Study of Bituminous Intersection Pavements in Texas

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Intersection-approach pavements often experience extreme forms of distress long before the tangent segments of the same pavement and long before the design life of the pavement is attained. Field and laboratory investigations of asphalt concrete intersection-approach pavements were conducted to determine the primary causes of premature failure and in order to suggest changes in materials specifications, pavement design, and construction procedures that can be used to prolong the service life of intersection pavement. The primary mode of failure of the intersections studied was rutting; in some cases shoving and flushing also occurred. The leading materials-related cause of pavement failure was asphalt content in excess of the design value. Most of the mixtures studies contained relatively high percentages of natural (uncrushed) sand and low voids in the mineral aggregate. Modifications in materials specifications, laboratory test techniques, design procedures, and construction methods are suggested to provide a margin of safety to minimize early failures. The potential for significant economic benefits appears promising if intersection approaches are designed and constructed to accommodate the special stresses to which they are subjected.

Standard pavement structural design methods and asphalt mixture-design procedures were developed for pavements with moving traffic without regard for high, repetitive shear stresses, such as those generated by decelerating and accelerating heavy vehicles at certain pavement locations. Traffic loading, often expressed as passages of an 18-kip equivalent single axle load (ESAL), as determined from the AASHO Road Test, are used in the calculation of damage factors to estimate design life of a pavement. By definition, the ESALs are applied by freely rolling tires, which principally apply a vertical load to the pavement. The only horizontal load in the pavement is the force component generated by the vertical load.

Asphalt concrete (AC) pavements are typically designed and built as if the complete paving project was a tangent section. For this reason, nontangent segments of a pavement, such as intersections, curves, approaches to railroad crossings, bus terminals, and steep grades, often experience extreme forms of distress long before the tangent segments of the pavement and long before the design life of the pavement is attained. As a result, maintenance or rehabilitation or both of the specially stressed segments are required early in the pavement's service life, which is costly in materials and labor and to the user.

The initial phases of the problem as described above were addressed in a recent study (*1*). The analysis was limited to intersections surfaced with AC. The overall purpose of the study was to identify techniques that can be employed in a cost-effective manner to design and build specially stressed portions of pavements that will exhibit performance equivalent to the tangent sections.

The findings of this study (*1*) indicate that existing technology can be used to design and construct pavements of adequate strength and stability to withstand the special stresses associated with intersection approaches. The full report recommends changes in existing Texas State Department of Highways and Public Transportation (SDHPT) materials specifications, laboratory test procedures, and asphalt mixture-design methods in order to decrease the probability of premature failure of intersection pavements. It suggests that alternatives other than standard dense-graded asphalt mixtures should be considered for construction of intersection-approach pavements because these standard mixtures are neither designed to withstand the special stresses applied at intersections nor have they proved to be successful in intersection applications. Initial costs of implementing improved intersection designs will be significantly more than those encountered in normal practice. However, use of the improved designs or paving materials or both may result in significant cost savings during the service life because spot-maintenance and associated user costs will be reduced. This will be particularly true for high-volume roadways.

The AASHTO guide (*2*) states, "The designer will need to concentrate on some aspects of design which are not always covered in detail in the Guide." There is a need to analyze the horizontal shear forces unique to certain portions of pavement systems and develop design procedures, specifications, and materials acceptance criteria that can be used to prolong pavement service life and reduce maintenance and rehabilitation activities in these specially stressed portions of pavement.

A rational approach for intersection mixture design to increase the probability of success is presented in this paper. Results of this work may be implemented to provide adequate structures in other specially stressed segments of pavements such as bus terminals, steep vertical and horizontal curves, and even airport runways and taxiways.

FIELD INVESTIGATION

A questionnaire was distributed among all the Texas highway districts in order to locate unsuccessful AC intersections. Unsuccessful intersections were defined as those that exhibited significant problems related to premature pavement distress, such as rutting or corrugations or both. Visual inspections

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were performed on about 20 unsuccessful intersections, and 8 were selected for sampling and further study. Some consisted of a series of thin overlays that would have been difficult to analyze from a materials standpoint.

Successful intersections were defined as those that were exposed to reasonably heavy traffic and exhibited less than 0.25 in. of rutting and insignificant corrugations or flushing or both after 4 or more years of service. Visual inspections were performed on approximately 30 successful intersections; 6 were considered for sampling and further study. Most of the intersections that were reported to be successful actually exhibited significant distress or they experienced low traffic levels and were eliminated from the study. A sufficient number of "good" intersection approaches that had been last overlaid more than 4 years previously were not found. Therefore, some of the good intersections selected for study had been overlaid less than 4 years before this evaluation but were subject to heavy traffic.

It was found that many districts have implemented an intersection maintenance program in which basically all intersections in the district exposed to significant amounts of traffic received regular maintenance every other year at the minimum. Although the program is performing well in maintaining intersection quality, it did cause some difficulty in locating candidate intersections for this study.

As previously indicated, some intersections were sampled and tested, whereas others were given a more cursory study. When possible, mixture-design data, materials properties, typical sections, and a sampling of daily construction reports were obtained. Rutting was found to be the primary mode of distress in all unsuccessful intersection approaches. A summary of the intersections selected for study is given in Table 1.

Sampling and Testing Program

Rut depths were measured on the approach side of the intersections from the cross street and back until the measurements became less than 0.125-in. Twenty-five cores 4 in. in diameter were obtained from the rutted areas of selected intersections. At the approach side of the intersections, five cores across the pavement, in and between the wheelpaths, were drilled in order to ascertain the profile of the transverse cross section of the pavement. Cores were drilled in accordance with this scheme at each of 5 different locations to obtain a total of 25 cores. The cores were conveyed to the laboratory, where the surface layer portions were carefully separated by sawing and were later tested in an attempt to identify the possible causes of pavement distress.

In some instances, the cores were found to consist of a series of up to 8 thin (less than 1 in.) layers of AC pavement. Mixture testing of these cores was not performed. In these cases, only limited testing and visual inspection was performed. Laboratory test results are described by district in the following sections for each of the intersections analyzed.

TABLE 1 SUMMARY OF SELECTED INTERSECTIONS

Location	Identification	Traffic, ADT,	Age of Pavement of Last Overlay	Rut Depth, in.	Other Distress
District 8 Abilene	SH 36 @ Judge Ely*	4,000	6½ yr	<0.25	None
District 10 Tyler	Loop 323 @ FM 756	38,000	5 mo	0.75-0.9	Flushing
	Loop 323 @ Mackim		5 mo	0.5-0.9	Flushing
	Loop 323 @ SH110		5 mo	<0.25	None
District 15 San Antonio	Toepperwein @ IH35*	12,000	2 yr	0	None
	Judson @ IH35*	12,000	5 yr	<0.10	Slight Flushing
	Coliseum @ IH35*	10,000	5 yr	0.05	None
District 18 Dallas	FM2170 @ SH5	18,800	4 yr	0.25-1.0	Shoving
	SH66 @ Rowlett*	14,000	3 yr	<0.2	None
District 19 Atlanta	US259 @ SH11	8,000	8 yr	0.13-1.0	None
	US67 @ FM989	6,700	9 yr	0.3-0.9	Shoving
	US59 @ FM989*	19,000	8 yr	0	None
District 20 Beaumont	US96 @ FM1013	10,000	6 yr	0.25-2.5	Shoving
	US190 @ US96	10,100	2 yr	0.13-1.0	Shoving

* Indicates good intersections

Test Results

District 10

Cores were collected from 3 intersections (2 rutted and 1 nonrutted) along Loop 323. Rut depths up to 0.875 in. were measured only 5 months after the mixture was placed. The air-void content (2 to 5 percent) was relatively low for a pavement of this age. Voids in the mineral aggregate (VMA) appeared acceptable because they were within the criteria specified by the Asphalt Institute (*3*), which recommends a minimum of 16 percent VMA for a mixture containing ⅜-in. maximum particle size. However, low air-void content with VMA that is within specified limits is an indicator of excess asphalt. This excess asphalt decreases the internal friction of the mixture, making it unstable under slow-moving or stationary traffic loads, particularly during hot weather on a newly placed pavement.

All the Loop 323 cores were extremely tender at higher test temperatures and, as a result, collapsed when the resilient modulus test at 104°F was attempted. Stiffness of the mixtures from the rutted sites was consistently lower than that from the nonrutted sites as evidenced by resilient modulus at 77°F and lower. In addition, Hveem stability was much lower (23 versus 55) for the cores obtained from the rutted sites. Marshall stability and flow of the rutted and nonrutted sections were not much different.

The aggregate gradation showed a notably high percentage of sand-sized particles, as indicated by a hump in the gradation curve at the No. 40 sieve (more than 30 percent passing). The aggregate system was composed of 100 percent crushed sandstone. The coarse aggregate was angular and rough in texture. However, on examination under a microscope, the fine aggregate was found to consist of a high percentage of individual sand particles that appeared to be mostly subangular, glassy, and nonporous. The sandstone was not well cemented and, on crushing and handling, a significant portion reverted to the original individual sand particles.

Asphalts were extracted from selected cores from the 3 locations, and penetration and viscosity were measured at 77°F and 140°F, respectively. The results indicated satisfactory materials. Measurements of asphalt content showed that the mixtures from the rutted intersections contained about 0.5 percent more asphalt than the optimum, whereas the nonrutted mix contained the optimum asphalt content (6 percent).

The major contributor to failure of this intersection mixture was the excess asphalt content, which created the low void content. The glassy, nonabsorptive character of the aggregate with excess sand sizes and the relatively low filler content (filler/asphalt ratio less than 0.5) made the mixture sensitive to asphalt content, and therefore increased the propensity for permanent deformation problems.

District 20

Rut depths at the intersection approach of US-96 at FM 1013 in Kirbyville measured 0.75 to 2.5 in. Nearest the intersection, where the vehicles halted, a ridge had developed, particularly alongside the outer edge of the outside wheelpath. Rut depths at the approach of US-190 at US-96 in Jasper measured 0.13 to 1 in. The pavements more than 250 ft away from the intersections appeared to be in good condition and had rut depths less than 0.125 in.

After examination of the cores, it was concluded, by matching layer profiles with the rut depths measured, that the pavement consisted of a succession of overlays, each of which had experienced various degrees of rutting. The layers within the cores were approximately 1-in. thick, and thus too thin to accommodate most of the standard mixture tests.

Only the uppermost overlay was tested. Data showed that air voids in the wheelpaths (2 percent) were less than half those outside the wheelpaths at both intersections. The voids in the mineral aggregate were, however, within the range specified by the Asphalt Institute.

The aggregates blended to produce these mixtures consisted of more than 30 percent natural, uncrushed sand. On the basis of results of sieve analyses, both mixtures were generally composed of aggregate significantly smaller than that specified by the design. It is recognized that the coring operation reduced the measured aggregate size, but not to the extent shown here, especially in the smaller size ranges. In addition, the gradation curve exhibited a notable hump at the No. 40 sieve, indicating an excess of sand, and thus a mixture relatively weak in shear strength and sensitive to a slight excess of asphalt. On examination under a microscope, the fine aggregate was found to be mostly subangular to subrounded, showing smooth to polished surfaces and a nonporous siliceous character. The gradations measured do not correspond well to the design gradations.

Extraction tests showed that the mixture from Kirbyville contained 0.8 percent more asphalt than the design content, whereas the mixture from Jasper contained an amount near the design content.

A combination of high field sand content and overall small aggregate size produced a mixture susceptible to plastic flow. This problem was compounded at Kirbyville by the excess asphalt. In time, traffic further densified the in-place mixtures to a low void level, which further decreased its shear strength in the wheelpath, and failure occurred as a result of rutting.

District 18

Rut depths in the intersection of FM 2170 and SH 5 were a maximum of 1 in. A second location (SH 66 at Rowlett Street) showed no signs of significant distress. Mix-design data for these pavements were not available. Both pavements were composed of a series of thin (less than 1 in.) overlays placed during a period of several years. Therefore, only a few tests were performed on the pavement cores.

Air voids in the uppermost pavement layer were low (1 to 2.5 percent) for the rutted intersection and acceptable (5 to 7 percent) for the nonrutted intersection. The gradation of the surface layer in the nonrutted intersection was coarser (½-in. maximum size) than that of the rutted intersection (⅜-in. maximum size). The presence of the larger stones in the surface layer may have been a significant factor in its resistance to plastic deformation; the composition of the subsequent layers and other factors such as traffic and subgrade were quite similar. In the minus No. 40 sieve sizes, the aggregates in the surface layers of both pavements were largely subrounded, smooth textured, and nonporous. Figure 1 shows that the gradation of the rutted mix was very near the maximum density line.

District 19

Rut depths ranged up to 1 in. for the intersection of US-259 and SH 11, and up to 0.9 in. for the intersection of US-67 and FM 989. Researchers originally understood that these pavements were about 2 years old; it was later determined that they were considerably older. Because a significant amount of data had been generated by that time, the pavements were included in the study. The intersection of US-59 and FM 989 exhibited no rutting or other forms of distress.

The top two layers of the two rutted intersection approaches exhibited significantly lower air-void contents than the upper layer of the nonrutted intersection approach (Table 2). Air voids in the wheelpaths of the rutted pavements were extremely low (about 1.5 percent) compared with the wheelpath of the nonrutted pavement (5.4 percent) and were also quite low outside the wheelpaths.

Asphalt contents in the uppermost layers were, on the average, higher for the rutted sections than for the nonrutted section. In the rutted portion of US-67 at FM 989, the measured binder content in the uppermost layer exceeded the design value by 1.2 percent. In the nonrutted pavement, the measured binder content was 0.9 percent less than the design value.

The aggregates in the upper layer of all three sections were crushed sandstone and field sand. Material in the plus No. 40 sizes from the top layers of all three intersections was angular and rough. However, the minus No. 40 material in all mixtures tested (both layers where applicable) was subrounded, smooth, and nonporous. The plus No. 40 material in the second layer of the rutted intersections was mostly pea gravel and was also subrounded, smooth, and nonporous. The pea gravel layer of FM 67 at FM 989 was measurably thicker in the cores from outside the wheelpath than in those from the wheelpath, which indicates that plastic flow (rutting) had occurred and may still have been occurring in this layer.

District 15

Three excellent intersection pavements on relatively high traffic-volume facilities were found in San Antonio (Table 1). Two of these pavements had been in service for 5 years, and 1 had been in service for 2 years. They showed no visible signs of distress. Each of the pavements was placed as new construction in two 1-in. lifts. Mixture-design data for these two mixes are presented in Table 3.

These mixtures were composed of 74 percent crushed limestone and 26 percent natural sand. It should be pointed out, however, that the sand was of exceptionally good quality in that the particles were angular to subangular and well graded. Typical gradations for the mixture are shown in Figure 2. The quantity of minus No. 200 sieve size material was comparatively low (about 3 percent). Asphalt contents were also comparatively low. However, asphalt film thickness in the mixtures at Toepperwein and Judson were calculated to be more than 9 microns, which is normally considered adequate for protection against moisture and oxidation.

District 8

An intersection that exhibited excellent performance after 6 years in service in Abilene was reported by District 8 personnel. It is located on SH 36 at Judge Ely Street and is exposed to average daily traffic of about 4,600 vehicles (Table 1). The surface mix was a ⅜-in. maximum size hot-mix asphalt

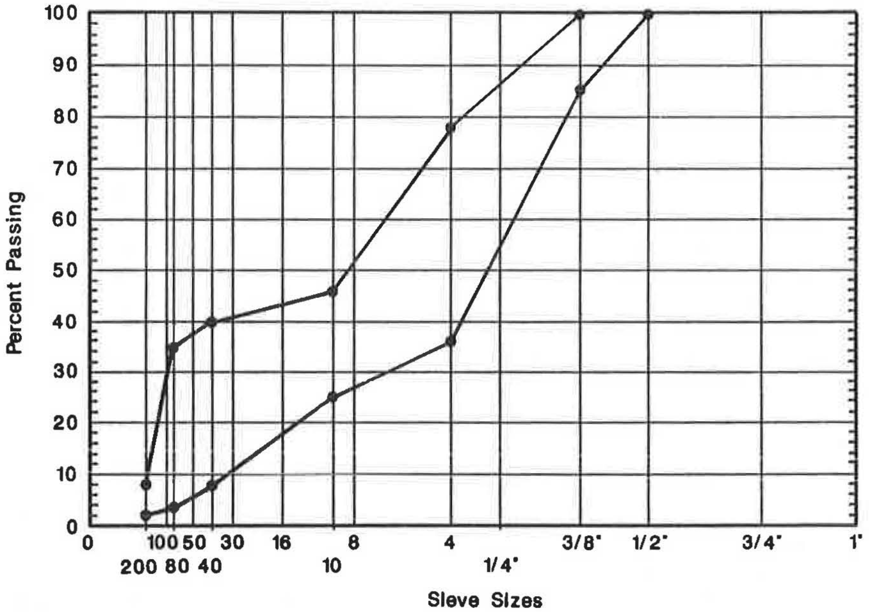

FIGURE 1 Gradation of extracted core for surface mix on intersection approach on FM 2170 at SH 5 in District 18 (sieve sizes raised to 0.45 power).

TABLE 2 PROPERTIES OF UPPER LAYERS IN CORES FROM INTERSECTIONS IN DISTRICT 19

	Location				
	US 259 @ SH 11		US 67 @ FM 989		US 59 @ FM 989
Rutting	Yes: 1.0-in.		Yes: 0.9-in.		No: 0-in.
Layer	1	2	1	2	1
Air Voids in Wheelpath, in.	1.5	1.4	1.8	1.4	5.4
Air Voids outside Wheelpath, in.	2.9	-	2.8	3.2	6.5
Asphalt Content, percent	5.7	5.9	6.9	4.7	5.1
Design Asphalt Content, percent	5.8	-	5.7	5.2	6.0
Hveem Stability for Mix Design	47	-	41	36	45
Aggregate Blend, percent					
Crushed Stone	58	-	65	-	60
Pea Gravel	-	-	-	50	-
Sand	25	-	25	35	20
Crusher Screenings	17	-	10	15	20

TABLE 3 MIX-DESIGN DATA FOR GOOD INTERSECTION PAVEMENTS IN DISTRICT 15

	Location			
Design Data	Toepperwein/Judson at IH 35		Coliseum Rd at IH 35	
Layer Identification	1 (Surface)	2	1 (Surface)	2
Specification Item	340	340	340	340
Mix Type	D	D	D	D
Aggregate Blend, percent				
Crushed Limestone	36	33	36	33
Crusher Screenings	7	7	7	7
Crushed Gravel	-	-	29	33
Crushed Sandstone	29	33	-	-
Field Sand	28	27	28	27
Absorption, percent	<1	<1	<1	<1
Minus # 200, percent	3.0	3.0	3.8	3.1
L. A. Abrasion, percent	30	30	30	30
Asphalt Source	Exxon	Exxon	Exxon	Exxon
Asphalt Grade	AC-20	AC-20	AC-20	AC-20
Asphalt Content	5.0	4.5	4.3	4.5
Avg. Specimen Density, percent	96.5	96.5	97.1	96.7
Initial Avg. Field Voids, percent	6.4 - 8.0	6.4 - 8.0	-	-
Average Hveem Stability	46	46	40's	40's
VMA, percent	15.0	15.0	13	15.0

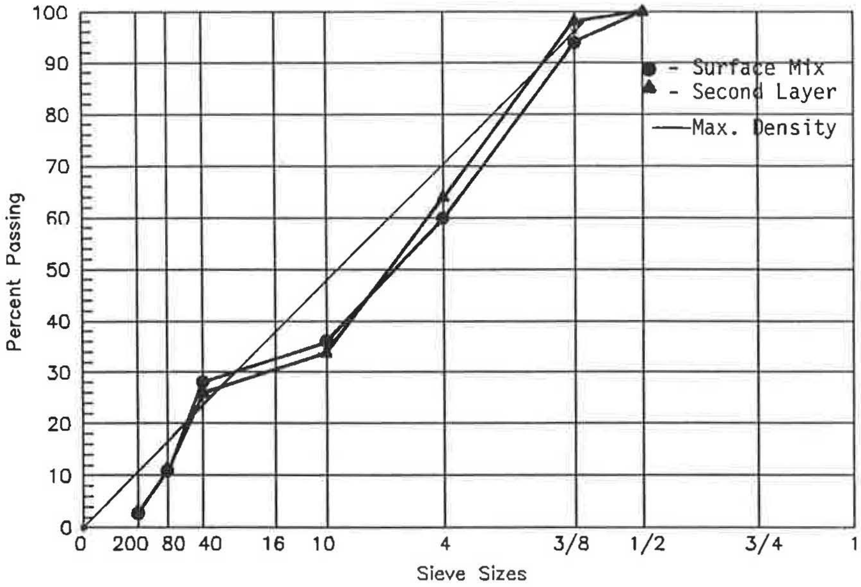

FIGURE 2 Design gradation for surface mixture and second layer on intersection approaches at Toepperwein and Judson at IH 35 in District 15 (sieve sizes raised to 0.45 power).

concrete (HMAC) overlay placed in a single 1½-in. lift. Visual inspection revealed no signs of plastic deformation, flushing, or other forms of distress.

The aggregate was composed of 88 percent crushed limestone and 12 percent field sand. The filler (minus No. 200) content was 4.0 percent. The design asphalt content was 6.2 percent, which yielded an average Hveem stability of about 51 percent. Field air voids after initial compaction were about 6 percent. The angularity of the coarse aggregate and the low field-sand content are partially credited with the satisfactory performance of this intersection pavement.

APPLICATION OF FINDINGS TO INTERSECTION ENGINEERING AND CONSTRUCTION

Although design engineers have no control of traffic volume, traffic loads, or environmental factors, adequate construction quality control as well as properly designed paving mixtures and structural systems are well within their jurisdiction. A well-designed asphalt paving mixture that is correctly mixed and placed can withstand the shear and compressive stresses of heavy traffic at intersection approaches and should exhibit adequate resistance to deformation when temperatures and wheel loads are at the peak. The following paragraphs offer suggestions designed to provide a margin of safety to minimize premature failures of specially stressed intersection pavements.

HMAC Specifications

Existing Texas SDHPT specifications for fine-graded HMAC surfaces allow and possibly encourage the use of gap-graded mixes (Figure 3). These mixtures are characterized by the hump in the gradation curve near the No. 40 sieve and a relatively flat slope between the No. 40 and the No. 10 sieves. This indicates a deficiency of material in the No. 40 to No. 8 sieve size range and an excess of material passing the No. 40 sieves. Mixtures of this type, particularly when the fines are composed primarily of natural sand, are termed "critical" because they lack resistance to plastic deformation, tend to rapidly loose stability if the asphalt content exceeds optimum, and become tender and shove during hot weather. One method of improving the aggregate grading specification to yield tough intersection mixes would be to lower the upper limit of the total percentage of material allowed to pass the No. 40 and 80 sieves. According to Chastain and Burke (*4*), in 1957, less than 20 percent of highway agencies allowed more than 37 percent passing the No. 40 sieve and more than 40 percent of them required less than 32 percent passing the No. 40 sieve.

The 0.45 power gradation chart, as used in this report, is particularly useful in evaluating aggregate gradations. A straight line, plotted from the origin of the chart to the percentage point plotted for the largest sieve with material retained, represents the gradation of maximum density. Aggregate gradation should be examined on the 0.45 power chart as a routine procedure during mixture design. When a plant inspector becomes accustomed to using this chart, it may help the inspector to recognize gradation problems early and make the necessary adjustments before large quantities of the mix are placed.

Although it is well known that rounded, smooth-textured siliceous gravels and sands generally produce AC mixtures subject to plastic deformation and moisture damage, existing Texas SDHPT HMAC specifications do not limit the use of these natural aggregate particles. The specification requires that a minimum of 85 percent of the particles retained on the No. 4 sieve have at least 2 crushed faces (primarily to address skid resistance). This is certainly a positive move regarding the coarse aggregate, but there is no limitation placed on the fine aggregate (minus No. 4). The quality and quantity of fine

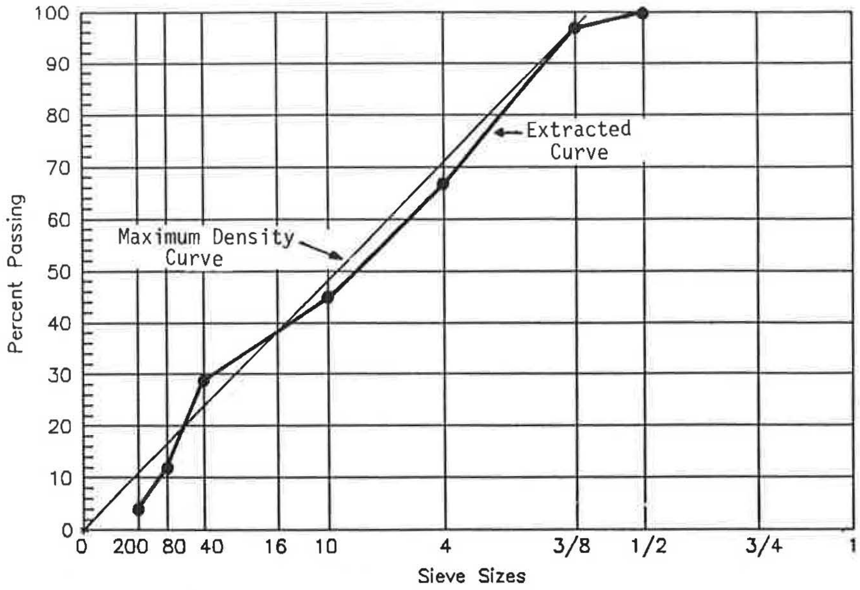

FIGURE 3 Aggregate specification limits for Texas SDHPT fine-graded asphalt concrete surface mixture (sieve sizes raised to 0.45 power).

aggregate is critical because it greatly influences the amount of asphalt a mixture can tolerate and the volume of air in the compacted pavement (*5–7*). Use of excessive quantities of poor quality natural sand is indirectly addressed in the specification by the requirement of a minimum Hveem stability. Experience, however, has shown that mixtures with satisfactory Hveem stability may yield unsatisfactory performance as surface courses on approaches to intersections that carry more than 7,000 vehicles a day. Evidence of this was demonstrated by the 2-year routine maintenance program for intersection pavements practiced in several districts. To provide a margin of safety, the natural aggregate particle content of mixtures to be applied at intersection approaches should not exceed about 15 percent (*5,8*). The quality of natural aggregate varies widely and should be considered by allowing special provisions to exceed the maximum limit when "sharp" natural sands with demonstrated good performance are used.

To meet gradation requirements with limited use of natural sand, it is usually necessary to replace these particles with "manufactured sand" (crusher screenings with limited minus No. 200). Texas currently has no specification for washed screenings, which has caused difficulties on occasion. For example, District 17 requisitioned washed screenings, but the material that was delivered contained only 3 percent less minus No. 200 material (15 instead of 18 percent) than the stone screenings usually received. A reasonable specification for washed screenings should require near 100 percent passing the No. 4 sieve and limit the amount passing the No. 200 sieve to less than 6 percent.

A target value for VMA should be obtained through the proper distribution of aggregate gradation to provide adequate asphalt film thickness on each particle and accommodate the design air-void system (*8*). Current Texas SDHPT specifications for HMAC do not require a minimum VMA. Recommended minimum VMA for various nominal maximum particle sizes have been developed by McLeod (*9*). These values are based on compaction using the Marshall hammer. Optimum values of VMA using the Texas gyratory compactor need to be established. On the basis of findings from a recent study sponsored by the National Cooperative Highway Research Program (*10*), it is reasonable to expect that acceptable VMA requirements using the gyratory compactor may be about 0.5 percent lower than those developed using the Marshall hammer.

Another item that is critical to mixture performance that is not addressed in the Texas SDHPT specifications is the ratio of filler (minus No. 200 aggregate) to asphalt. This ratio is computed by dividing the weight percent or mass of filler by the weight percent or mass of asphalt, respectively, and should range between a minimum of 0.6 and a maximum of 1.2 (*8*). Mixtures containing preponderantly absorptive aggregates will need less filler than mixtures composed primarily of nonabsorptive aggregates. Theoretically, absorptive aggregates will selectively absorb the lighter, more mobile components (lower viscosity) of the asphalt more deeply into the aggregate, leaving, in effect, a harder grade material to act as binder. In such cases, it may be advisable to design at the lower limit of filler content to ensure adequate mixture flexibility. (When using highly absorptive aggregates, improvements in mixture quality may be gained by specifying an asphalt one grade softer than usual to provide for loss of the low viscosity materials due to absorption. Research has not been performed to establish the critical level of absorption above which a softer asphalt should be used.)

Finally, incorporation of some or all of the above recommended changes in the Item 340 specification will result in a substantial increase in the Hveem stability. As a measure to further ensure that the mixture will withstand the special stresses applied at intersection approaches, the minimum required Hveem stability should be raised to a value near 40. A value of 37 is recommended by the Asphalt Institute (*3*) and the Federal Highway Administration (FHWA) (*8*) for traffic volumes exceeding 1 million equivalent single axle loads during the design life.

Methods of Testing

In the search for possible reasons for the excess asphalt found in some paving mixtures, standard Texas test methods were investigated. Design of hot bituminous mixtures in Texas requires the use of test methods Tex-205-F (mixing) and Tex-206-F (compaction) for specimen preparation. These test methods specify a mixing temperature of 275°F and a compaction temperature of 250°F, regardless of the grade or viscosity-temperature relationship of the asphalt cement. Examination of 1988 data for AC-20 asphalts used in Texas revealed that the viscosity may range from 6 to 14 St at 250°F and from 2.8 to 6.8 St at 275°F. On the basis of the experience of the authors, it is believed that this range of viscosities will significantly affect density of the compacted specimens. Higher viscosity will, of course, result in higher air voids. Because optimum asphalt content is selected at 97 percent density (or 3 percent air voids) by the Texas method, it follows that the harder asphalts (at compaction temperature) will require higher asphalt contents. Now, because the materials under discussion are all AC-20s, the viscosity range at high pavement service temperatures (e.g., 140°F) is comparatively small (1,610 to 2,280 St, based on 1988 Texas asphalt data). Therefore, in service, the higher asphalt content required by the design procedure may be detrimental to resistance to plastic deformation of the mix. Furthermore, when modified asphalts, which often have significantly lower-than-usual temperature susceptibilities (or much higher viscosities at the compaction temperature), are used, the standard design procedure may require a binder content in excess of that desirable for optimum performance.

The potential for these standard test methods to produce mixes with excess asphalt should be investigated. If it is determined that the risk is unacceptable, the test methods should be modified to require mixing and compaction at some preselected viscosity instead of the constant temperatures. Guidelines for the Marshall design procedure (*3*, AASHTO T245-82) recommend a mixing temperature that provides 170 cSt and a compaction temperature that provides 280 cSt. Asphalt viscosity at compaction temperatures when the Texas gyratory compactor is used may not be as critical as viscosity when the Marshall hammer is used, but this needs to be verified.

Design Considerations

In contrast to the current empirical pavement design procedures in which one is unable to determine if a paving mixture of specific strength parameters is capable of sustaining vertical and horizontal loads of varying magnitude, a mechanistic design method may provide a rational approach to design of intersection pavements capable of withstanding the applied vertical and horizontal loads (*1*).

The octahedral shear stress ratio (OSR) concept (*11*) can be used to evaluate the potential of an AC overlay, over existing AC or portland cement concrete (PCC), to rut or deform under traffic. This ratio is based on the principle of octahedral shear stress, which is a scaler or numerical representation of the stress state at any point within the pavement cross section. This scaler quantity is calculated from the three normal and six shear stresses acting at a given point within the pavement. Because materials fail in different modes on the basis of the conditions of loading and temperature and because a number of failure criteria exist, selecting the proper failure mode and criterion by which to judge failure potential is of great importance. It makes sense that the potential of an AC pavement to deform, shove, or rut at an intersection should be evaluated on the basis of a shearing failure criterion.

The procedure is summarized in the following steps:

1. Compute the maximum octahedral shear stress in the AC overlay under the climatic, structural, and loading conditions involved. Ameri-Gaznon and Little (*11*) accomplished this for the majority of conditions that will normally be encountered.
2. Measure the octahedral shearing strength of the AC material used in the overlay at the same state of stress at which the maximum octahedral shearing stress occurs within the pavement (Step 1). This can be accomplished by following the procedure for testing and analysis outlined elsewhere (*1*).
3. Compute the ratio of the maximum octahedral shear stress developed within the AC overlay to the octahedral shear strength of the AC material used in the overlay at the same stress state that occurs in the overlay at the critical point.

When the OSR is high, the potential to deform excessively is high. When the OSR is low, the potential to deform is low. Theoretically, an OSR equal to unity represents incipient failure. However, limited dynamic creep data have shown that conditions favoring excessive deformation can result at OSRs of 0.65 in highways subjected to normal loading conditions. Although it is currently not possible to identify an OSR that represents a selected quantification of deformation, the OSR is an excellent way to compare the relative potential of various mixtures of AC to resist permanent deformation in specific structural and climatic categories.

Tougher Asphalt Mixtures

It is possible to substantially reduce plastic deformation of the pavement by using larger nominal maximum size aggregates that are mixed with harder grade of asphalt (e.g., AC-30) or modified asphalt binder. Davis (*12*) states the largest stone size should be two-thirds the pavement thickness. Large crushed aggregate generally require less energy to produce and less asphalt and are, therefore, less expensive. Research has shown that certain polymer additives will produce a significant increase in asphalt viscosity at high pavement service temperatures while having little affect on viscosity at low pavement service temperatures (*13,14*). Higher-than-usual compaction energy may be required for these mixtures.

Plant mix seals or open-graded friction courses are quite resistant to rutting. These mixtures may provide a viable alternative to the usual fine-grained dense-graded mixtures for overlays or reconstruction of intersection approaches. Additional benefits provided by plant mix seals include improved surface friction and resistance to hydroplaning and reduced glare at night, which are important factors to consider at intersections.

Stone-filled mixtures (*15*), briefly described by Button and Perdomo (*5*), should also provide excellent service on intersection approaches. Stone-filled mixtures essentially consist of a small top-size, dense-graded asphalt-concrete mix combined with about 45 percent (by total weight of mix) of a larger single-sized stone of about ¾ in. for surface courses. A stone matrix is formed by the large stones, and the voids between are filled with the fine-grained asphalt mix. The bridging effect of the large stones resists plastic deformation and further densification under traffic in a manner similar to the open-graded mixes.

PCC

An alternative approach to eliminate plastic flow of the pavement surface materials at intersections is the application of PCC (*5*). Generally, the major portion of load-carrying capacity of pavements surfaced with PCC is provided by the slab itself. This is in contrast to the flexible pavement, wherein the strength of the pavement is provided by the thick layers of the subbase or base or both (*2*).

Construction Sequence

An efficient and possibly cost-effective approach to alleviate permanent deformation at critically stressed pavement sections is to employ a sequential construction technique. In this approach, the intersections and other critical areas that receive a higher concentration of vehicle maneuvering are constructed first with a preselected mixture that is designed to conform with the intensity of the traffic and applied vertical and horizontal loads. Once construction of these areas is completed, construction of the tangent sections may begin; the normal mixture that is compatible with the type of traffic to which those sections are exposed should be used. On occasion, it may be advantageous to let bids separately for construction or overlaying of intersections and work on connecting tangent sections.

Intersection Geometries

Traffic monitoring was conducted at several intersections to estimate the distance from the intersection at which braking force is first applied to reduce vehicle speed and then further applied to bring a vehicle to a complete stop. As mentioned previously, rut depths were measured along the intersection approaches. This information was used to estimate the average length of the damaged zone of typical intersection approaches, and thus to estimate the length of approach that should receive specially designed pavements. Evidence indicates that the typical length of an intersection approach that should receive special treatment ranges from 100 to 250 ft, depending on the amount and speed of traffic, traffic control methods, and the average length of the queue that forms during stoppages.

Economic Considerations

The potential for significant economic benefits appears promising when intersection approaches are engineered specifically to accommodate the special stresses to which they are subjected. Cost comparisons of these alternatives on both a first-cost and life-cycle basis are of interest to the engineer and should be considered when the optimum rehabilitation alternative for a particular intersection approach is selected. An example to illustrate the potential savings follows.

On the basis of the findings in this study, it seems reasonable to assume that an improperly designed intersection will need to be maintained by overlaying or milling or both every 2 years. As a basis for comparison, assume an intersection approach consisting of four 12-ft lanes 150 ft in length will be (*a*) overlaid with 1 in. of asphalt maintenance mix every 2 years or (*b*) designed and built with special hot mix to serve without maintenance for 10 years. The approximate costs of the materials, equipment, and labor for the two alternatives are presented in Table 4. It can be seen from this oversimplified example that a savings of $4,920 per intersection approach can be realized every 10 years when an approach pavement is built during initial construction or rehabilitation to withstand special stresses. If pavement user cost was considered at an intersection, it would be significant because traffic flow on at least two different thoroughfares is interrupted when maintenance or rehabilitation activities are required.

Additional benefits that can be gained by considering the special stresses associated with intersections during pavement design and construction include (*a*) improved driver safety as a result of the good condition of the pavement surface (no rutting or flushing and adequate surface friction in wet weather) and (*b*) no buildup of maintenance mix, which is often of lower quality than hot mix.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The most common form of distress associated with failure of AC intersection-approach pavements was plastic deformation manifested in the form of rutting. Shoving and flushing were evident in some cases. In all cases investigated, rut depths more than 250 ft from the intersection were practically negligible. Ruts always become progressively deeper nearer the intersection. This combination of findings clearly indicates that the slower the traffic and the greater the frequency of horizontal forces (deceleration and acceleration), the greater the damage to AC pavements.
2. The leading cause of intersection pavement failure related to AC materials was binder in excess of that required by the optimum mixture design. It also appears that on occasion asphalt content is arbitrarily increased to facilitate compaction.
3. Most of the mixtures studied contained relatively high percentages of natural (uncrushed) sand. The smooth, rounded, nonporous, glassy character of these fine aggregates causes the mixture to be sensitive to asphalt content and weak in shear strength, which thus imparts a higher propensity for permanent deformation. Approximately 30 percent minus No. 40 sieve size material, which was largely field sand, was found in all the problem intersections. [State specifications for fine-graded surface mix (⅜-in. maximum size) allow up to 40 percent passing the No. 40 sieve.]

TABLE 4 PAVEMENT TREATMENT ALTERNATIVES AND COST COMPARISONS

Maintenance Alternative:

One-inch thick level-up course of asphalt mix placed by maintenance forces every 2 years for 10 years. Assume 1 day required to perform maintenance each time.

Materials -	42 tons HMCL at $20/ton	$ 850
Equipment -	2 dump trucks at $30 ea/day	60
	1 sign truck at $30/day	30
	1 steel wheel roller at $20/day	20
	1 distributor truck at $30/day	30
	1 grader at $50/day	50
	Total Equipment	$ 190
Labor -	1 crew leader at $100/day	100
	2 maint. operators at $80 ea/day	160
	3 maint. workers at $65 ea/day	195
	1 flagman at $50/day	50
	Total Labor	$ 505
	TOTAL DAILY COST	$ 1,545

Assume 4 repetitions of the above maintenance activity will be performed in 10 years.

TOTAL 10 YEAR COST	$ 6,180

Ten-Year Design Alternative:

During construction, apply 3 inches of special hot mixed asphalt concrete (HMAC) designed to perform satisfactorily without maintenance for 10 years.

Materials -	Additional Cost of 126 tons of Special HMAC, $10/ton	$ 1,260

Savings = $ 6,180 - $ 1,260 = $ 4,920 per intersection per 10 years

4. Aggregate gradations appeared to be dense (low VMA) for some intersection pavements that experienced early failure. Dense aggregate gradations leave little room for asphalt binder, and the mixture may become unstable with a slight excess of asphalt. This is particularly true for fine-graded asphalt mixtures.

5. Air-void contents obtained from almost all the rutted intersection pavements were comparatively low (less than 3 percent), particularly in the wheelpaths. This indicates that either the mixture designs were too dense or that they were overcompacted during construction such that additional densification by traffic caused the mixtures to become unstable soon after construction and exhibit plastic flow (rutting or shoving or both).

6. Several districts had established a routine 2-year maintenance program, wherein most intersection approaches in the district with significant traffic received treatment every other year. This is an indicator of the severity of the problem of pavement service life at intersections.

7. The potential for significant economic benefits appears promising when intersection approaches are designed and constructed specifically to accommodate the special stresses to which they are subjected.

8. A rational approach for design of asphalt mixtures for intersections using the OSR appears capable of providing suitable mixtures. This procedure needs verification.

Recommendations

1. Reduce the allowable quantity of sand-sized (minus No. 10 to plus No. 200) particles in asphalt mixtures to be used on intersection approach pavements.

2. Limit the natural (uncrushed) sand content of mixes to be used on intersection pavements to about 15 percent. Special provisions should be allowed for "sharp" natural sands that have demonstrated good performance wherein they may exceed the specified value.

3. Institute a specification for voids in the VMA considering that the gyratory compactor generates a specimen that simulates final density after significant traffic. Optimum VMA values for gyratory compacted specimens may be slightly lower than those proposed by FHWA and the Asphalt Institute.

4. Require a minimum Hveem stability of 40 for mixes to be applied on the surface of intersection approaches that have high traffic volumes. This is an indirect method of ensuring good aggregate quality.

5. Use of comparatively large maximum-size aggregate or asphalt modifiers or both to increase viscosity at higher pavement service temperatures may offer cost-effective alternatives to prolong intersection pavement life. Options include dense-graded large-stone mixes (⅝- and ⅞-in. maximum size), stone-filled mixes, and plant mix seals. The National Asphalt Pavement Association recommends a maximum aggregate size of 3 in. or up to two-thirds the pavement layer thickness, whichever is smaller, for heavy-duty mixes.

6. Specify constant asphalt viscosities during mixing and compaction instead of constant temperatures for standard test methods. Use of the mixing temperature of 275°F and the compaction temperature of 250°F for hard or modified asphalts with the standard Texas mix-design procedure may result in excess binder content, which could lead to rutting or flushing.

7. Consider the use of PCC for intersection approaches for which economic analyses of the alternatives indicate its appropriateness.

8. Employ a sequential construction technique in which all intersection approaches within the project are built or overlaid before the remainder of the job with a special, tough mix to accommodate the special stresses.

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Publication of this paper sponsored by the Section on Bituminous.