Early Rutting of Asphalt Concrete Pavement Under Heavy Axle Loads in Hot Desert Environment: Case History

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A case study of early rutting of an asphalt concrete pavement under heavy axle loads in a hot desert environment is presented. A section of four-lane divided Dubai–Hatta Highway in the Dubai Municipality of the United Arab Emirates experienced a 13-mm (0.51-in.) rutting in a mere 10-month period. Review of the project documents indicated that the pavement section under consideration was properly designed and constructed by a mix design procedure that used the Marshall test equipment applicable to heavy-duty asphalt pavements. By this procedure a design asphalt content of 4.3 percent by the weight of mix was selected. During the course of the investigation the design asphalt content was confirmed by the Hveem mix design procedure. However, neither of these conventional mix design methods indicated any potential for rutting; moreover, the method of laboratory test specimen fabrication did not produce compaction levels representative of those obtained in situ under the actual traffic loading. On the basis of the results of this investigation the most probable cause for premature rutting was attributed to axle loadings that exceeded the loading conditions for which the Marshall and Hveem mix design criteria have empirically been developed. Creep testing appeared to better characterize asphalt concrete in a more fundamental manner with a potential use in mechanistic analysis to estimate the propensity of the mix for rutting. Its limited use in the study confirmed that the rutting that did occur was to be expected for the existing unconventional loading conditions for the environment in which the pavement was located. Although not performed in the present study, an improved analysis method developed by Strategic Highway Research Program Project A-003A researchers to evaluate rutting is briefly described.

In February 1987 a 29-km (18.1-mi) asphalt concrete pavement was constructed on a section of the four-lane, divided Dubai–Hatta Highway by the Municipality of Dubai in the United Arab Emirates. The asphalt concrete pavement was designed and constructed by accepted conventional methods generally applicable to heavy-duty asphalt pavements. Within several months it became evident that veining and rutting were beginning to develop within the asphalt concrete itself and in the wheelpaths of the outer lanes in both directions, although they were more pronounced in the eastbound direction (i.e., toward Dubai). By December 1987, after about 10 months of truck traffic, the early rutting was quite pronounced, ranging up to 13 mm (0.51 in.) in the asphalt concrete surfacing layer.

Consequently, a study was immediately initiated to determine the most probable cause of this early rutting of the asphalt concrete. Cores were obtained from the pavement for analysis, and samples of the original asphalt and the aggregate used to produce the asphalt concrete were supplied by the contractor for a program of laboratory testing, evaluation, and analysis. Tests included Hveem stabilometer and creep tests on field cores and Hveem stabilometer tests on laboratory-fabricated specimens of the same materials in similar proportions at a range of compactive effort by using the Triaxial Institute Kneading compactor.

The results of the study were quite revealing with respect to the shortcomings of present conventional methods of asphalt concrete mix design, which are empirically related to rutting resistance. It also demonstrates, quite dramatically, the need for a method and procedure for fabricating more realistic test specimens in the laboratory if engineers are to rely on laboratory-generated mix designs and their associated job-mix formulas to produce rut-resistant asphalt concretes.

It was therefore considered highly desirable to record the results of this particular study as a case history to underscore for the engineering practitioner the limitations of present mix design methods, which are based on empirical analysis, while simultaneously pointing out to the research community the extent of the problem and suggesting a direction that could be taken for its ultimate solution.

DESIGN AND CONSTRUCTION ASPECTS

A review of the project documents and an inspection of the laboratory facilities indicated that the laboratory equipment was in good order and was operated by qualified laboratory technicians. In all respects everything was in line with present standards for the design of conventional heavy-duty highways.

The design criteria included in the project specifications for the asphalt concrete wearing course were those associated with the so-called 75-blow Marshall procedure for heavy-duty asphalt concrete. Figure 1 presents the results of the mix design developed in the field laboratory with a well-graded, fully-crushed granite aggregate with a maximum size of 19 mm (0.75 in.) and a 60–70 penetration-grade asphalt. The granite aggregate had a bulk specific gravity of 2.93 and a water absorption value of less than 0.5 percent. In addition, it appeared to have the requisite particle surface microtexture to produce a highly rut-resistant asphalt concrete in a properly formulated mix. The selection of the 4.3 percent asphalt content was predicated on meeting the voids-filled-with-asphalt criterion of 70 percent minimum; otherwise, a 4.1 percent asphalt content would most likely have been used. The job-mix formula used on this project was based on the Marshall method of mix design, as depicted in Figure 1.

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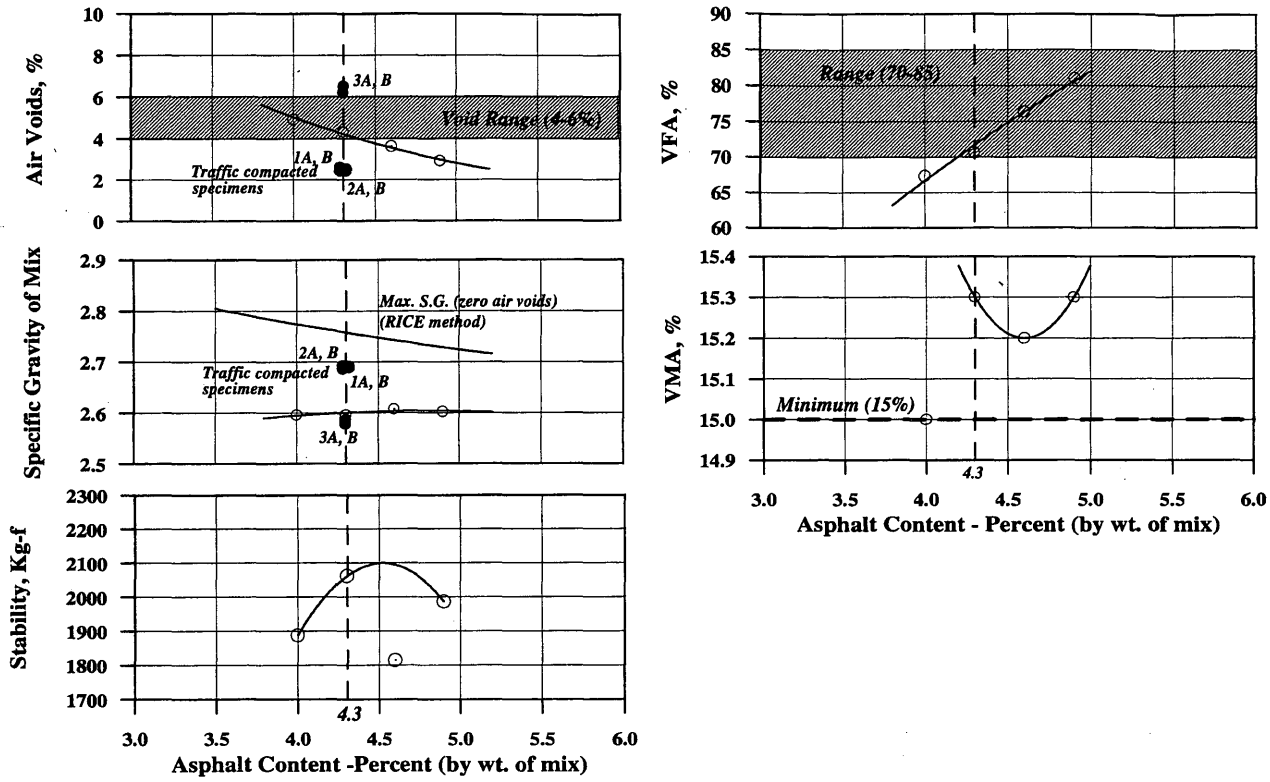

FIGURE 1 Asphalt concrete mix design by Marshall method for wearing course on Dubai-Hatta Highway with specific gravities and air voids from added field cores.

The asphalt concrete paving was placed in February 1987 in dry warm weather, with no difficulties encountered. A review of the records of the quality control program showed that the asphalt concrete readily conformed with the project specification and the job-mix formula requirements. No factors in the design and construction aspects of this project would lead one to expect any rutting problem, let alone an early expression of wheel-track rutting in a mere 10 months after opening to traffic.

FIELD PERFORMANCE OBSERVATIONS

The following observations were made during a visual examination of the condition of the asphalt concrete surface course in December 1987, which was approximately 10 months after construction:

1. The asphalt concrete wearing course definitely exhibited early rutting in the wheelpaths of heavy truck traffic, particularly in the Dubai-bound outer traffic lane (Figure 2). Although the depths of the most noticeable ruts were generally less than 13 mm (0.51 in.), the manifestation of a permanent deformation of this magnitude occurring in the relatively short time span of 10 months was indicative of the potential development of sufficiently deep ruts under additional wheel-load repetitions to affect adversely the rideability of the pavement surface.
2. Where rutting had already occurred and in many areas where rutting was not yet visible, migration of the asphalt binder to the pavement surface between aggregate particles (often referred to as *veining*) was evident. This veining was more extensive in the wheelpaths of the Dubai-bound outer lane, but it was also incipient in the Hatta-bound outer lane in several areas.
3. The trucks, of which there is a continual stream, that use the Dubai-bound outer lane were observed to be heavily loaded (Figure 2 inset), whereas the same types of three-axle trucks and five-axle tractor trailers that use the Hatta-bound outer lane were, in general, moderately loaded or empty.
4. All other aspects of the asphalt concrete wearing course other than the veining and early rutting appeared to be in good order. The pavement surface appeared to be smooth and free of defects, with good texture and no segregation. The workmanship was good, with well-formed longitudinal and transverse joints.

FIGURE 2 Early rutting in channelized wheel tracks of heavy truck traffic in the Dubai-bound outer traffic lane at station 73 + 335 (inset is typical truck loaded with rock).

Examination of a trench excavated across the Dubai-bound outer lane indicated that rutting was confined to the top 60-mm (2.4-in.) lift of the 120-mm (4.8-in.) asphalt surfacing itself, with no apparent contribution to the rutting by other structural layers or by the subgrade soil. Consequently, the early rutting appeared to be a deficiency in the asphalt concrete strength characteristics (i.e., resistance to rutting) or to be the result of the application of loading intensities (i.e., contact pressures) far beyond those for which the Marshall mix design criteria had been established. The Figure 2 inset shows an example of an excessively loaded five-axle tractor trailer carrying rocks, estimated to weigh approximately 68 metric tons (150,000 lbs), using the Dubai-bound outer traffic lane.

LABORATORY TEST PROGRAM

A limited laboratory program of research was initiated with the objective of determining whether the cause of the rutting could readily be discovered on the basis of deficiencies either in the development of the job-mix formula or in the proportioning of the materials by the contractor to meet the mix design requirements.

To ascertain the reason(s) for the development of premature rutting in the Dubai–Hatta Highway, six cores of 101.6 mm (4 in.) in diameter, along with the original samples of asphalt and aggregate, were obtained from the construction site for laboratory testing and evaluation. Figure 3 shows the locations of the six cores obtained from the wheel tracks of the Dubai-bound lanes (seen visually in Figure 2) at station 73 + 335.

Tests on Cores

The following series of tests were carried out on the cores in the indicated order:

1. Unconfined axial creep tests on the cores, as received, under a static compressive stress of 138 to 207 kPa (20 to 30 lb/in.^{2}) at a temperature of 37.8°C (100°F).
2. Hveem stabilometer tests at 60°C (140°F) on specimens of the wearing course layer sawn from the top of the core [approximately 60 mm (2.4 in.) high].

It should be noted that this order of testing and the single temperature of 37.8°C (100°F) in axial creep were selected to preserve intact the specimens of 101.6 mm (4 in.) in diameter for subsequent testing in the Hveem stabilometer.

Analysis and Evaluation of Results

Table 1 contains a summary of the heights and bulk specific gravities of the cores of 101.6 mm (4 in.) in diameter as received and of the top wearing course layer sawn off the cores, as well as the air void content and Hveem stability values of the wearing course layer. Figure 4 shows the axial creep modulus-versus-time relationship for the cores tested as received.

From Table 1 it can be seen that the bulk specific gravities of the full thicknesses of cores 1A, 1B, 2A, and 2B, as received, are quite similar to those of the wearing course layers, with a maximum difference of 0.009 for Core 2B, which is quite close to the reproducibility of the test method. This is most likely because these cores

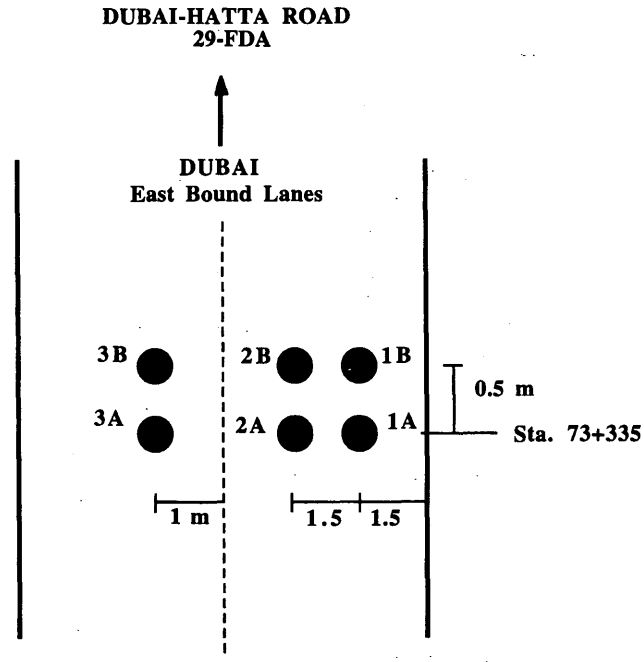

FIGURE 3 Locations of field cores taken for laboratory testing.

were taken from the wheel tracks of the outer lane and have been thoroughly compacted. Cores 3A and 3B show differences of 0.013 and 0.032 in specific gravity, respectively, most likely because they are from the outer wheel track of the inner lane and have not been subjected to the repeated loading of heavy truck traffic.

From these laboratory test results in Figure 4 it is evident that although the axial creep curves show no sharp break up to a 3,600-sec (1-hr) loading time at 37.8°C (100°F), they do show a significant difference in modulus values (i.e., 103 versus 345 MPa) between Cores 1A-1B, which were taken from the outer wheel track of the outer lane, where substantial rutting has occurred, and Cores 2A-2B, where rutting is less pronounced, and Cores 3A and 3B, where rutting is not yet visible, even though the creep stress applied was higher for Cores 2A, 2B, 3A, and 3B, namely, 207 versus 138 kPa (Figure 4).

Following testing asphalt extraction and recovery tests were performed on the top portions of the cores. The extraction was necessary to ensure that the asphalt contents were reasonably close to the target design asphalt content of 4.3 percent. The recovery of the asphalt component was considered highly desirable to ascertain the viscosities of the recovered asphalt at the service temperature of 60°C (140°F).

The results of the extraction and recovery tests are tabulated in Table 2. From Table 2 it can be seen that the asphalt contents vary from 3.93 to 4.52 percent, which results in an average of 4.29 percent with a standard deviation of ±0.28 percent. This compares quite favorably with the target design asphalt of 4.3 ± 0.2 percent tolerance of the job-mix formula. It should be noted that in asphalt concrete production the usual tolerance range for asphalt content is ±0.3 percent, which, if applied here, would show excellent control of the work by the contractor.

From Table 2 it is also seen that at 60°C (140°F) the viscosities of the asphalt range from 4,560 to 13,250 poises. This range is within what is normally expected of asphalts after about a year of service in the road. The noticeable variation here is that the vis-

TABLE 1 Specific Gravity, Height, and Hveem Stability Values of Asphalt Concrete Test Specimens Sawn from Field Cores Taken at Station 73 + 335, Dubai–Hatta Highway

Core No.	Bulk Specific Gravity			Height of Test Specimens		**Air Voids in Top Layer	Hveem Stability Top Layer
	All Layers	Top Layer	Difference	All Layers mm.	*Top Layer mm.		
1A	2.686	2.686	0.000	115.9	60.0	2.6	24
1B	2.692	2.689	0.003	114.3	60.7	2.5	32
Average							28
2A	2.684	2.692	0.008	119.0	59.5	2.4	36
2B	2.682	2.691	0.009	119.9	59.9	2.4	42
Average							39
3A	2.610	2.587	0.013	124.6	64.3	6.2	40
3B	2.610	2.578	0.032	123.8	62.7	6.5	30
Average							35

* Top layer is essentially the wearing course
** Based on theoretical maximum density (TMD) of 2.757

cosities in the heavily loaded wheelpaths of the outer lane (i.e., Cores 1A, 1B, 2A, and 2B) are substantially less than those in the lightly loaded wheelpaths of the inner lane. Such differences are normally encountered in service. Moreover, the viscosities measured in this case are still sufficiently low to permit deformations to occur under repeated loads of truck tires at high pavement contact pressures and high pavement temperatures.

Tests on Laboratory-Prepared Specimens

A series of tests were performed on laboratory-compacted specimens. The Triaxial Institute Kneading Compactor (ASTM D1561; Standard Method for Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor) was used to prepare the majority of the specimens, although a few were compacted by the impact compaction procedure (ASTM 1559; Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus). This test program included

1. Tests on specimens compacted at asphalt contents ranging in 0.5 percent increments from 3.5 to 5.0 percent (by weight of mix) for stabilometer tests at 60°C (140°F), using the standard Hveem method of 150 tamps in the kneading compactor.
2. Tests on specimens prepared at asphalt contents of 4.1 and 4.3 percent for stabilometer tests at 60°C (140°F), using higher levels of kneading compaction, namely, 300, 600, 1,200, and 2,400 tamps.

Hveem Stabilometer Tests Results

The samples of aggregate and asphalt received were used to perform an asphalt concrete mix design based on the standard Hveem stabilometer method (i.e., 150 tamps) to see how it compared with the Marshall method (i.e., 75 blows) performed for this project in

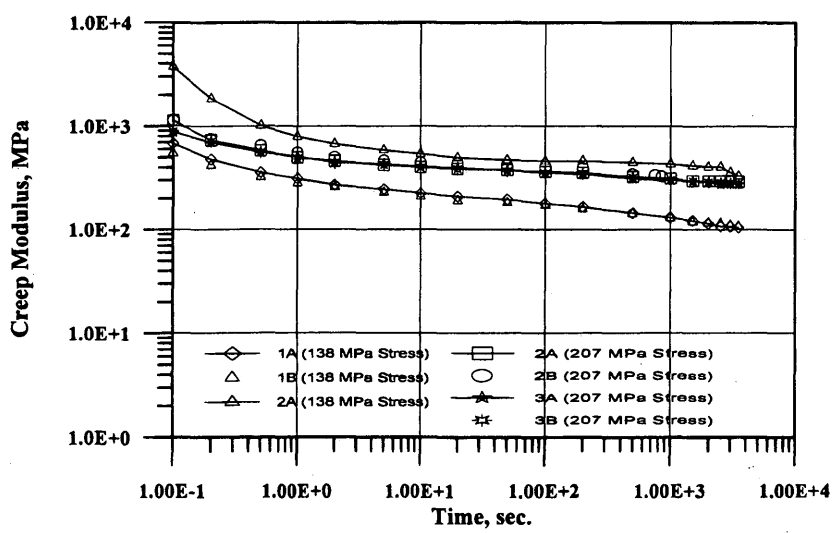

FIGURE 4 Axial creep test results for field cores, creep modulus versus time (37.8°C).

TABLE 2 Extraction and Recovery of Asphalt from Asphalt Concrete Cores, Dubai–Hatta Highway

Test	Method	Measured					
		Core 1A	Core 1B	Core 2A	Core 2B	Core 3A	Core 3B
Quantitative extraction of bitumen Recovery of asphalt from solution	ASTM D2172 ASTM D1856						
Asphalt Content, percent of total per 100 aggregate		4.52 4.73	4.31 4.51	3.96 4.13	3.93 4.10	4.49 4.71	4.52 4.74
Silt correction, %		0.72	0.71	0.47	0.41	0.30	0.32
Unaccounted loss, %		0.18	0.15	0.15	0.13	0.17	0.13
Tests on recovered asphalt: Absolute viscosity at 140°F, P	ASTM D2171	4560	4770	6260	6850	11,980	13,250

Dubai. The results of the Hveem test procedure on mixes containing 3.5, 4.0, 4.5, and 5.0 percent asphalt content (by weight of mix) are plotted in Figure 5, which shows the stabilometer values, bulk specific gravities, and percent voids as functions of asphalt content. On the basis of the results presented in Figure 5, the most appropriate target design asphalt content by the Hveem method is shown to be 4.3 percent for conventional truck traffic (i.e., meeting legal axle load limit requirements in the United States). Hence, it is evident that the Hveem method of mix design produced for this project the same target asphalt content selected by the Dubai's engineering consultant by the Marshall method of mix design and used by the contractor on this project.

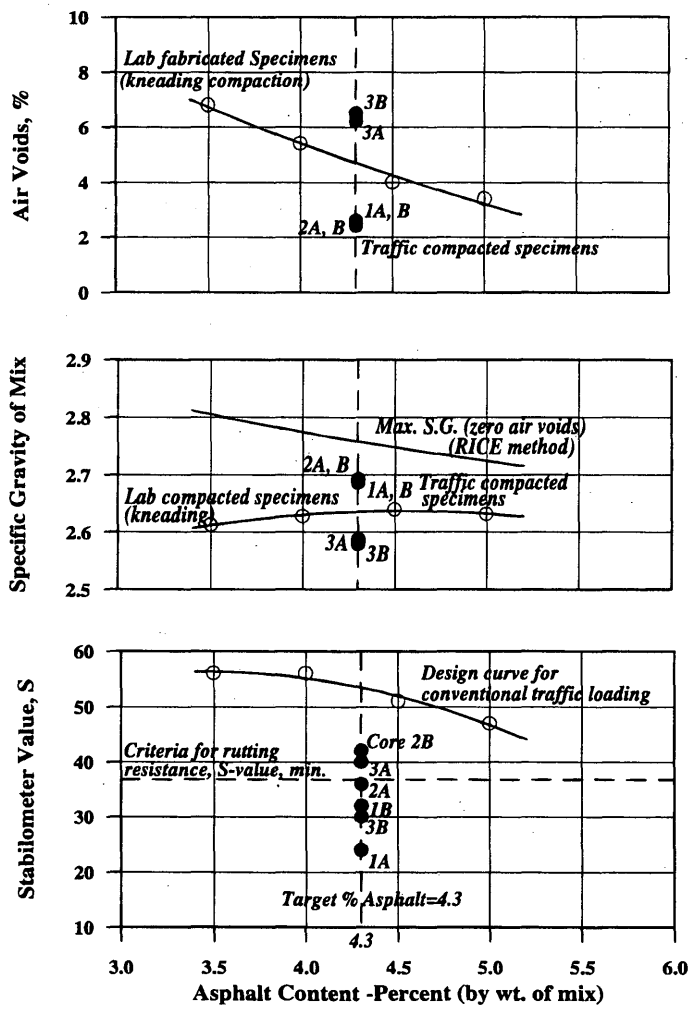

FIGURE 5 Comparison of Hveem stabilometer test results between field cores and laboratory-compacted specimens.

Comparison of Test Results for Laboratory-Compacted Specimens and Field Cores

Figures 1 and 5 also show the available results of Marshall and stabilometer tests on the field cores, respectively. In Figure 1 it is observed that the specific gravities of the field cores from the wheelpaths (Cores 1A, 1B, 2A, and 2B) are substantially higher than those of corresponding specimens produced by the 75-blow impact compaction effort. Similarly, the void contents of the specimens are below 3 percent, a value that is generally considered a desirable lower limit to ensure that instability in the mix will not develop. The specific gravities and air void contents of the cores from the inner lane (Cores 3A and 3B) indicate that they have not been subjected to the same amount of trafficking as the cores in the outer lane.

Relative to the stabilometer data (Figure 5) it is seen that the bulk specific gravities of the cores from the outer lane are higher than those produced by the recommended compaction procedure of the Hveem method (California Test 304; Method of Preparation of Bituminous Mixtures for Testing), namely, 150 tamps at 3.5 MPa (500 lb/in.^{2}) of compaction pressure. Similarly, the air void contents are lower. The cores from the less trafficked inner lane have lower specific gravities and higher air void contents, indicating that this portion of the roadway had not yet attained conditions corresponding to those from the compactive effort in the laboratory.

Relative to the Hveem stabilometer test results, Table 1 and Figure 5 show that the Hveem stabilometer values of the traffic-compacted wearing course layer range from a low of 24 to a high of 42, with an overall average value of 34, which is below the criterion of 37 (minimum) generally specified for heavy-duty pavements on major highways with high volumes of truck traffic. Hence, the asphalt concrete on this project was found to be inadequate with respect to its resistance to deformation (i.e., rutting) when it was compacted to the degree indicated by the low air voids that have resulted from the 10 months of heavily loaded truck traffic in the Dubai-bound direction. In other words, had the laboratory compaction duplicated that of the Dubai-bound traffic, the Hveem stabilometer would have predicted the high potential for rutting that did occur. This will be illustrated in the next section with the results of tests on specimens subjected to additional compactive effort.

Since the densities obtained in the field were higher than those obtained in both the 75-blow impact compaction procedure and the current Hveem standard procedure, an additional test series was initiated to study the change in the characteristics of laboratory-prepared specimens of the Dubai materials with increased compactive effort with the kneading compactor.

Effect of Increased Compactive Effort on Laboratory-Compacted Specimens

To attempt to duplicate the increased bulk specific gravities obtained in the wheel tracks of the outer lane, laboratory-prepared mixtures were subjected to additional compactive efforts in the kneading compactor. One series of specimens with the design asphalt content (4.3 percent) was prepared. To ascertain the influence of reduced asphalt content in mixture stability under the same circumstances, another series with an asphalt content of 4.1 percent (only 0.2 percent lower) was prepared.

Both mixtures were subjected to additional numbers of tamps in the kneading compactor, holding the compaction pressure constant at 3.5 MPa (500 lb/in.^{2}). For the mix containing 4.3 percent asphalt, additional specimens were prepared at 300, 600, and 1,200 tamps, whereas at 4.1 percent asphalt, 300, 600, 1,200, and 2,400 tamps were used. Infrared lamps, directed onto the compaction molds, were used to keep the specimens hot during the extended compaction process.

Stabilometer tests were performed on the compacted specimens at 60°C (140°F). Only two specimens were prepared under each condition since materials were limited. Figure 6 illustrates the influence of the number of tamps on the specific gravity, air void, and stabilometer values.

In Figure 6 it can be seen that the Hveem stability value of the mix with 4.3 percent asphalt decreased with an increasing number of tamps. For the mix with 4.1 percent asphalt the stability value increased with increased compactive effort to 600 tamps. However, at 1,200 tamps the stability value dropped to a level less than that obtained at the bulk specific gravity associated with 150 tamps and dropped still further with an increase in the number of tamps to 2,400. Moreover, at the increased compactive efforts, asphalt appeared on the surfaces of the specimens (flushing).

To ascertain the compactive effort in kneading compaction comparable to that obtained in the wheelpaths of the outer lane of Dubai–Hatta Highway over the 10-month period, Figure 7 was prepared. The curve labeled 150 tamps is based on the bulk specific gravity data reported in Figure 5. The specific gravity-versus-asphalt content curves for the other compactive efforts were interpolated from the data shown in Figure 6 for specimens containing 4.1 and 4.3 percent asphalt.

The bulk specific gravity values for the cores were also plotted in Figure 7. From this analysis it would appear that a compactive effort corresponding to about 1,200 tamps, rather than 150 tamps, would be required to assess the stability characteristics of the mix in the particular situation encountered with the exceedingly heavy axle loadings in Dubai, where no legal load limit is in place.

When compacting specimens in the laboratory to this number of tamps there is a possibility of excessive fracture and degradation of the aggregate. To determine this probability for the material used in the study, gradations after extraction were determined on specimens subjected to both 150 and 2,400 tamps of the kneading compactor. These results are plotted in Figure 8. Note that there is a slight increase in the fines for the mix subjected to 2,400 tamps; otherwise, the gradations are essentially the same.

RUTTING ANALYSIS

The rutting observed in the outer lane in the Dubai-bound direction provided an opportunity to use the analytically based procedure suggested by Shell (*1*) and modified by Finn et al. (*2*) to estimate the amount of rutting by using the results of the creep tests shown in Figure 4 and the traffic data presented in Table 3. Table 3 was prepared from the available traffic information and summarizes the total number of equivalent 9-metric ton (20,000-lb) axle load repetitions applied daily to various sections of the Dubai–Hatta Highway. This tabulation shows that, in general, the greater numbers of equivalent axle loads are in the Dubai-bound direction, particularly at the Al Hibhab roundabout where, for example, the equivalent single axle loads (ESALs) are 1,220 per day in the Dubai direction and only 296 per day in the Hatta direction.

However, whereas the numbers of axle load applications have a bearing on the depth of rutting whenever an asphalt concrete has the propensity to deform, a more significant factor is the tire contact pressure. Unfortunately, information on tire pressure was not avail-

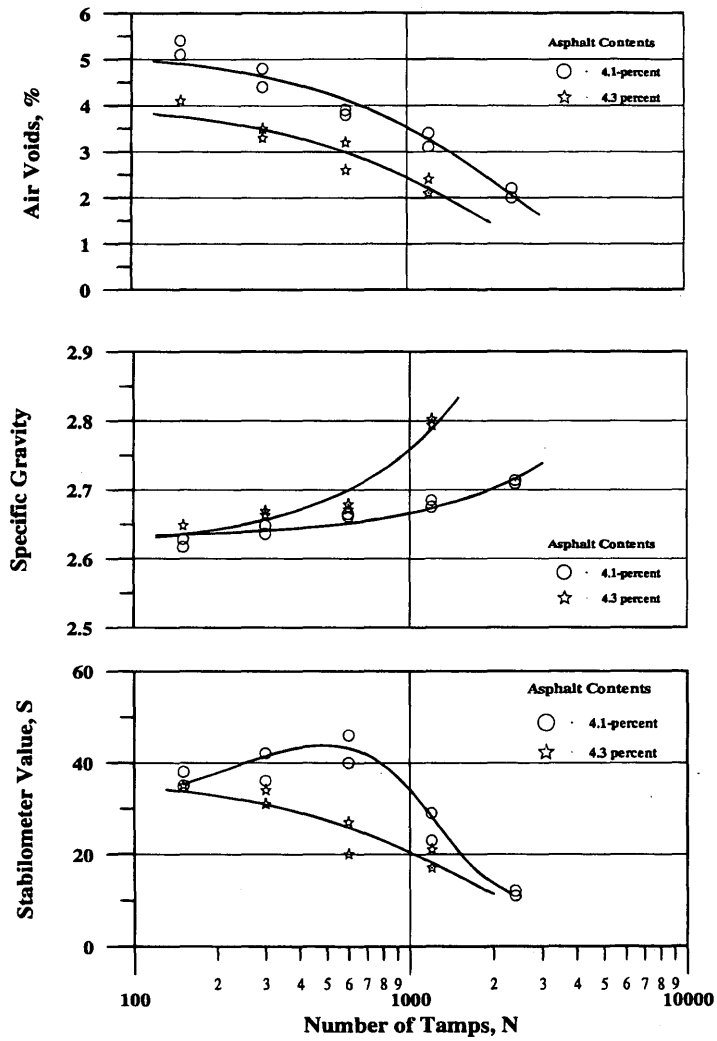

FIGURE 6 Influence of the number of tamps on specific gravity, air void, and stability values.

able at the time of the study. It is known, however, that for steel-belted radial tires the contact pressure on the pavement can reach levels of 1.8 times the air pressure in the tire for a tire loading exceeding that for which the tire was designed, for example, a tire designed for 4.5 metric tons (10,000 lbs) carrying 9 metric tons (20,000 lbs) of loading due to axle overloading (*3*).

In this connection from a review of the traffic data, overloading of the trucks that use the Dubai–Hatta Highway is quite common if one assumes that the "normal" load is 9 metric tons (20,000 lbs) for a single axle and 15 metric tons (33,000 lbs) for a tandem axle. For example, at the Al Hibhab roundabout in the Dubai direction, the data for three-axle trucks indicated that 30 of the 34 tandem axles were loaded to 21 metric tons (46,000 lbs) or greater, with 5 of the 30 trucks with tandem-axle loads of 40 metric tons (88,000 lbs).

By using the creep data in Figure 4 and the relationship (*2*)

$$\Delta h_1 = C_M h_1 \left(\frac{\sigma_{ave}}{S_{mix}}\right) \quad (1)$$

where

h_1 = thickness of the asphalt-bound layer,
σ_{ave} = average stress in the asphalt-bound layer,
S_{mix} = the value of the mix stiffness determined as described elsewhere (*4*), and
C_M = correction factor for the so-called "dynamic effect," which takes account of differences between static (creep) and dynamic (rutting) behavior (this factor is dependent on the type of mix and has been found empirically to be in the range 1 to 2),

a rut depth of about 10 mm (0.4 in.) was estimated over a 10-month period for a traffic level of 1,000 trucks per day with tire contact pressures of up to 1.4 MPa (200 lb/in.^{2}), daytime atmospheric conditions that result in pavement temperatures of 49°C to 60°C (120°F to 140°F) year around, and a seasonal range of axial creep moduli of 83 to 138 MPa (12,000 to 20,000 lb/in.^{2}) at a loading time of approximately 2,000 sec.

MEASURES TO IMPROVE ASPHALT CONCRETE MIX RUTTING RESISTANCE

Although it was beyond the scope of the investigation to evaluate alternatives that could mitigate rutting in this particular situation,

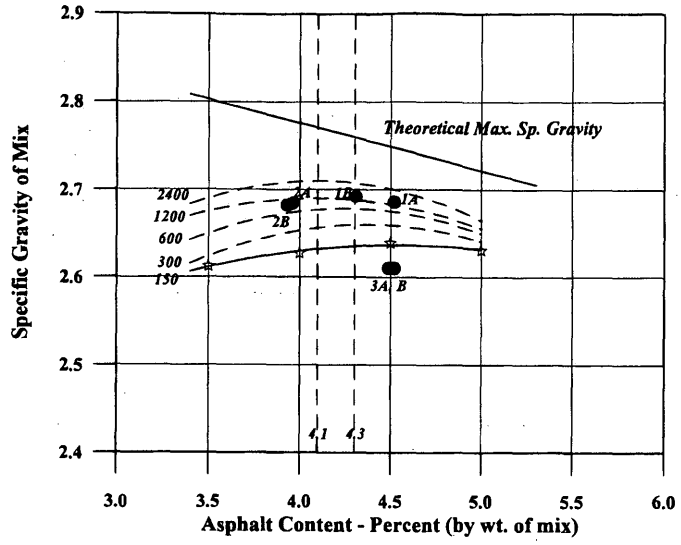

FIGURE 7 Effect of asphalt content and number of tamps on specific gravity values.

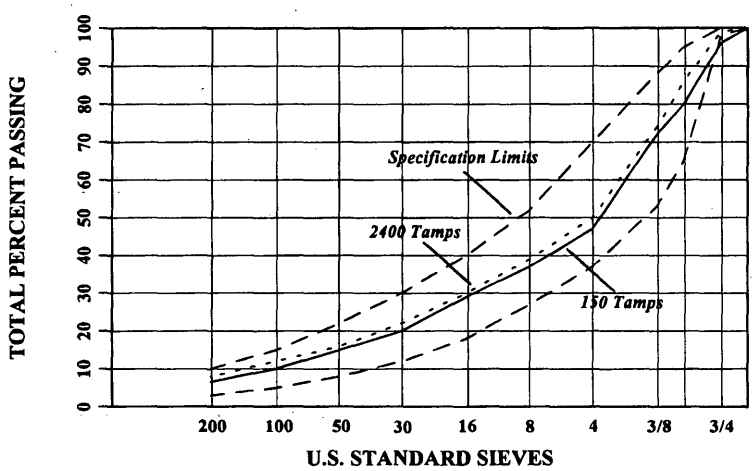

FIGURE 8 Extracted aggregate gradations of specimens subjected to 150 and 2,400 tamps at 3.5 MPa (500 lb/in.^{2}) in the kneading compaction.

some measures that may be taken to improve the rutting resistance of mixes include modification of aggregate gradation to incorporate a higher proportion of the large particles, use of additives and modifiers, and use of mechanistic and performance-based mix design methodologies. One such mix design methodology developed under the Strategic Highway Research Program (SHRP) is briefly described in the next paragraph.

The present study was conducted before the completion of the SHRP Asphalt Research Project A-003A. The authors, all of whom were associated with the A-003A research endeavor, suggest that the methodology for permanent deformation analysis developed in the A-003A study provides an improved way to analyze the performance of a project such as the one described here. The approach uses the repetitive simple shear test equipment developed during Project A-003A and the methodology reported elsewhere (*5*).

Briefly the procedure is as follows:

1. Estimate the traffic applied to the project to the time of the evaluation. One procedure would be to express the traffic in terms of ESALs.

2. Determine the critical temperature, T_c, for the site. [Deacon et al. (*6*) provide a methodology for doing this.]

3. Convert the total ESALs applied to the equivalent number at T_c, that is,

$$\text{ESALs}_{Tc} = \text{ESALs} \times \text{TCF} \quad (2)$$

where TCF is the temperature correction factor.

4. To convert the ESALs at T_c to an equivalent number of repetitions in the laboratory test, it is necessary to multiply the ESALs_{Tc} by a shift factor [the suggested shift factor is about 0.04 (*5*)]. This value is termed N'.

5. Select a value of shear strain γ_p', from the relationship

$$\text{Rut depth (in.)} = k(\gamma_p') \quad (3)$$

which was determined from finite-element analyses of representative pavement structures (*5*). A value of the coefficient k of 10 to 11 can be used for comparatively thick asphalt concrete layers. For an investigation of the type reported here the prescribed value of

TABLE 3 Summary of Daily Equivalent 9-Metric Ton (20,000-lb) Single Axle Loads at Roundabouts Along Dubai–Hatta Highway

Roundabout	2-axle	3-axle	4 to 7-axle	Total
Bu Kidra				
Dubai	34	621	177	832
Hatta	8	143	120	271
Rashidiya				
Dubai	29	341	220	790
Hatta	24	108	302	434
Awir				
Dubai	1	454	301	756
Hatta	3	56	75	134
Al Hibhab				
Dubai	2	898	320	1220
Hatta	6	158	132	296
Madam				
Dubai	0	561	736	1297
Hatta	19	35	119	173

the rut depth would correspond to that measured at the time of the investigation.

6. Plot N' determined in Step 4 and γ_p' determined from Step 5 as shown in Figure 9.

7. Perform the repeated-load, constant-height simple shear test at T_c on representative specimens of the mix used in the project.

8. Plot the results of the γ_p versus N determined from a simple shear test on the plot (Figure 9).

9. If the curve of γ_p versus N determined from the simple shear test does not pass through the plotted point (γ_p, N') adjust the shift factor used in Step 4.

10. To design an adequate mix for the site, plot the permanent shear strain associated with a prescribed rut depth and the design traffic demand termed N_{demand} (determined according to Steps 3 and 4 but using the adjusted shift factor obtained in Step 9) as shown in Figure 9.

11. Select a mix whose γ_p-versus-2 N relationship determined in a constant-height simple shear test at T_c passes through or to the right of (γ_p'', N_{demand}) (Figure 9).

SUMMARY

This paper presents a case study of early rutting of an asphalt concrete pavement in a hot desert environment. Although it was properly designed and constructed by accepted conventional design

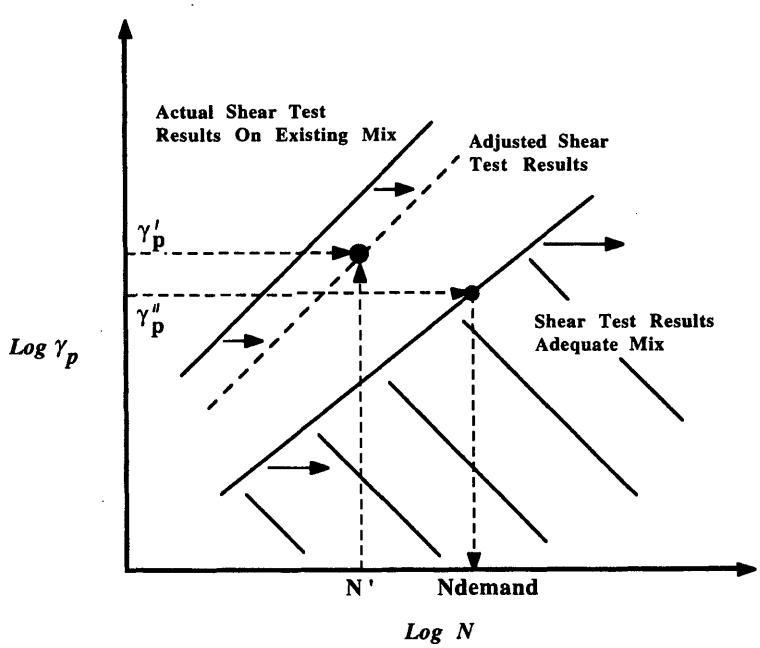

FIGURE 9 Schematic of permanent shear strain versus stress applications in constant-height simple shear test.

methods generally applicable to heavy-duty asphalt pavement, a section of the four-lane divided Dubai–Hatta Highway in the Dubai Municipality of the United Arab Emirates experienced premature rutting a mere 10 months after being opened to traffic.

An investigation to determine the most probable cause for this early rutting revealed the shortcomings not only of the present conventional methods of asphalt concrete mix design (Marshall and Hveem), which are empirically related to the rutting resistance, but also of the procedure for the fabrication of test specimens in the laboratory, which compares more realistically to the field condition. Asphalt mix design methods must be able to account for unconventional traffic loading and environment if engineers are to rely on laboratory-generated mix designs and their associated job-mix formulas to produce rut-resistant asphalt concretes.

Traffic survey information for the project indicated that the traffic loads imparted to the asphalt concrete pavement far exceeded the legal loads for which the Marshall and Hveem mix design parameters have empirically been correlated to rutting. Under this severe loading condition, the asphalt concrete was compacted to a degree far beyond that which was expected from design considerations for the conventional legal traffic load, leading to premature rutting.

Use of creep testing to establish creep modulus-versus-time relationships appeared to characterize the asphalt concrete mix response in a more fundamental way, suggesting that mechanistic analysis has the potential to permit estimates of deformation under any set of loading and environmental conditions. Its limited use in the present study confirmed that the rutting that did occur was to be expected for the existing unconventional loading conditions for the given environment.

Subsequent to this case study an improved method for the evaluation of mix performance was developed as part of SHRP Project A-003A. Unfortunately, no additional materials were available to permit the samples in this particular project to be evaluated by the new methodology. Nevertheless, the authors have provided a brief outline of the proposed approach and recommend its use as part of future case studies of the type described here.

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