as the standard specifications are satisfied, including gradation and stability requirements. The amount of local sand that can be used is limited in only the surface E-mix to 30 percent.

Recently Georgia has been using an asphalt content of 5.5-7 percent in sand-asphalt mixes. In the Albany and Bainbridge areas, screenings are generally blended with the sand, and an asphalt content of 7-7.5 percent is usually required. Type 1 sand-asphalt (SA-1) requires a minimum 50-blow Marshall stability of 1.55 kN (350 lbf), and type 2 sand-asphalt (SA-2) requires a minimum stability of 3.1 kN (700 lbf). Both sand-asphalt mixes require a maximum air voids content of 15 percent, a flow of 5-15, a 24-h immersion compression retention of 70 percent, and 95 percent unstripped aggregate. The sand equivalent required is 25, although if blending is performed, the sand equivalent of the natural sand could be as low as 20. Some problems with clay balling have been reported with sands that have sand equivalencies in the vicinity of 20-22 when a drum mixer is used. In conventional asphalt plants, the clay balls are screened out and have not caused any problems. Gradation specifications for the sand require that 100 percent pass the 300-μm (No. 50) sieve and between 2 and 20 percent pass the 75-μm (No. 200) sieve.

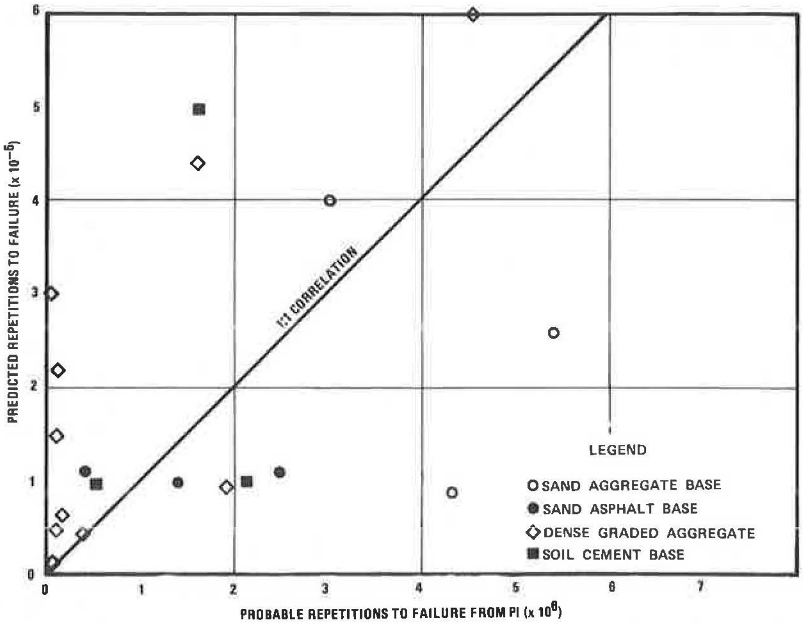
Experience in Georgia and elsewhere has shown that a dirty sand that has approximately 4-7 percent clay is probably best, provided the clay breaks down and does not form balls during mixing.

Sand-asphalt base courses are placed in 50-mm (2-in) maximum-lift thicknesses and have a total thickness of usually 150 mm (6 in). Leveling courses are placed in 25-mm (1-in) lift thicknesses and have a maximum total thickness of 50 mm. The sand-asphalt mix is generally laid at 140°C to 150°C (280°F to 300°F), although mixes are sometimes placed at temperatures as low as 116°C (240°F). Some problems with obtaining a good bond of the sand-asphalt have been experienced. As a result, specifications now require either an SS-1 or AC tack coat; the AC tack coat is preferred by some engineers.

Maryland

The Maryland Department of Transportation typically has placed 130-180 mm (5-7 in) of AC over a 50-mm (6-in) sand-asphalt base. An asphalt content of typically 4.2-4.8 percent is used, and good performance is observed for this type construction. Specifications allow the use of either a natural sand, screenings, or sand-aggregate blends. The only gradation requirement is that not more than 12 percent pass the 75-μm sieve. Also, the sand-asphalt base mixes are required to have a 50-blow Marshall stability of not less than 1.1 kN (250 lbf) and flows of less than 16. The sand-asphalt base is placed at a density of 95 percent of the 50-blow Marshall value.

Figure 4. Relationship between observed and predicted pavement failure for selected Maryland pavements.



To overcome problems experienced with separation between 75-mm (3-in) layers, Maryland has begun either to use one 150-mm (6-in) layer or to increase the asphalt content by approximately 0.5 percent (4). The sand-asphalt is mixed at a temperature of about 149°C (300°F), and rolling begins at about 77°-132°C (260°-270°F). A detailed description of construction of thick and thin lifts is given elsewhere (4, 5).

Sand-asphalt base mixes have been frequently used for subdivision streets, parking lots, and other private work in Maryland. Usually a 40-mm (1.5-in) AC surfacing is placed over a 130-mm (5-in) sand-asphalt base that has about 4 percent asphalt cement. To minimize the quantity of asphalt cement, a dirty sand is used that has loose gradation requirements. The plant is run on the cold side at 120°-135°C (250°-275°F), and a mixing time of 30-35 s is used. This low asphalt content sand-asphalt is compacted immediately after placement by using a rubber-tired roller followed about 60 m (200 ft) by a steel-wheel roller. For this sand-asphalt base, 150 mm is assumed to be equivalent to 100 mm (4 in) of crushed-stone black base.

Maryland Base-Course Study

Stromberg (6, 7) studied the performance of 31 pavements in Maryland that have various base types, including sand-asphalt, soil-cement, sand-aggregate, crushed stone, gravel, and water-bound macadam. Traffic loadings were on the order of 1-2 million 80-kN (18-kip) equivalent axle loads. The soil-cement pavement sections typically consisted of a 150-mm soil-cement base placed beneath 150 mm of AC. The sand-asphalt sections consisted of 75-90 mm (3-3.5 in) of AC above a 130- to 180-mm (5- to 7-in) sand-asphalt base. Extraction tests indicated that the sand-asphalt bases had an average asphalt content of 4-4.5 percent, 3.7-4.3 percent fines, and void contents in the range of 13.8-14.6 percent. The soil-cement base had an average unconfined compressive strength of 11 400 kPa (1653 lbf/in^2).

Two of the three sand-asphalt base pavements were found to perform extremely well (Figure 4), and the performance of the third section was below that predicted. In general, the sections that had sand-asphalt and soil-cement bases exhibited good performance when compared with the dense-graded aggregate base pavements. Predicted pavement life was generally greater than observed. After 1 million repetitions, the sand-asphalt base sections had 15 mm (0.15 in) of rutting, which was approximately the same as in the dense-graded aggregate-base sections. Probably the relatively small amount of rutting in the sand-asphalt bases was primarily due to using an average asphalt content of only 4-4.5 percent and a relatively high degree of compaction.

South Carolina

The South Carolina Department of Highways uses sand-asphalt extensively for bases in the Coastal Plain. On Interstate work, a structural section has been used consisting of a 50-mm (2-in) AC surfacing, 100-mm (4-in) AC binder, and 150-mm (6-in) sand-asphalt base. Thicker sections were previously used. Only A-4 soils or better are used in the top 460 mm (18 in) of the subgrade for Interstate work. On primary roadways, a section often used consists of a 40- to 60-mm (1.5- to 2.5-in) AC surfacing, 60-mm (2.5-in) AC binder, and a 150-mm sand-asphalt base.

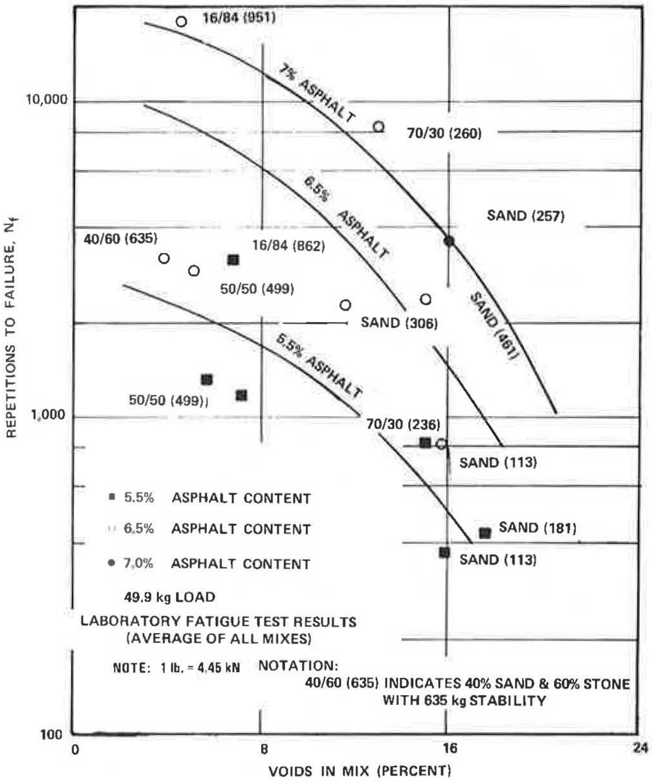
Sand-asphalt is used as a thin surface overlay on existing secondary roads; the overlay thickness typically varies from 19-20 mm (0.75-0.8 in). Sand-asphalt is seldom used for new construction on lightly traveled roads in South Carolina.

Many pavements constructed with sand-asphalt bases (such as I-20) have performed satisfactorily. One section on I-20 was observed to be in excellent condition after 1.2 million equivalent 80-kN axle loads (one direction). Cracking was not observed in this or similar sections, although rut depths measured with a 1.2-m (4-ft) straightedge were typically 6-10 mm (0.25-0.4 in). This section consists of 200 mm (8 in) of AC overlaying a 200-mm sand-asphalt base. No problems with ponding of water have been reported on I-20, which has a cross slope of 1.67 percent.

An AC-20 viscosity grade asphalt cement usually is used in sand-asphalt mixes that have asphalt contents that vary from 4.2 to 4.8 percent. Substitution of local sands for the finer portions of surfacing and binder mixes is also permitted in South Carolina. For sand-asphalt base mixes, essentially the only gradation specification requires that the sand have less than 12 percent fines (as determined by washing) with up to 6 percent clay (as determined by the elutriation test). Although a 1.3-kN (300-lbf) Marshall stability mix is used for most work, a stability of 2.2 kN (500 lbf) has been used on some primary and Interstate construction. In some instances, sand-asphalt mixes have been used that consist entirely of crushed-stone screenings and have a sand equivalent greater than 35. The sand-asphalt is mixed at temperatures from 121°C to 163°C (250°F to 325°F) with a maximum reduction in temperature of 11°C (20°F) at the time of rolling.

No specification requirements are placed on either density or rolling procedures. South Carolina has experienced rutting problems in some sections; reported rut depths in the worst case were 25-40 mm (1-1.5 in) on several roadways that used sand-asphalt bases. Undoubtedly these rutting problems were caused partially by the lack of field density control and perhaps by the use of low-stability sand-asphalt bases up to 250 mm (10 in) in thickness.

Figure 5. Effect of air voids and asphalt content on fatigue life of sand-asphalt and sand-stone blend mixes.



LABORATORY FATIGUE AND RUTTING TESTS

Fatigue and rutting tests were performed on a wide range of sand-asphalt and sand-stone base-course mixes. The materials used, test procedures, and equipment have been described in detail elsewhere (5). Bituminous base materials tested included both pure sand-asphalt mixes and also sand-stone blends that have stone contents that vary from 30 to 84 percent. The asphalt-cement content varied from 5 to 7 percent, and an AC-20 viscosity grade asphalt was used in all the tests.

The fatigue test consisted of applying a cyclic load until failure at the center of a rectangular beam specimen supported on a rubber subgrade. The repeated-load triaxial test used to evaluate the rutting properties of the mix consisted of subjecting a cylindrical specimen to 100 000 repetitions of axial load. An axial repeated deviator stress of 170 kPa (25 lbf/in^2) and a confining pressure of 34 kPa (5 lbf/in^2) was used for this study (5).

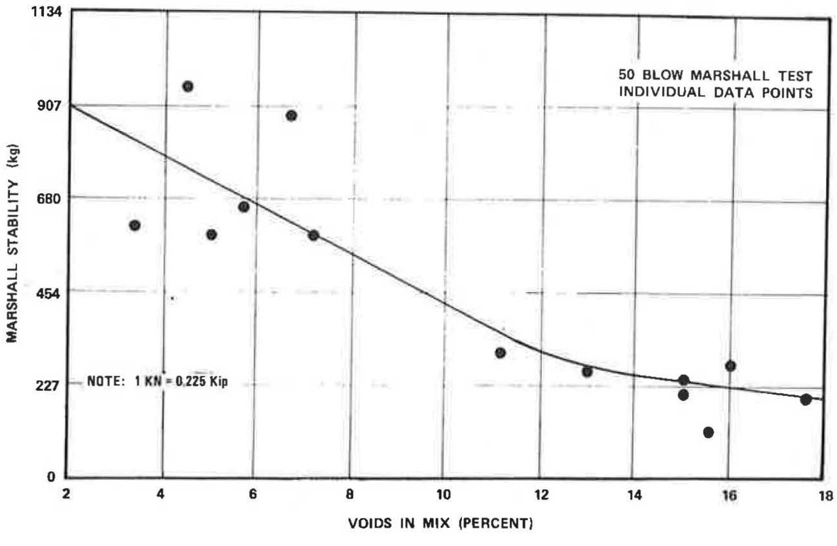
Fatigue Test Results

Recent research has shown that, in general, fatigue curves given in terms of tensile strain cannot be directly compared (5, 8, 9). The constant-load method of interpreting the fatigue test results, therefore, was used in this study (5). The constant-load method of interpretation consists of comparing, for a constant applied load (of equal magnitude for each test), the number of repetitions required to cause failure of different stabilized mixes. The constant-load method gives a reliable comparison when the fatigue test simulates field support and loading conditions with reasonable accuracy (5, 9).

Larger asphalt contents and lower air voids in the sand and sand-stone blend mixes were found to increase fatigue life significantly, as illustrated in Figure 5.

A general trend was found between air voids in the mix and Marshall stability for the sand-asphalt and sand-stone blend base mixes tested (Figure 6). Therefore,

Figure 6. Relationship between Marshall stability and voids in mix for sand-asphalt and sand-stone blends tested.



the data from Figure 5 can be replotted by using 50-blow Marshall stability rather than void content, as illustrated in Figure 7. Increased fatigue life with increasing Marshall stability and asphalt content occurred for Marshall stabilities between 0.9 to 8.9 kN (200 to 2000 lbf), which was the range of stabilities tested.

These test results clearly show that the fatigue life of a sand-asphalt or sand-stone blend mix is directly related to asphalt content and air voids that have also been found for conventional mixes (7, 8). For the sand and sand-stone mixes studied, other undefined variables also appeared to influence the test results. Although Marshall stability is probably not a fundamental independent variable, as air voids appears to be, Marshall stability (or air voids) together with asphalt content can be used in design for estimating the fatigue resistance of sand-asphalt and sand-stone blends.

Rutting Test Results

Rutting test results for the sand and sand-stone asphalt mixes are summarized in Figures 8 and 9. Laboratory test results are presented in terms of the theoretical rut depth that would occur in the base of a typical pavement section that has a sand-asphalt or sand-stone blend base. Comparisons of rut depths are made for full-depth bituminous pavements that have a 90-mm (3.5-in) AC surfacing and a 180-mm (7-in) sand-asphalt or sand-stone blend base. This pavement section is assumed to be constructed over a reasonably good subgrade that has a modulus of elasticity of approximately 28 000 kPa (4000 lbf/in^2). The pavement section is assumed to be located in the coastal plain area of the southeast, where the mean pavement temperature for rutting is close to 35°C (95°F). The rut depths given are for 1.2×10^6 equivalent 80-kN (18-kip) single axle loads.

By comparing predicted rut depths rather than the measured plastic strains, a better feeling is developed for the effect of the mix variables on the actual relative magnitude of rutting that is likely to develop in a typical pavement section. The theoretical approach used to calculate the rut depth has been described in detail elsewhere (5).

With an increase in asphalt content, rut depth in the sand-asphalt and sand-stone blends tested rose at a slightly increasing rate (Figure 8). For an increase in asphalt content from 5.5 to 6.5 percent, the rut depth increased by 40-70 percent, which is similar to the rate for a typical AC black-base mix.

Figure 8 shows that the addition of crushed stone to a sand-asphalt mix is effective in reducing rutting of the mix. The reduction in rut depth due to increased stone content is probably due to increased internal friction of the mineral skeleton that results from the presence of large-size stone aggregate in the sand-stone blends. The large-size aggregate tends to decrease the number of grain-to-grain point contacts and increase aggregate interlock.

The influence on rut depth of Marshall stability and asphalt content for Altamaha sand-stone blends is shown in Figure 9 as solid lines. For these mixes, which were composed of similar materials, rut depth for a given asphalt content was found to be almost inversely proportional to the 50-blow Marshall stability of the mix. This finding indicates that Marshall stability can be used as a rough guide for evaluating the relative beneficial effect on rutting of blending crushed stone with sand or blending two sands together.

When all the mixes shown in Figure 9 are considered, more scatter in data occurs than for just the Altamaha mixes that were prepared from the same materials. This indicates that other less well-defined characteristics of the mix, such as grain size, angularity, and gradation of the sand, also have important effects on rutting.

The theoretical method proposed by Barksdale and others (5) for estimating rutting in pavements that contain sand-asphalt and sand-stone blends should be used when a reasonably reliable estimate of rut depth is required. A preliminary estimate of the relative susceptibility of a sand-asphalt base to rutting can, however, be obtained from the generalized design relationship given in Figure 10 (5). The total rut depth of the section is obtained by adding the rut depth in the sand-asphalt base obtained from the figure to that which occurs in the surfacing and subgrade. The design section on which this figure is based was previously given in this section.

Figure 10 was developed for a mean pavement temperature with respect to rutting of 35°C (95°F), which was found to exist in the coastal plain areas of the southeast. Since the magnitude of rutting is influenced by other factors (in addition to voids or Marshall stability), this figure should only be used as a general guide. Neither of the proposed methods fully considers the relationship of constant or increasing rut depth with base thickness observed at the Marianna test road for low-stability sections (Figure 3).

ALLOWABLE RUT DEPTH

The allowable rut depth that a pavement can undergo is controlled by both safety and structural considerations. If a sufficient amount of water ponds in a rut, hydroplaning or loss of skid resistance will occur. The amount of rutting that occurs before ponding depends on the cross slope of the pavement and the transverse width of the rut. For rolled asphalt construction in England, Lister and Addis (10) have found that rut depths greater than approximately 13 mm (0.5 in) result in the ponding of water on pavements that have a 2.5 percent cross slope. They also found that the optimum time for overlaying a rolled asphalt pavement corresponds to a rut depth of approximately 10 mm (0.4 in) measured with a 1.8-m (6-ft) straightedge. The 10-mm rut depth is the limiting value of rutting before loss of structural strength starts to occur. In the United Kingdom, a rut depth of 19 mm (0.75 in) is generally defined as pavement failure.

The PSI value of sections at the American Association of State Highway Officials (AASHO) Road Test were found by Lister and Addis (10) to be inversely proportional to rut depth. The relationship appears to be conservative for pavements that have sand-asphalt bases (5).

Field inspections indicate that the rutting developed in sand-asphalt base pavements is relatively wide, which possibly accounts for the higher than expected PSI ratings. To take into consideration the width of the rut, Verstraeten and others (11) have developed rut criteria for use in Belgium based on the transverse slope of the rut. For highways in Switzerland, Huschek (12) proposed a 4-mm (0.15-in) limiting water film on the surface. To satisfy this criterion, Huschek indicated that the rut depth must be less than 18 mm (0.7 in) for a 2.5 percent cross slope, which agrees with the criteria for rut depth proposed by Verstraeten and others (11). Use of sand-asphalt mixes requires that relatively large rut depth be permitted. For now, an allowable average design rut depth of 10 mm (0.4 in) is recommended for primary and Interstate pavements and 15 mm (0.6 in) for secondary roads constructed by using high asphalt contents or sand-asphalt mixes. This level of rutting is in agreement with the finding of Lister and Addis (10). Rut depths of this magnitude have been observed on test sections in Florida (2) and Interstate pavements in South Carolina (5). No problems due to this level of rutting were reported either

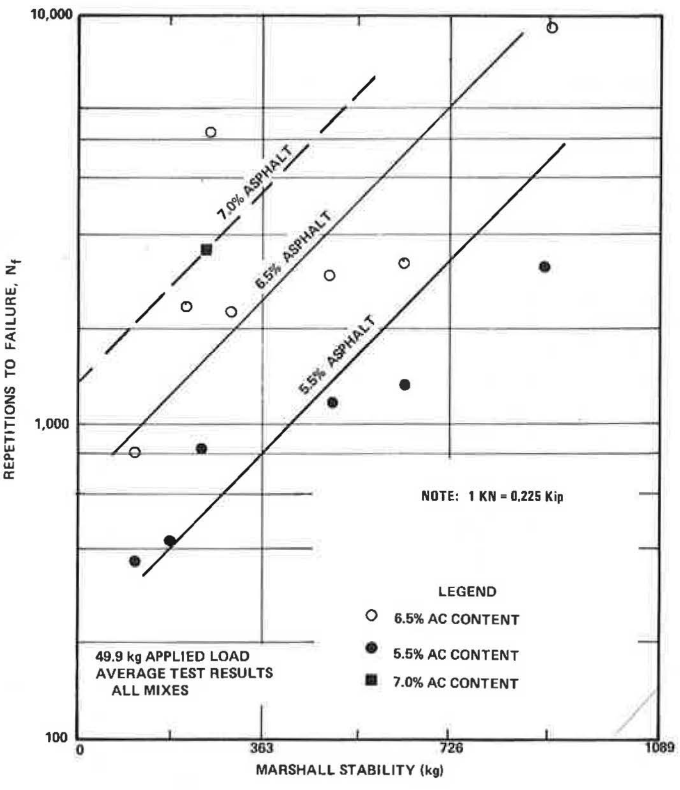


Figure 7. General effect of Marshall stability and asphalt content on fatigue life: all sand-asphalt and sand-stone mixes.

Figure 8. Relationship between stone content and rut depth for varying asphalt contents.

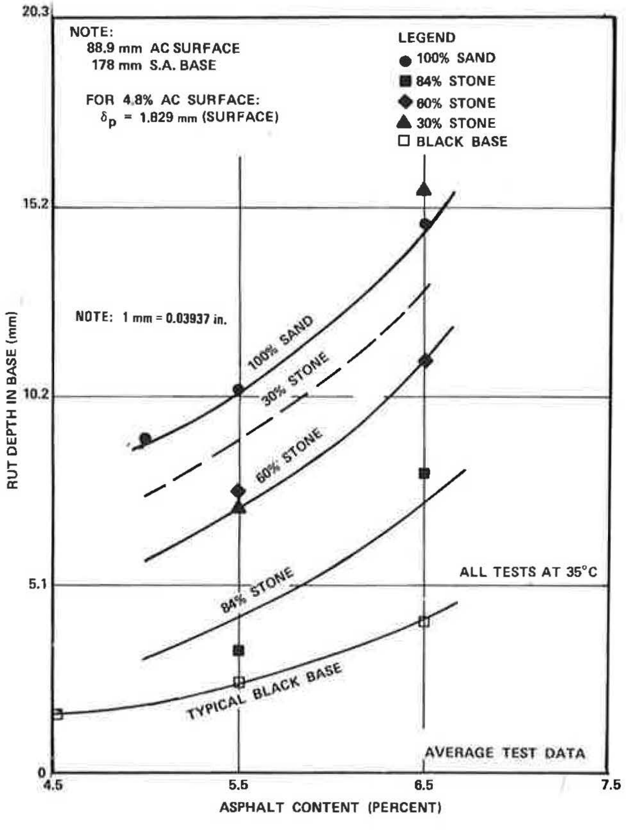
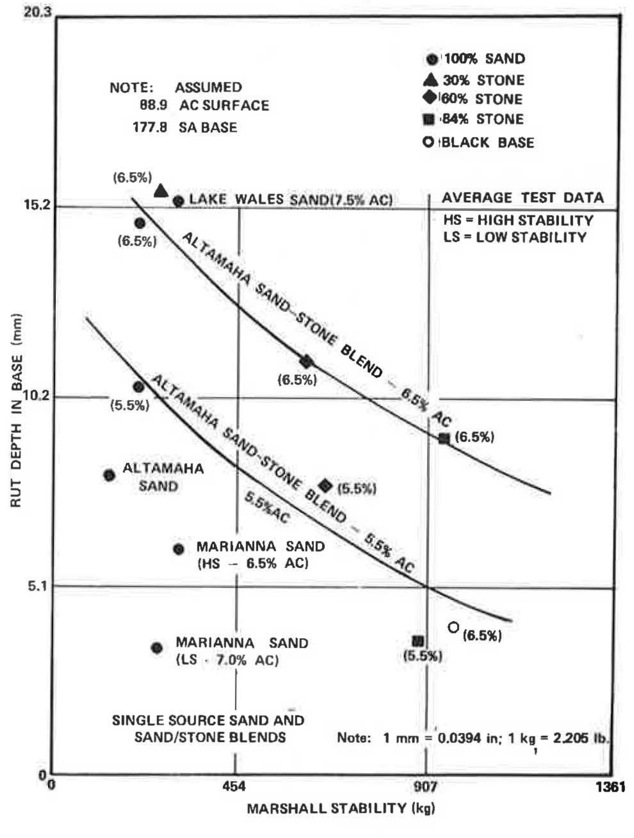


Figure 9. Effect of Marshall stability and asphalt content on rut depth.



in these test roads or at numerous pavements visited during this study that have similar levels of rutting.

STRUCTURAL THICKNESS DESIGN

At the current time, the required structural section can be most readily determined by using the AASHO Interim Guide (13) and a PSI value of at least 2.5 (5). Of course, other more mechanistic design methods based on the fundamental fatigue and rutting modes of distress can be used.

A conservative value of the laboratory test results should be used in estimating the soil support value for use in the Interim Guide. An analysis of the results of a field performance study in Maryland and also past experience indicates that the soil support value based on CBR results is often too high (7). The soil support values given in Table 2, based on the American Association of State Highway and Transportation Officials (AASHTO) soil classification, can be used as a general guide in

Figure 10. Design relationship for estimating preliminary rut depths in sand-asphalt and sand-stone blend bases: 266.7 mm structural section supported by a fair subgrade.

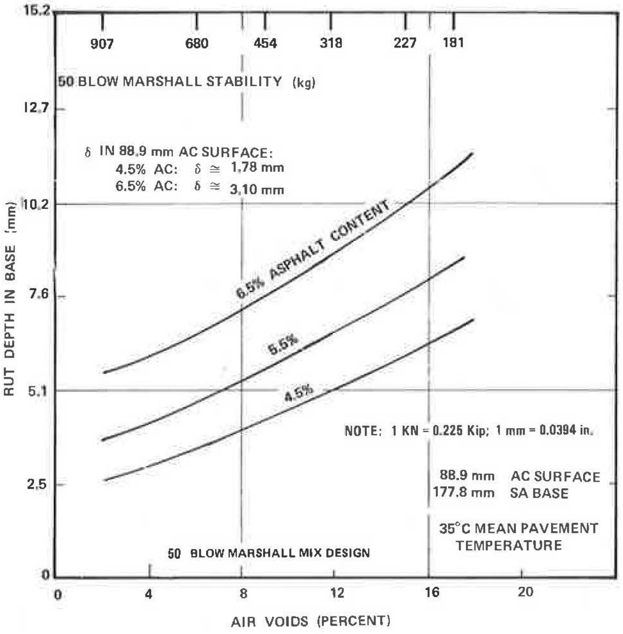


Table 2. Limiting soil support values based on AASHTO soil classification.

Classification	Description	Upper Soil Support Value
A-1a	Largely gravel but can include sand and fines	6.5
A-1b	Gravelly sand or graded sand; may include fines	6
A-2-4	Sands, gravels with low-plasticity silt fines	5
A-2-4	Micaceous silty sands	2.5-3.0
A-2-5	Sands, gravels with plastic silt fines	4
A-2-6	Sands, gravels with clay fines	4.0-5.0
A-2-7	Sands, gravels with highly plastic clay fines	4.0
A-3	Fine sands	4.5
A-4	Low-compressibility silts	4.0
A-5	High-compressibility silts, micaceous silts, and micaceous sandy silts	2.5-3.5
A-6	Low- to medium-compressibility clays	3.5-4.5
A-7	High-compressibility clays, silty clays, and high-volume change clays	3-4

Table 3. Recommended AASHTO Interim Guide structural coefficients for thickness design.

			General Requirements			
Structural Layer	Class	Structural Coefficient	Asphalt Content (%)	Air Voids (%)	Marshall Stability[a] (kN)	Other
Surface and binder course (weighted average)						
AC	1	0.48	>6.0	2-4	>6.67	
	2	0.44	≥4.8	2-6	>5.34	
	3	0.35	<4.4	2-8	>3.11	
Sand asphalt	1	0.35	>5.8	<14	>2.45	
	2	0.27	<4.8	<18	>1.78	
Base course						
Crushed stone, untreated	1	0.14				Well graded; 38 mm or greater top size; 3-8 percent fines; 100 percent T180 compaction
AC	1	0.34	>5.8	2-4	>5.34	
	2	0.28	<4.8	<8	>5.34	
Sand asphalt	1	0.25	>5.8	14	>2.67	
	2	0.17	<4.5	18	>1.56	
Sand cement	1	0.24				>4138 kPa, 7-day compressive strength
	2	0.18				>2759 kPa, 7-day compressive strength
Inverted structural section—experimental[b]						
Unstabilized sand base		0.10-0.12				Clean, medium to coarse sand, <4-8 percent fines
Unstabilized sand-crushed stone blend		0.16				

Note: 1 kN = 225 lbf; 1 mm = 0.04 in; 1 kPa = 0.15 lbf/in^2.

[a] Given Marshall stabilities are for a 50-blow mix design.

[b] Structural section consisting of unstabilized clean sand or crushed stone placed between a sand-cement base and AC surface course. Use structural coefficients for sand-cement base and AC surface course given above.

establishing upper limiting values.

Recommended structural coefficients for use in the AASHO Interim Guide for surface and base courses are given in Table 3 for construction by using sand-asphalt and sand-cement pavement sections. The actual value of the structural coefficients can vary greatly depending on the quality of materials used, level of stabilization, construction specifications, and the quality control program followed during construction. In general, the higher-quality construction should be used where practical to optimize the life of the pavement by taking advantage of the dramatic increase in fatigue life and durability of materials stabilized with slightly higher levels of asphalt content (7).

DISCUSSION

Sand-asphalt and sand-stone blend AC can be successfully used as base courses, surfacings, and leveling courses. The 50-blow Marshall mix design method supplemented by the findings presented in this paper gives a practical procedure for designing sand-asphalt base mixes. At the current time, two different approaches were found to be followed in the design of sand-asphalt base mixes in the four states visited. Florida designs a sand-asphalt mix that typically has 6.5-7.5 percent asphalt content and a 50-blow Marshall stability greater than 2.2 kN (500 lbf) and often greater than 3.1 kN (700 lbf). This type of sand-asphalt base mix is usually placed beneath AC surfacings, typically 75 mm (3 in) in thickness and used for moderate to heavy traffic-loading conditions. On the other hand, Maryland and South Carolina use a mix that has typically 4 to 5 percent asphalt content. This type mix is generally placed beneath 125-150 mm (5-6 in) of AC and used under moderate to heavy traffic-loading conditions. Georgia follows a design between these two extremes.

An increase in fatigue resistance and decrease in rutting potential is directly related to an increase in 50-blow Marshall stability and inversely related to air voids content of the mix. The laboratory fatigue tests indicate that the fatigue resistance of a sand-asphalt mix can be increased by a factor of approximately four by increasing the asphalt content from 4.5 to 5.5 or 6 percent. Likewise, an increase in Marshall stability from 1.5 kN (350 lbf) to 3.1 kN should increase the laboratory fatigue life by a factor of about three. Based on observed field performance and laboratory fatigue tests, the recommendation is made that, for at least moderate to heavy traffic conditions and AC surfacings 75-100 mm (3-4 in) in thickness, the higher-quality sand-asphalt base construction, which has Marshall stabilities greater than 2.2-3.1 kN, should be used.

For thicker AC surface courses or light traffic conditions, lower stability or asphalt-content mixes can be used successfully. For this mix and construction, the sand-asphalt base very likely functions more like a subbase and has considerably lower strengths (and hence lower base-course coefficients) than the higher-quality sand-asphalt mixes. For either mix, to maximize fatigue life, the stability of the mix should be made as great as practical and the air voids in the mix should be minimized.

Blight and others (14) have found that soluble salt contents greater than 2 percent can cause deterioration of an AC pavement. Also, even for lower salt contents, the surfacing may be rapidly abraded away, although the primary effect of rapid abrasion is to increase skid resistance. Three samples of sand from tidal fluctuation areas in rivers were tested for soluble salt content. Very low salt contents were found present in these sands (5). Based on the absence of observed problems in the field and these limited results, high soluble salt content is probably not a major problem, although some sands undoubtedly have excessive soluble salt concentrations present (14).

In general, the sand equivalent has been found in this study and others (15, 16) not to be a good indicator of the quality of a sand for use in sand-asphalt. Clay balling in some materials may become a problem when the sand equivalent is less than 22-24 when these materials are used in a drum dryer. Sands with high sand equivalent values are too coarse and require the addition of fines. Generally, the fines content should be approximately equal to or greater than the asphalt content of a mix (17).

Both experience and the laboratory tests indicate that approximately 4-7 percent clay (as determined by the elutriation test) is actually desirable in a sand-asphalt mix. Hence, the sand equivalent test is not a very valid indicator of potential performance, and sands should only be rejected if the sand equivalent is less than 20 and for some materials as low as 15. Of course, the sand should be angular and well graded. The specific criteria developed for gap-graded mixes by Freeme (15) and summarized elsewhere (5) can also be used as a general guide for sand-asphalt mixes.

Finally, the use of sand-stone blend AC base-course mixes with up to 75 percent stone content offers an excellent way on some projects to reduce the overall cost of the mix while at the same time obtaining a high-quality AC base. These mixes can be designed to have good fatigue properties and reasonably low asphalt contents in the range of 4.5 to 5.5 percent. At the same time, such mixes should experience on the order of 25 percent less rutting than a pure sand-asphalt (Figure 8).

GENERAL CONCLUSIONS

Field inspections conducted in four southeastern states indicate that sand-asphalt and sand-stone blend asphalt mixes can be successfully used as base courses under both light and heavy traffic conditions. Rutting in pavements constructed by using a sand-asphalt base is typically between 8 and 15 mm (0.3 and 0.6 in). As a result, more consideration must be given to rutting in the mix design of sand-asphalt bases compared with conventional mixes. An allowable rut depth of 10 mm (0.4 in) is recommended on primary and Interstate pavements and 15 mm (0.6 in) on secondary roadways.

The 50-blow Marshall method can be used for mix design of sand-asphalt bases. Results of dynamic tests are described for the evaluation of fatigue and rutting of sand and sand-stone asphalt mixes. Variables that influence the fatigue and rutting performance of these sand-asphalt mixes are discussed.

Use of sand-stone blend AC base-course mixes offers an excellent way on some projects to reduce the overall cost of the mix, while also obtaining a high-quality AC base. Sand-stone blend mixes should experience on the order of 25 percent less rutting than a pure sand-asphalt.

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Performance of Sand-Asphalt and Limerock Pavements in Florida

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This paper presents a summary of three test roads that were constructed between 1964 and 1971 by the Florida Department of Transportation. The test sections were designed and constructed to be included as a part of the state's Satellite Test Road Program. The sections were designed to provide variations in surface and base-course thicknesses, type of base materials, and stability levels of sand-asphalt hot mix. The base courses evaluated included limerock, sand-asphalt hot mix, and shell. The individual test sections have been monitored to determine their structural behavior, condition, and serviceability. Test parameters for the constructed pavements were analyzed as a basis of comparison to test data on performance collected over several years.

The performance of flexible pavements in Florida has been investigated more intensely during the past 10 years. Numerous test roads have been constructed to evaluate design and construction material variables. This paper presents a summary of three test roads that were constructed between 1964 and 1971. These test roads were designed to provide variations in surface and base-course thicknesses, type of base-course materials, and stability of sand-asphalt hot mix (SAHM). Base-course materials include limerock, SAHM, and shell. The quality of the aggregates would probably be considered as poor in comparison to the harder, more durable crushed stone and gravels used in other states.

These test roads have been monitored to determine their structural behavior, condition, and serviceability. This information was extracted from data summaries and reports prepared by the Florida Department of Transportation (1, 2). Test parameters for the constructed pavements were analyzed for comparison to performance test data that were collected over several years. Additional data were selected from reports that evaluated the fatigue fracture and dynamic properties of specimens recently cut from some of the existing test road sections (3, 4).

The significance of the test road monitoring programs and laboratory evaluation tests is evident when the performance achieved by using marginal aggregates is considered. Both limerock and SAHM bases can con-