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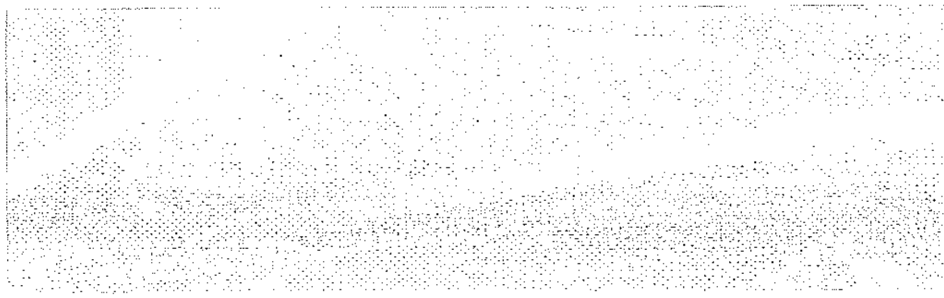
# COMPARISON OF CRACKED AND UNCRACKED FLEXIBLE PAVEMENTS IN MICHIGAN
Final Report

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION





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Comparison of cracked and uncracked flexible pavements in Michigan final report

# COMPARISON OF CRACKED AND UNCRACKED FLEXIBLE PAVEMENTS IN MICHIGAN
Final Report

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Materials and Technology Division
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## ABSTRACT

Nine flexible pavements from throughout the state were investigated to determine the relationship between pavement performance and the characteristics of their constituent materials. Age of the pavements ranged from 17 to 34 years and all consisted of bituminous surfacing placed over aggregate base with a granular subbase.

Field measurements were made on the nine sections which included crack surveys, rut depth and deflection measurements, and core sampling. Core samples were tested in the laboratory for tensile and thermal properties and for resilient modulus values over a wide range of temperatures. Asphalts recovered from the core samples were tested for penetration and viscosity at several temperatures in order to determine temperature susceptibility. Cores were also analyzed for asphalt content, air voids, aggregate gradation, and thermal contraction coefficient.

Transverse cracking of the pavements was found to be directly related to the stiffness of the bituminous mixtures and to the temperature susceptibility of the asphalts. High air voids were found to be associated with in-service hardening of the asphalts which contributed to the stiffening of the mixtures.

Surface rutting was found to be a direct function of traffic loadings and base course thickness.

Recommendations resulting from the study call for the use of softer grades of asphalt, limiting the temperature susceptibility of the asphalts, and controlling the potential for in-service hardening of the asphalts through strict enforcement of specifications.

## INTRODUCTION

This research project was initiated in November 1978 in an attempt to identify factors influencing the performance of flexible pavements in Michigan. The primary concern of this study was transverse cracking which was thought to be associated with temperature susceptibility of the bituminous mixtures.

As initially conceived, this study was to compare badly cracked sections of pavement on I 75 in Crawford and Otsego Counties with uncracked sections of US 31 in Muskegon County. Transverse cracking of the I 75 sections occurred almost immediately after construction whereas the US 31 sections remained essentially crack free after nearly twenty years of service. During the planning stage of the study it was felt that additional sections of cracked and uncracked flexible pavements should be included in order to better substantiate any conclusions that might be reached. In all, nine pavement sections were included in the study as shown in Figure 1. Selection of the nine pavements resulted in sections where cracking varied through a wide range of severity rather than simply cracked and uncracked sections as originally contemplated.

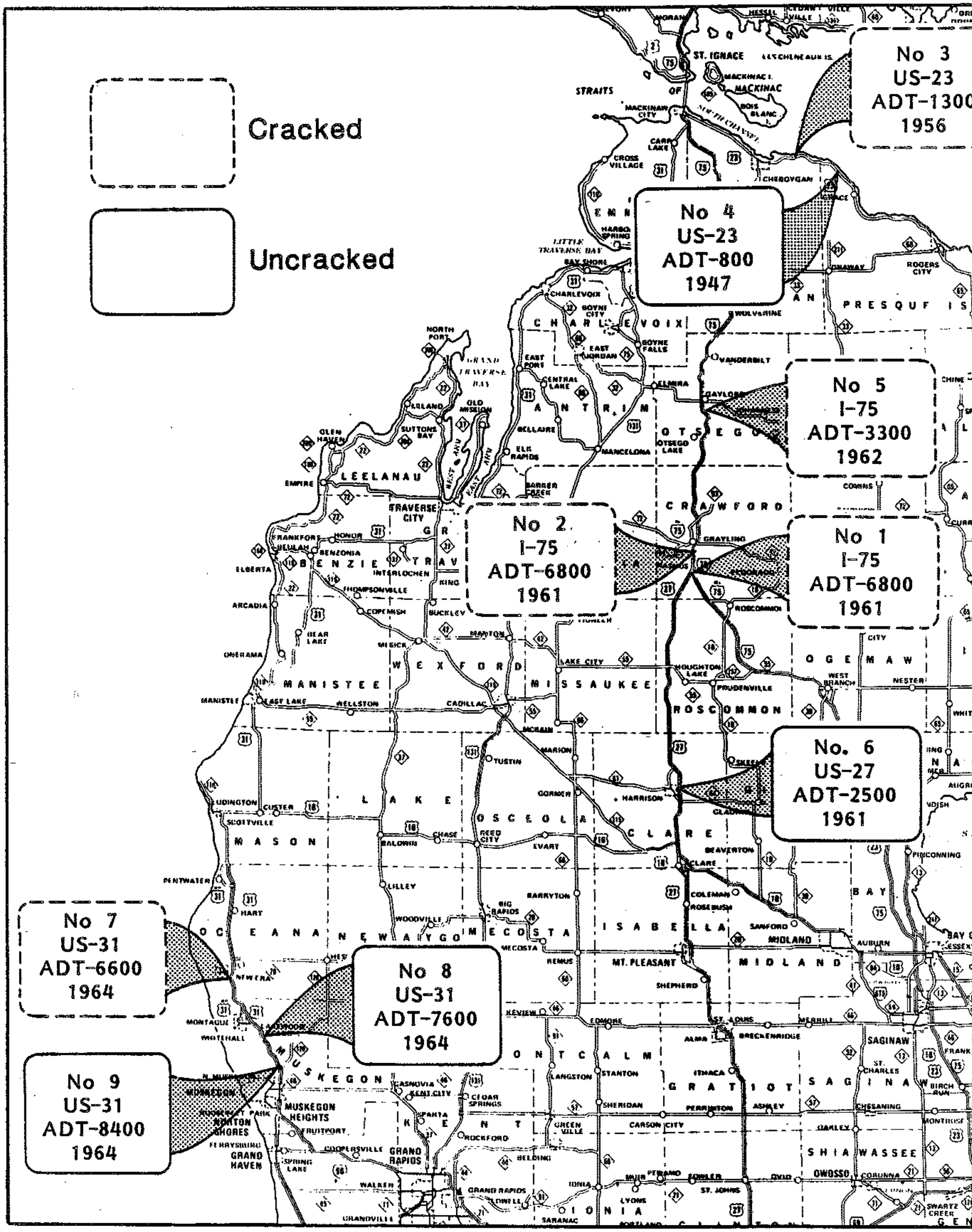



Figure 1. Location of nine test sections representing good performing (uncracked) and poor performing (cracked) flexible pavements.

Field measurements were made for the nine sections which included crack surveys, rut depth and deflection measurements, and core sampling. Core samples were tested in the laboratory for tensile and thermal properties and for resilient modulus values over a wide range of temperatures. Asphalts recovered from the core samples were tested for penetration and viscosity at several temperatures in order to determine temperature susceptibility. Cores were also analyzed for asphalt content, air voids, aggregate gradation, and thermal contraction coefficient. Field measurements for the nine sections are summarized in Table 1 showing rut depths, cracking index (CI) and maximum deflections.

TABLE 1
SUMMARY OF FIELD PERFORMANCE MEASUREMENTS

| Section | Cracking Index | Rut Depth, in. | | Maximum Deflection in. x $10^3$ | Age[1] | Traffic, 18 KEALS millions |
|---|---|---|---|---|---|---|
| | | OWP | IWP | | | |
| 1 | 37.5 | 0.20 | 0.45 | 12.6 | 20 | 1.38 |
| 2 | 28.3 | 0.19 | 0.36 | 12.9 | 20 | 1.38 |
| 3 | 17.5 | 0.03 | 0.02 | 29.0 | 25 | 0.32 |
| 4 | 0 | 0.01 | 0.02 | 14.5 | 34 | 0.35 |
| 5 | 20.3 | 0.19 | 0.25 | 12.0 | 19 | 0.43 |
| 6 | 0 | 0.18 | 0.23 | 12.5 | 20 | 0.34 |
| 7 | 4.5 | 0.14 | 0.19 | 15.4 | 17 | 0.78 |
| 8 | 0 | 0.10 | 0.18 | 13.1 | 17 | 0.76 |
| 9 | 0.2 | 0.09 | 0.17 | 12.1 | 17 | 0.84 |

[1] Years of service at time of 1981 field measurements

Seven of the sections were of the same basic design consisting of 4 in. of bituminous surfacing (binder, leveling, and wearing courses), 10 in. of aggregate base and 15 in. of sand subbase placed on the subgrade. Bituminous surfaces consisted of Michigan Specification No. 4.12 Bituminous Concrete (made with 60/70 penetration grade asphalt cement) over a binder course made with 9A aggregate (a coarse crushed material). Section 3 had been surfaced with a 1-in. oil-aggregate mixture then resurfaced with two bituminous aggregate layers (85/100 penetration asphalt cement) in 1956 and a final bituminous aggregate course in 1970 made with 120/150 penetration asphalt cement. The total thickness of all bituminous layers in Section 3 was essentially the same as for the seven sections previously described. Section 4 differed from the other sections in that it consisted of only 2-1/2 in. of oil-aggregate surfacing placed on a 5-in. aggregate base.

Stiffness, or modulus values were determined for the core specimens in connection with the laboratory tests on the pavement mixtures. Three different stiffness parameters were obtained depending on the testing procedure. The failure stiffness, E, (Table 2) was obtained from the indirect tensile breaking tests using the stress and strain values at specimen failure in the computation which are also presented in Table 2. Resilient modulus, $M_r$, values were measured under dynamic repetitive loadings. Seventy-five pound loads were applied every 3.0 seconds with load durations selected to duplicate typical traffic speeds. $M_r$ values given in Table 2 were determined at room temperature (74 F) and at 0.1 second load duration.

TABLE 2
CHARACTERISTICS OF BITUMINOUS MIXTURES AS
DETERMINED BY LABORATORY TESTING OF CORE SPECIMENS

| Section | Indirect Tensile Test Values at Failure | | | Resilient Modulus | Creep Modulus |
|---|---|---|---|---|---|
| | Stress, psi | Strain, in./in. | E, psi $\times 10^{-3}$ | $\times 10^3$ $M_r$, psi | $\times 10^3$ $S_c$, psi |
| 1 | 149.8 | 0.0092 | 34 | 935 | 17 |
| 2 | 133.1 | 0.0091 | 30 | 735 | 13 |
| 3 | 95.6 | 0.0094 | 21 | 291 | 10 |
| 4 | 19.1 | 0.0036 | 11 | 38 | 4 |
| 5 | 112.8 | 0.0114 | 21 | 532 | 9 |
| 6 | 92.3 | 0.0097 | 20 | 332 | 7 |
| 7 | 76.8 | 0.0076 | 22 | 386 | 13 |
| 8 | 78.7 | 0.0116 | 14 | 313 | 7 |
| 9 | 87.7 | 0.0103 | 18 | 461 | 10 |

Constant load creep tests performed on selected samples from each section were used to arrive at creep stiffness values using the applied load and the specimen deformation after 1/2 hour of loading, in the computation. Tests were run at temperatures of 0, 20, 40, and 74 F. Creep stiffness values obtained at room temperature (74 F) are presented in Table 2. These stiffness parameters were also measured at temperatures as low as zero degrees Fahrenheit with resilient modulus also measured at load durations of 0.05 and 1.0 seconds; stiffness values obtained under these conditions, however, did not correlate as well as the values shown in Table 2 and are not included.

Performance of the pavements was indicated by Cracking Index (CI), and rutting of the inner wheelpath of the driving lane. Rutting of the outer wheelpath was also measured. Table 1 summarizes these performance parameters along with the estimated number of 18-kip equivalent single-axle loads (18 KESAL) applied to each pavement since construction.

Benkelman beam deflection measurements were made to determine the structural characteristics of the test sections. The level of performance of the pavements should be related to their overall structural characteristics as well as to the traffic and environmental loadings placed upon them. The nine selected test sections were supposedly of similar structural capacity; therefore, other factors could be compared without the influence of either extremely weak or strong sections to be accounted for in the analysis. Maximum deflection and layer thicknesses were used to estimate the stiffness values for each of the non-bituminous pavement layers for the nine sections. These stiffness values were back-calculated using techniques described in Ref. 1. Table 3 summarizes the stiffness and layer thickness values for the sections. The bituminous moduli are the composite values for all the bituminous layers on each section as used in the back-calculations for the unbound layers.

TABLE 3
STRUCTURAL CHARACTERISTICS

| Section | Modulus[1] and Thickness Values | | | | | | |
|---|---|---|---|---|---|---|---|
| | Bit. Surface | | Base | | Subbase | | Subgrade |
| | $E_1$ | $t_1$ in | $E_2$ | $t_2$ | $E_3$ | $t_3$ | E |
| 1 | 1,020.0 | 4.5 | 44.2 | 12.2 | 15.7 | 15.0[2] | 5.0 |
| 2 | 1,067.2 | 4.4 | 50.3 | 11.1 | 20.1 | [2] | 8.0 |
| 3 | 429.2 | 4.7 | 37.4 | 8.6 | 14.1 | 14.3 | 2.4 |
| 4 | 60.0 | 2.5 | 40.9 | 5.2 | 20.4 | 12.0 | 8.2 |
| 5 | 856.1 | 4.7 | 52.7 | 11.8 | 21.3 | [2] | 8.8 |
| 6 | 612.7 | 4.5 | 47.9 | 11.9 | 18.0 | [2] | 6.6 |
| 7 | 442.2 | 4.0 | 47.3 | 10.3 | 18.4 | [2] | 6.8 |
| 8 | 529.4 | 4.3 | 56.2 | 15.0 | 20.8 | [2] | 8.5 |
| 9 | 586.0 | 4.2 | 51.9 | 10.8 | 21.0 | [2] | 8.7 |
| Avg. | 622.5 | 4.2 | 47.6 | 10.3 | 18.9 | 15.0 | 7.0 |
| Std. Dev. ± | 317.6 | 0.7 | 6.0 | 2.2 | 2.5 | 0 | 2.1 |

[1] All stiffness values are in psi x $10^{-3}$

[2] Subbase and subgrade layers are the same material. 15 in. as shown on plan cross-sections was used in layer analysis computations.

In addition to the physical properties of the mixtures as measured on core specimens, laboratory tests were performed on asphalts and aggregates as recovered from core samples.

Results of the analyses of materials recovered from the mixtures are contained in Tables 4 through 6. Analysis of the cores for specific gravity, air voids, and recovered asphalt content are given in Table 4 for each of the paving layers. Table 5 summarizes the gradation of aggregates while Table 6 shows the penetration and viscosity values determined for

TABLE 4
SPECIFIC GRAVITY AND VOIDS ANALYSIS OF PAVEMENT CORE SAMPLES

| Section | Course[1] | Extracted Asphalt, Percent | Average Thickness, in. | Specific Gravity | Compaction, Percent Max. Theor. | Air Voids, Percent | Voids in Mineral Agg. |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 4.61 | 2.15 | 2.367 | 96.3 | 3.66 | 14.24 |
| | 2 | 4.82 | 1.32 | 2.342 | 96.0 | 3.97 | 15.00 |
| | 3 | 5.78 | 0.85 | 2.389 | 98.8 | 1.25 | 14.57 |
| 2 | 1 | 4.48 | 2.02 | 2.356 | 95.8 | 4.13 | 14.37 |
| | 2 | 4.89 | 1.42 | 2.341 | 95.5 | 4.47 | 15.68 |
| | 3 | 5.78 | 0.78 | 2.391 | 98.5 | 1.48 | 15.01 |
| 3 | 1 | 3.60 | 0.97 | 2.421 | 97.4 | 2.56 | 10.03 |
| | 2 | 5.67 | 1.36 | 2.415 | 97.2 | 2.87 | 16.03 |
| | 3 | 5.43 | 1.10 | 2.407 | 96.0 | 3.92 | 16.49 |
| | 4 | 5.44 | 1.10 | 2.370 | 95.1 | 4.90 | 17.33 |
| 4 | 1 | 3.44 | 1.50 | 2.388 | 93.4 | 6.56 | 14.04 |
| | 2 | 3.14 | 0.98 | 2.385 | 92.7 | 7.31 | 14.53 |
| 5 | 1 | 4.48 | 1.73 | 2.361 | 96.5 | 3.50 | 13.86 |
| | 2 | 4.62 | 1.16 | 2.320 | 94.8 | 5.16 | 15.68 |
| | 3 | 5.43 | 1.04 | 2.367 | 97.8 | 2.20 | 14.61 |
| 6 | 1 | 5.17 | 2.06 | 2.425 | 98.4 | 1.64 | 13.90 |
| | 2 | 5.42 | 0.93 | 2.495 | 97.8 | 2.25 | 15.49 |
| | 3 | 5.61 | 1.02 | 2.412 | 98.8 | 1.14 | 14.41 |
| 7 | 1 | 4.49 | 1.91 | 2.543 | 98.0 | 2.07 | 13.24 |
| | 2 | 5.01 | 1.12 | 2.510 | 97.3 | 2.72 | 15.04 |
| | 3 | 5.58 | 0.89 | 2.503 | 98.9 | 1.07 | 14.77 |
| 8 | 1 | 4.80 | 2.01 | 2.463 | 98.4 | 1.59 | 13.18 |
| | 2 | 5.03 | 1.07 | 2.412 | 97.3 | 2.69 | 14.61 |
| | 3 | 5.54 | 0.89 | 2.412 | 98.8 | 1.17 | 14.29 |
| 9 | 1 | 4.76 | 1.92 | 2.549 | 97.9 | 2.09 | 13.99 |
| | 2 | 4.88 | 1.33 | 2.395 | 96.0 | 3.68 | 15.48 |
| | 3 | 5.50 | 0.88 | 2.438 | 99.3 | 0.66 | 13.80 |

[1] Course 1 - Binder
Course 2 - Leveling
Course 3 - Top (Wearing)
Course 4 - Top

TABLE 5
GRADATION OF AGGREGATES RECOVERED FROM PAVING MIXTURES

| Section | Course[1] | Sieve Sizes and Cumulative Percent Passing | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1-in. | 3/4-in. | 1/2-in. | 3/8-in. | No. 4 | No. 8 | No. 16 | No. 30 | No. 50 | No. 100 | No. 200 |
| 1 | 1 | 99.18 | 83.63 | 56.48 | 46.15 | 36.30 | 32.93 | 31.31 | 29.54 | 17.22 | 5.45 | 2.63 |
| | 2 | 100 | 100 | 96.10 | 79.01 | 44.92 | 32.87 | 29.19 | 26.49 | 16.07 | 5.63 | 2.83 |
| | 3 | 100 | 100 | 98.13 | 87.45 | 60.79 | 47.20 | 40.86 | 33.08 | 13.51 | 6.43 | 5.54 |
| 2 | 1 | 99.84 | 85.70 | 58.68 | 47.63 | 37.02 | 33.13 | 31.04 | 28.43 | 17.37 | 5.31 | 2.74 |
| | 2 | 100 | 100 | 95.86 | 80.22 | 44.60 | 32.67 | 28.98 | 26.20 | 14.71 | 5.12 | 2.98 |
| | 3 | 100 | 100 | 97.62 | 85.84 | 58.69 | 46.16 | 40.24 | 33.01 | 13.66 | 6.39 | 5.49 |
| 3 | 1 | 100 | 99.21 | 94.19 | 86.96 | 62.33 | 40.10 | 32.07 | 25.64 | 15.41 | 8.84 | 6.42 |
| | 2 | 100 | 100 | 92.04 | 81.60 | 61.92 | 50.02 | 43.26 | 36.82 | 19.51 | 9.20 | 7.19 |
| | 3 | 100 | 100 | 91.90 | 81.34 | 61.29 | 49.43 | 42.39 | 35.86 | 18.02 | 8.72 | 6.96 |
| | 4 | 100 | 100 | 88.29 | 76.61 | 55.26 | 43.51 | 37.90 | 33.29 | 15.43 | 7.44 | 5.83 |
| 4 | 1 | 100 | 99.80 | 85.76 | 75.06 | 59.26 | 50.01 | 43.26 | 36.86 | 19.71 | 9.29 | 7.42 |
| | 2 | 100 | 99.84 | 86.64 | 76.14 | 59.32 | 49.96 | 43.19 | 36.92 | 20.73 | 9.56 | 7.60 |
| 5 | 1 | 99.52 | 89.31 | 66.27 | 53.51 | 38.46 | 33.12 | 30.73 | 28.24 | 19.11 | 7.11 | 3.29 |
| | 2 | 99.84 | 99.84 | 97.37 | 82.37 | 45.43 | 32.69 | 29.00 | 26.34 | 18.41 | 7.26 | 3.53 |
| | 3 | 100 | 100 | 97.02 | 82.87 | 53.00 | 43.69 | 40.83 | 37.96 | 26.52 | 10.40 | 5.87 |
| 6 | 1 | 99.73 | 82.44 | 50.94 | 42.87 | 34.90 | 32.12 | 30.00 | 27.11 | 17.46 | 6.21 | 2.50 |
| | 2 | 100 | 100 | 98.00 | 80.03 | 43.18 | 34.38 | 31.51 | 28.34 | 18.22 | 7.53 | 3.39 |
| | 3 | 100 | 100 | 97.80 | 77.82 | 50.19 | 44.12 | 42.32 | 39.56 | 25.70 | 14.63 | 7.03 |
| 7 | 1 | 99.23 | 71.91 | 44.52 | 36.67 | 30.51 | 28.38 | 27.10 | 24.41 | 14.54 | 5.54 | 2.16 |
| | 2 | 100 | 100 | 99.21 | 83.26 | 39.47 | 28.32 | 25.52 | 22.66 | 14.70 | 6.68 | 2.72 |
| | 3 | 100 | 100 | 97.79 | 79.01 | 48.59 | 41.69 | 39.09 | 35.07 | 23.66 | 10.21 | 5.24 |
| 8 | 1 | 99.21 | 85.02 | 56.00 | 47.88 | 40.74 | 30.31 | 24.30 | 19.63 | 11.61 | 3.42 | 2.09 |
| | 2 | 100 | 100 | 96.20 | 79.86 | 44.19 | 30.12 | 23.87 | 19.42 | 11.98 | 3.82 | 2.43 |
| | 3 | 100 | 100 | 96.68 | 86.77 | 63.47 | 46.69 | 37.88 | 30.82 | 19.28 | 7.38 | 5.61 |
| 9 | 1 | 100 | 78.03 | 55.02 | 45.46 | 35.93 | 27.54 | 22.88 | 19.06 | 11.29 | 3.24 | 1.99 |
| | 2 | 100 | 100 | 96.34 | 81.20 | 43.97 | 28.94 | 22.54 | 18.10 | 10.98 | 3.77 | 2.60 |
| | 3 | 100 | 100 | 97.66 | 87.71 | 63.84 | 46.83 | 37.79 | 30.69 | 19.46 | 8.17 | 6.73 |

[1]Course 1 - Binder
Course 2 - Leveling
Course 3 - Top (Wearing)
Course 4 - Top

## TABLE 6
## PROPERTIES OF ASPHALTS RECOVERED FROM PAVING MIXTURES

| Section | Course[1] | Recovered Asphalt Cement | | | | | | Penetration Index | |
|---|---|---|---|---|---|---|---|---|---|
| | | Percent Extracted | Penetration | | Rec. Pen., Percent of Original | Viscosity | | McLeod Method | Heukelom Method |
| | | | @ 25c - 20 dmm | @ 4c-200g 60 sec dmm | | Absolute 140 F Poises | Kinematic 275 F Centistoke | | |
| 1 | 1 | 4.61 | 28.4 | 12.7 | 47.3 | 16,520 | 866.3 | -0.51 | -2.1 |
| | 2 | 4.82 | 19.4 | 8.3 | 32.3 | 25,456 | 1034.0 | -0.65 | -3.0 |
| | 3 | 5.78 | 28.2 | 13.6 | 47.0 | 13,334 | 800.0 | -0.61 | -1.7 |
| 2 | 1 | 4.48 | 23.1 | 10.0 | 38.5 | 18,827 | 923.4 | -0.64 | -3.1 |
| | 2 | 4.89 | 21.0 | 9.1 | 35.0 | 21,629 | 1010.3 | -0.65 | -3.1 |
| | 3 | 5.78 | 29.3 | 14.6 | 48.8 | 10,354 | 747.8 | -0.69 | -1.3 |
| 3 | 1 | 3.60 | — | — | — | 14.6[2] | — | — | — |
| | 2 | 5.67 | 46.9 | 19.6 | 55.2 | 4,034 | 477.9 | -0.78 | -1.2 |
| | 3 | 5.43 | 21.3 | 12.9 | 25.0 | 14,726 | 783.6 | -0.95 | -1.4 |
| | 4 | 5.44 | 41.2 | 18.1 | 34.3 | 4,243 | 506.1 | -0.86 | -1.3 |
| 4 | 1 | 3.44 | — | — | — | 20.9[2] | — | — | — |
| | 2 | 3.14 | — | — | — | 19.9[2] | — | — | — |
| 5 | 1 | 4.48 | 28.8 | 13.0 | 48.0 | 13,312 | 790.1 | -0.62 | -2.0 |
| | 2 | 4.62 | 20.7 | 9.9 | 34.5 | 21,422 | 994.7 | -0.67 | -2.9 |
| | 3 | 5.43 | 27.3 | 10.2 | 45.5 | 19,700 | 1029.1 | -0.34 | -3.2 |
| 6 | 1 | 5.17 | 43.4 | 18.0 | 72.3 | 5,393 | 603.8 | -0.55 | -1.4 |
| | 2 | 5.42 | 41.4 | 17.8 | 69.0 | 5,668 | 650.6 | -0.51 | -1.4 |
| | 3 | 5.61 | 31.6 | 15.7 | 52.7 | 9,651 | 764.3 | -0.59 | -1.3 |
| 7 | 1 | 4.49 | 51.4 | 20.0 | 85.7 | 5,783 | 561.8 | -0.45 | -1.3 |
| | 2 | 5.01 | 57.2 | 19.7 | 95.3 | 6,951 | 580.1 | -0.27 | -1.7 |
| | 3 | 5.58 | 53.7 | 20.9 | 89.5 | 5,037 | 560.6 | -0.40 | -1.3 |
| 8 | 1 | 4.80 | 52.0 | 22.4 | 86.7 | 3,800 | 490.4 | -0.65 | -1.0 |
| | 2 | 5.03 | 40.6 | 17.3 | 67.7 | 5,296 | 557.7 | -0.73 | -1.4 |
| | 3 | 5.54 | 45.2 | 22.3 | 75.3 | 5,037 | 541.6 | -0.64 | -0.5 |
| 9 | 1 | 4.76 | 43.8 | 18.7 | 73.0 | 5,106 | 548.7 | -0.67 | -1.2 |
| | 2 | 4.88 | 37.1 | 16.2 | 61.8 | 8,947 | 679.6 | -0.57 | -1.5 |
| | 3 | 5.50 | 51.9 | 21.1 | 86.5 | 4,682 | 544.2 | -0.51 | -1.3 |

[1] Course 1 is binder; Course 3 is top or wearing

[2] Cone plate viscosity at 77 F, K poises

each of the paving courses. It should be noted that the courses are numbered in the order of paving, i.e., course 1 is the binder or base course while course 3 is the wearing course. The fourth course in Section 3 was an additional wearing course applied some time after initial construction in a portion of the project.

Also presented in Table 6 are penetration index values calculated from the penetration and viscosity data using two different methods. Penetration index (PI), is a measure of the change in the consistency as measured by penetration or viscosity of the asphalt cement with changes in temperature (i.e., temperature susceptibility) and has been found to be an indicator of thermal cracking potential.

Hardening of the asphalts was measured by the ratio of the penetration of the recovered asphalt to the penetration of the original asphalt as given in Table 6.

## RESULTS

Performance of these pavement sections was measured in terms of transverse cracking, wheelpath rutting, and deflection under a wheel load. These performance factors were found to be related to the stiffness of the bituminous surfacing materials as well as to the structural characteristics of the the underlying layers of granular materials. Mixture stiffnesses were found to be related to certain properties of the aggregates and asphalts. A strong correlation between cracking and the temperature susceptibility of the asphalt was established, as were relationships between rutting, traffic, and the thickness of the aggregate base layer. Findings regarding each of the three performance factors are described in the following discussions.

### Cracking

Transverse thermal cracking as indicated by the Cracking Index was shown to be related to the stiffness of the bituminous mixtures (Fig. 2) and to the temperature susceptibility (Penetration Index), as well as to hardening of the asphalt cements. Thermal cracking occurs when tensile stresses generated by cooling, exceed the tensile strength of the bituminous surfacing. Stress-strain characteristics were measured in the laboratory to determine what measurement (stress, strain, or stiffness) provided the better indication of susceptibility of the paving mixtures to thermal cracking.

Cracking was correlated with asphalt properties by using recovered penetrations and viscosities to calculate Penetration Index in accordance with two widely used methods (2). These correlations, presented in Figure 3, show a better correlation between PI and performance for the Heukelom method than for the McLeod procedure. The McLeod method used in this study uses the penetration at 77 F and viscosity at 275 F in computing the PI; whereas, in the modified Heukelom method penetrations at 39.2 F and 77 F along with the viscosity at 140 F are used. The lower temperatures of the modified Heukelom method are thought to be in the range which generates thermal cracking on the roadway and probably accounts for the better correlation obtained in this study. Hardening of the asphalt also seems to affect cracking as shown in Figure 4 relating recovered penetration ratios to CI.

### Rutting

Rutting was found to be directly related to the amount of traffic carried throughout the life of the sections as well as the thickness of the base course layer. These relationships are shown in Figures 5 and 6, respectively. Rutting could also be expected to be inversely related to mix stiffness depending on how much of the rutting is due to deformation occurring within the bituminous layers. A direct rather than inverse relationship between rutting and mix stiffness was obtained, however, as shown in Figure 7. This would indicate that the measured rutting was

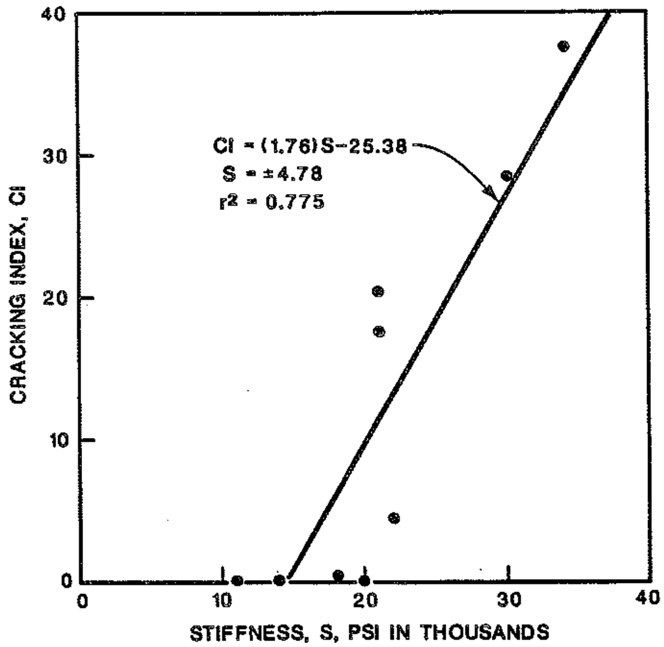



Figure 2. Relationship between Cracking Index and mixture stiffness measured by the indirect tensile test at 74 F.

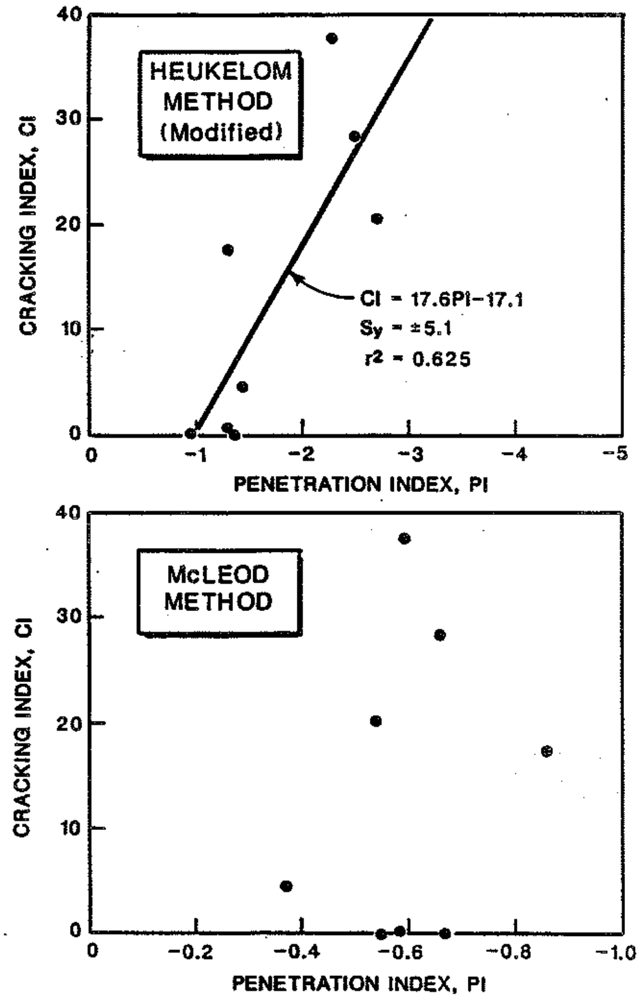



Figure 3. Relationship between pavement Cracking Index and Penetration Index of recovered asphalt cements.

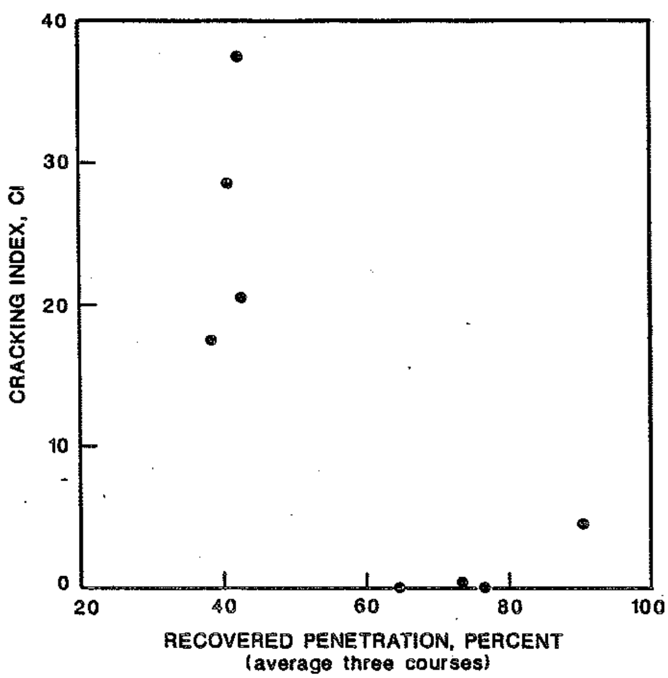



Figure 4. Relationship between Cracking Index and hardening of asphalt binder as measured by penetration of the recovered asphalt.

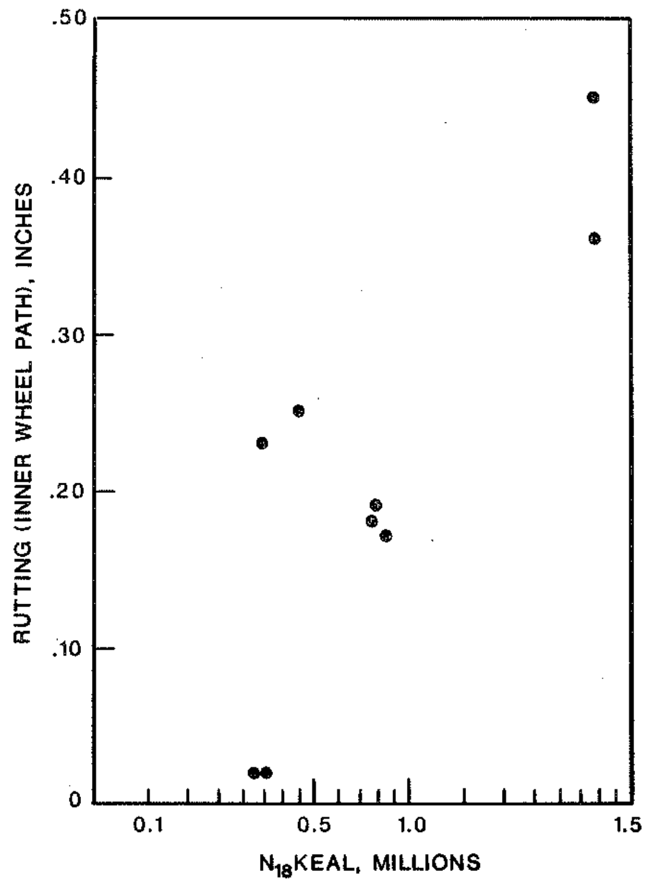



Figure 5. Relationship between rutting and traffic carried since construction.

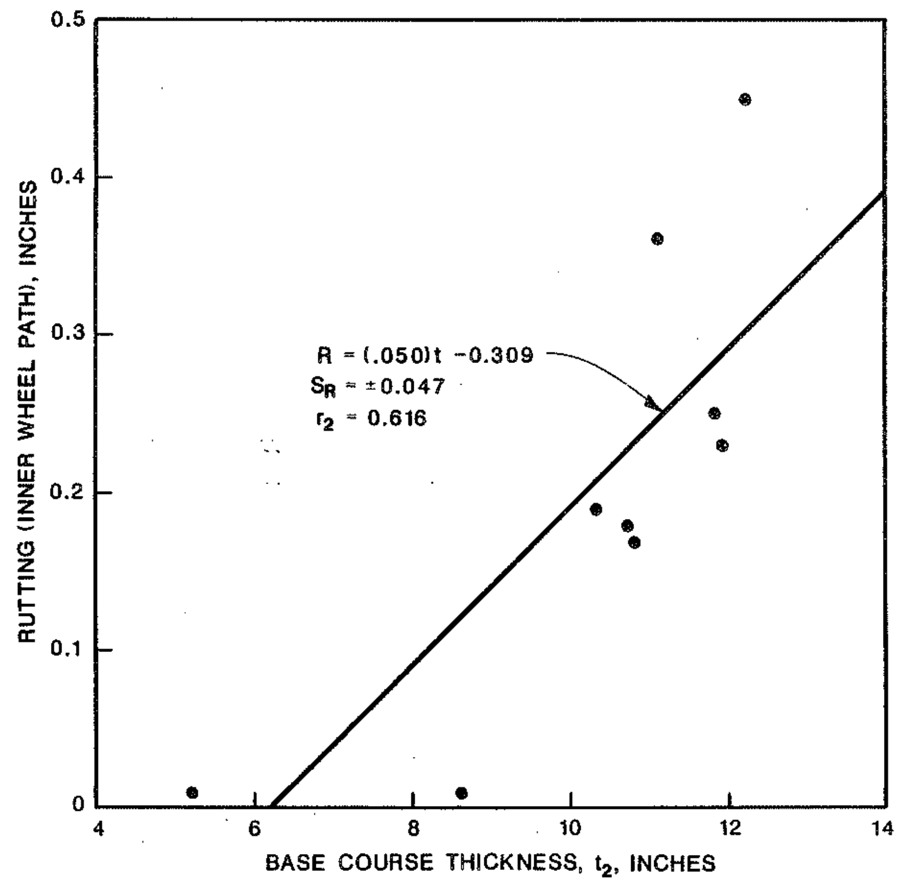



Figure 6. Relationship between rutting and thickness of base course.

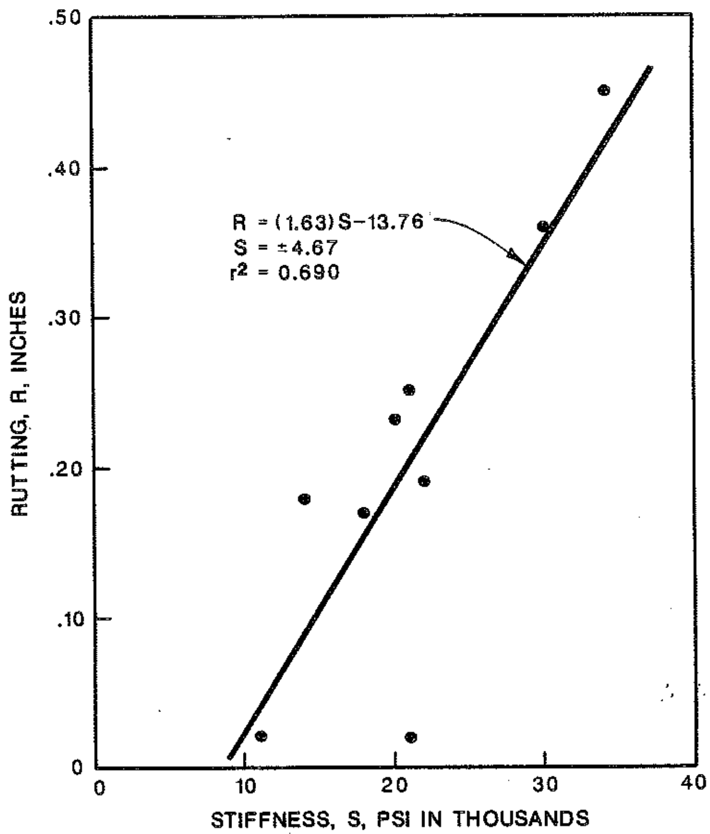



Figure 7. Relationship between rutting of the inner wheelpath and mix stiffness measured by the indirect tensile test at 74 F.

the result of deformation in the underlying granular layers or the subgrade rather than in the bituminous layers. Figure 6 would tend to verify this reasoning.

The direct relationship between rutting and surface course stiffness may seem inconsistent with expectations. Several factors, including traffic, layer stiffnesses and thicknesses, as well as permanent deformation characteristics of the granular layers, can interact to cause the measured ruttings. Of these factors, traffic is the primary cause of deformation.

Findings of this study thus indicate that when designs call for thicker granular layers to carry heavy traffic or to meet frost and drainage requirements, increased rutting due to granular deformations could result, even with relatively stiff bituminous surfaces. This additional rutting would depend on the deformation characteristics of the granular layers which were not investigated in this study. Mixes with lower stiffness would be expected to rut even more if placed on these thicker bases.

Rut depths as measured in this study consist of the total deformations of all the layers in the pavement system. The relative difference in elevation in the pavement surface in the wheelpath as compared to that between wheelpaths (i.e., rut depth) can be caused by both vertical and horizontal displacement of materials in each of the layers. In a flexible pavement, the bituminous layer is designed to transmit loads to the underlying granular materials while at the same time resisting excessive deformations due to traffic. This resistance to rutting by traffic is supposedly accomplished through the stability and flow requirements of the Marshall mix design method. Properly designed bituminous surfacing mixtures should not experience significant deformations even though rutting may occur due to the deformation of other materials underneath. In fact, current mechanistic thickness design technology, concerning rutting, is based on limiting the vertical compressive strain on the subgrade layer. Results obtained in this study (i.e., rutting vs. base thickness) indicate that another criterion, perhaps stress on the granular layers, should be considered when mechanistic design methods are used.

## Deflection

Benkelman beam rebound deflections were measured for each section and the moduli for base, subbase, and subgrade layers were back-calculated using procedures described in a previous report (1). Maximum deflections are presented in Table 1 while the layer modulus values and corresponding thicknesses are given in Table 3. With the exception of Section 3 the deflections and modulus values are proportional in magnitude. This means that variations in cracking of these sections were not due to variations in pavement stiffness and support so no correlations with performance data were attempted. Section 3 deflections, however, were twice as large as those for other sections; modulus values for the unbound layers of Section 3 were lower than for the other sections, with the subgrade stiffness approximately 1/3 of that for the other sections. In spite of the higher deflection of this section (29.0), three others had greater cracking with less than half the deflection of this section. Deflection of the oil-aggregate section (Section 4) was typical of that for the others (except Section 3) but had a Cracking Index of 0 while CI for the others varied from 0 to as much as 37.5 (average CI for all sections was 12.0); this seems to be a further indication that the observed cracking in these pavements was due to something other than their structural characteristics.

Even though these results were not of critical importance to this study the information contained in Table 3 is included in this report as it provides useful information on typical structural parameters for materials in several areas of the state.

## Material Properties

Results of tests performed on core samples are presented in Tables 4 through 6. Specific gravity, voids, asphalt content, and thickness of the core specimens are given in Table 4. The gradation of aggregates extracted from the cores are given in Table 5 while characteristics of the recovered asphalts are summarized in Table 6.

Hardening of the asphalts during service was influenced by air voids for binder, leveling, and wearing courses (Fig. 8). Data from the top course

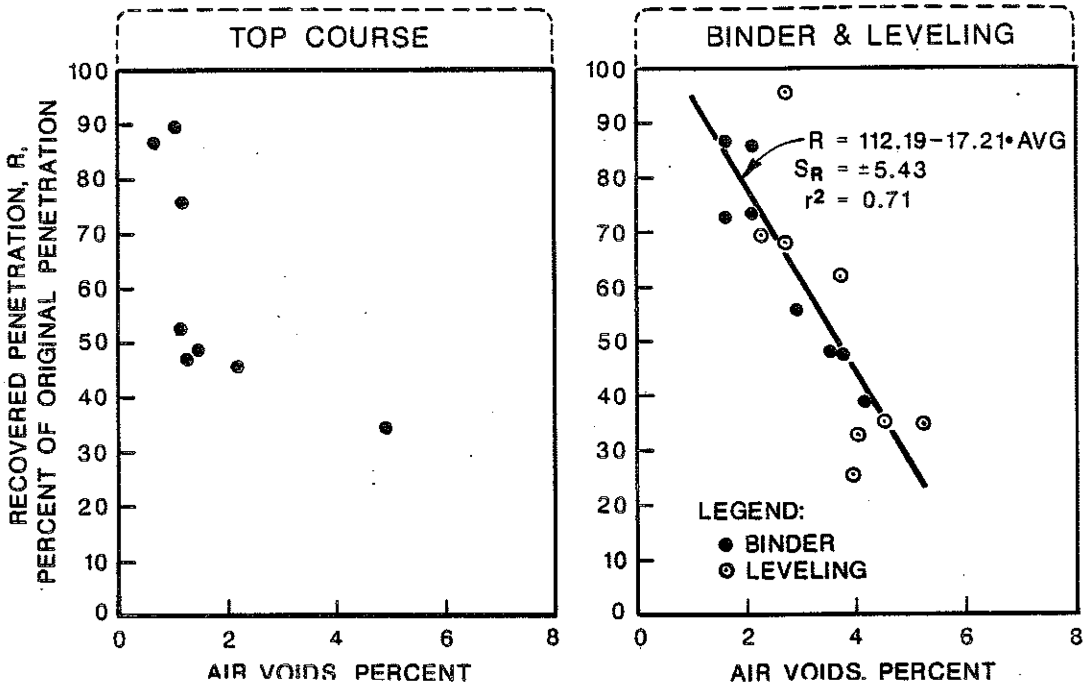



Figure 8. Relationship between asphalt hardening and air voids measured from core samples.

(upper graph, Fig. 8) are shown separately from binder and leveling mixes since the top course is exposed to oil and fuel drippings as well as to sunlight and the atmosphere which could cause the hardening to differ from that of the underlying courses.

The gradation of aggregates recovered from the mixtures, Table 5 and Figures 9 and 10, appear similar for all sections. The fine aggregate portion (passing the No. 30 sieve and retained on the No. 100 sieve) shows an influence on the mixture stiffness as shown in Figure 11; more fines result in stiffer mixes. As previously discussed, the stiffer mixes have been associated with greater amounts of cracking which is reasonable; and also with greater rutting, which is apparently an anomaly due to the specific base conditions present in the sections that were selected.

Asphalt cements recovered from the pavement cores were tested for penetration and viscosity with results summarized in Table 6. Penetration Index values calculated from these data show a strong relationship with transverse cracking of the pavement sections (Fig. 3). Recovered penetrations (expressed as percent of the penetration of the original asphalt prior to mixing) averaged only 41 percent for the sections with Cracking Indexes ranging from 17.5 to 37.5 while recovered penetrations for the relatively uncracked sections averaged 76 percent. The hardening process (or cause of the stiffening that was noted) as measured by these recovered penetrations was not investigated in this study. The amount of air voids in the pavement mixtures is considered as one factor which influences the hardening of asphalt after it has been placed on the roadway. Figure 8 shows the relationship between recovered penetration and air voids

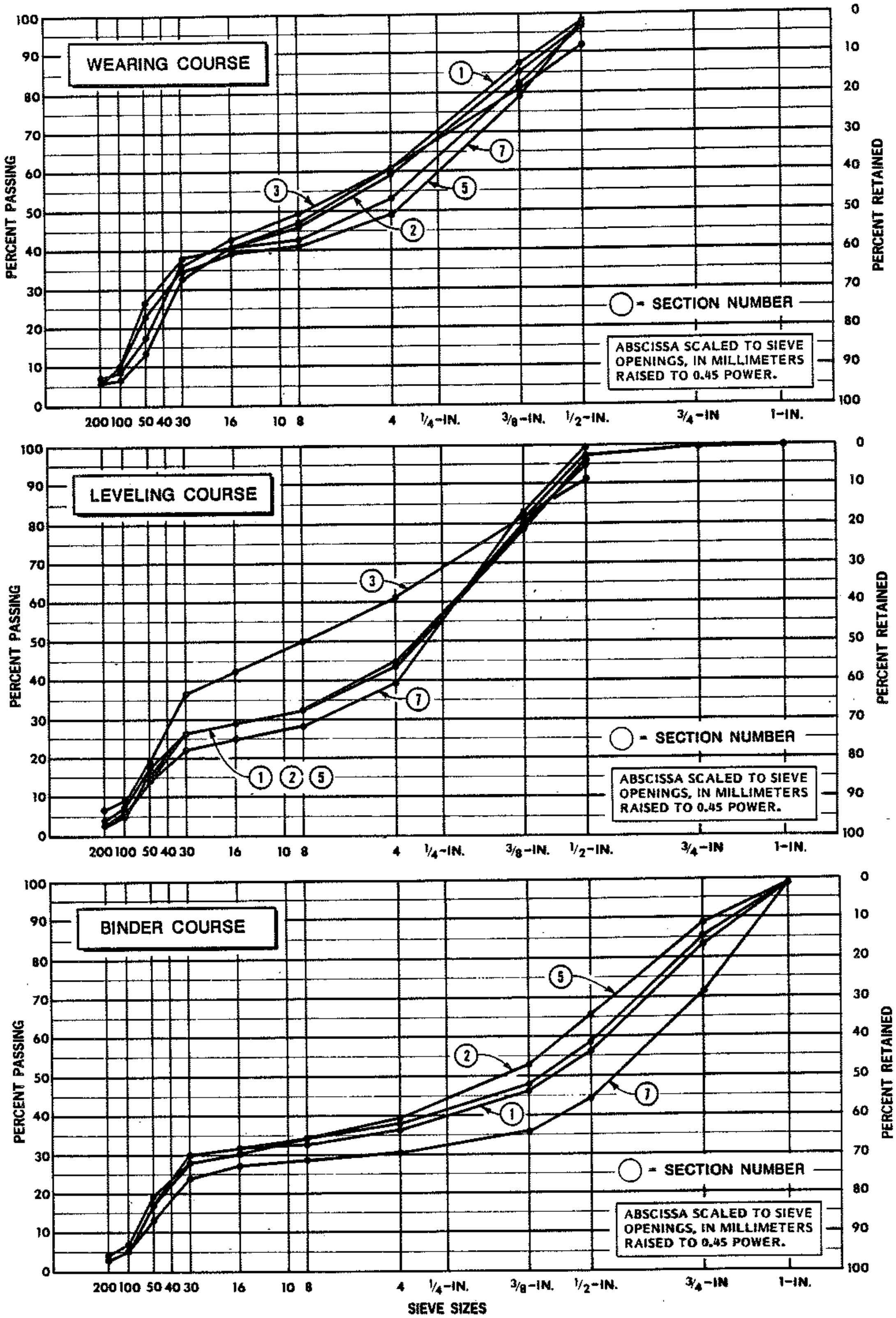



Figure 9. Gradation of aggregates recovered from core specimens from highly cracked sections (C1 = 4.5-37.5).

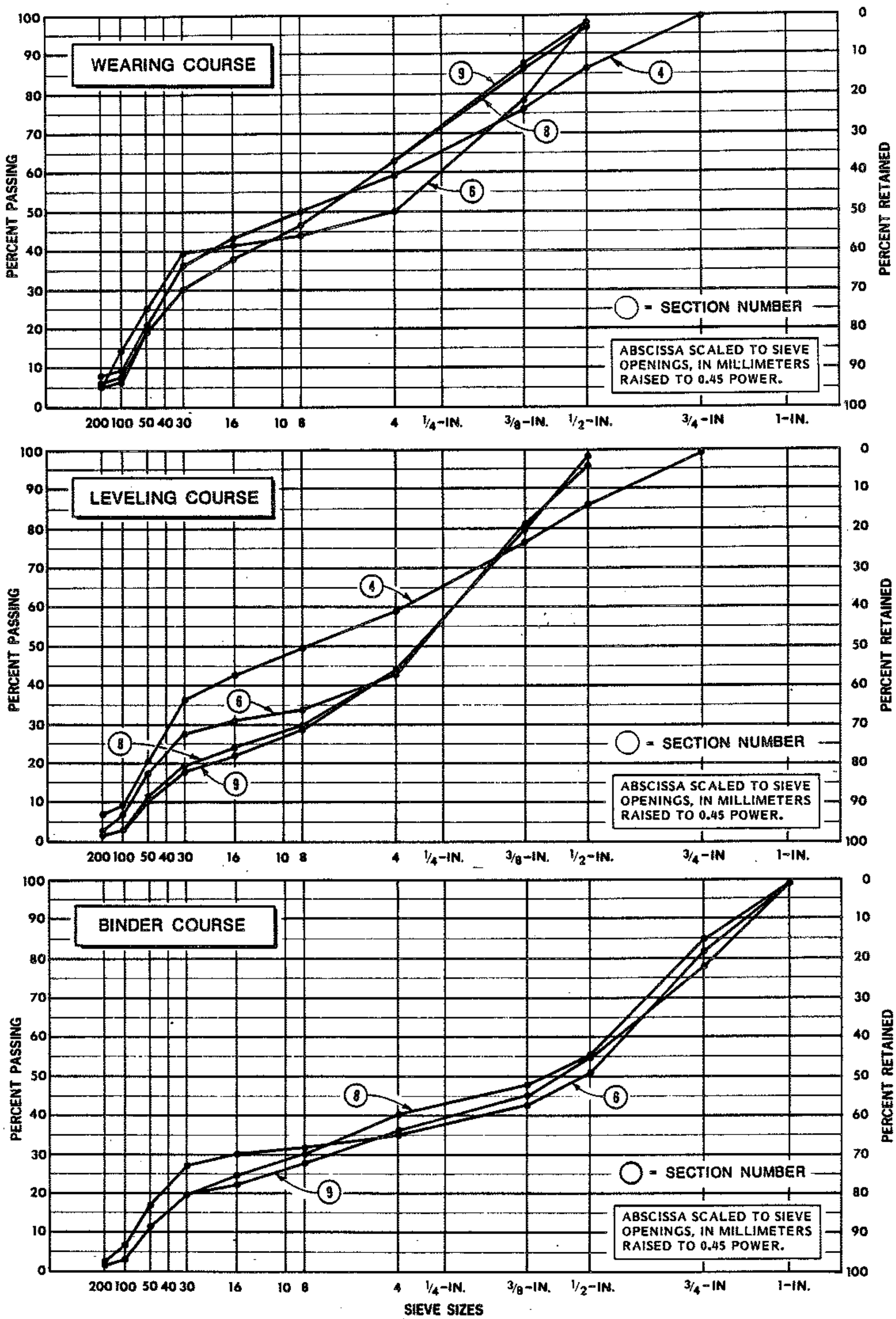
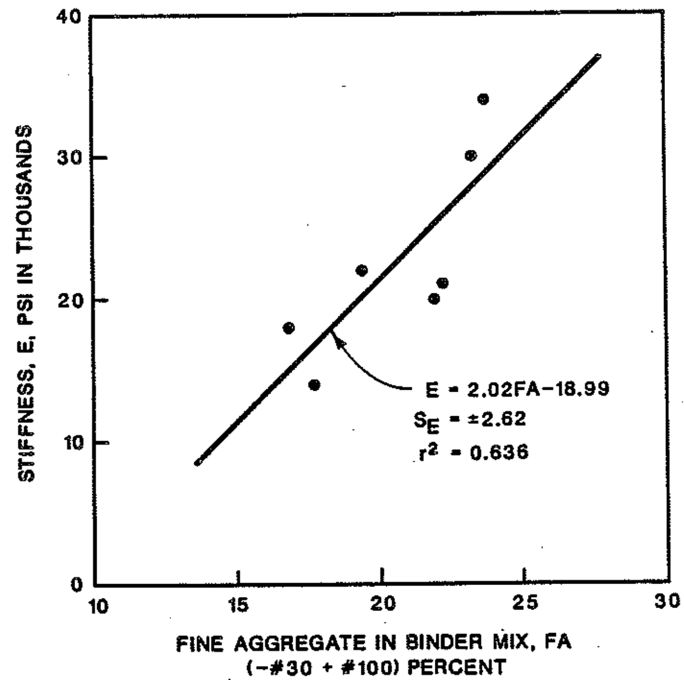



Figure 10. Gradation of aggregates recovered from core specimens from uncracked sections (Cl; 0-0.2).

Figure 11. Relationship between mix stiffness and fine aggregate content.




measured from core samples. All of the projects listed in this figure were of about the same age yet recovered penetrations ranged from 25 to 95 percent, depending upon the air voids in the mixtures. Penetration values could not be obtained for the 34 year old oil-aggregate project due to the softness of the asphalt binder.

Projects with less hardening (i.e., greater recovered penetration percentages) have experienced little or no cracking (Fig. 4), while projects which have hardened have correspondingly suffered greater cracking.

## CONCLUSIONS

The findings of this study were not as conclusive and definite as the distress symptoms displayed by the pavements which prompted it. Seven of the nine projects were built using one penetration grade (60/70) of asphalt cement and most involved aggregates of similar gradation and composition. Only one oil-aggregate pavement was involved so that comparing results would be like comparing a tangerine with eight oranges as citrus fruits. Age of the pavements at the time of testing ranged from 17 to 34 years with lifetime traffic loadings of from 0.3 to 1.4 million 18-kip equivalent single-axle loads.

Transverse cracking of the pavements was found to be directly related to mixture stiffness and temperature susceptibility of the asphalts. Mixture stiffness was affected by the amount of fine sand (-No. 30, +No. 100) in the aggregate. Hardening of the asphalts was related to air voids in the mixtures; this would result in stiffening of the mixtures after paving.

Rutting of the pavements was found to be a direct function of traffic loadings (18-kip equivalent single-axle loadings) and the base course thickness. It was also found that the pavements with stiffer mixtures generally experienced greater rutting. These findings would indicate that the rutting on these projects occurred as a result of deformations in the unbound granular layers, especially in the base course.

The relatively good performance of the one oil-aggregate pavement would not justify changing to that type of mix but would tend to substantiate the use of softer asphalt grades as recommended.

Despite the observed differences in distress levels for the nine pavements, all have performed reasonably well considering that they were probably designed for a 20-year life. At the time this study was initiated none had required reconstruction or rehabilitation. Only four projects (19 to 25 years old) exceeded the Cracking Index value of 15 recommended as a 20-year design criterion (2). Rutting on only four other projects (19 to 25 years old) exceeded the 0.2-in. resurfacing criterion recommended by the FHWA (3) to prevent hydroplaning.

## RECOMMENDATIONS

Results of this study suggest several steps which should be taken to reduce premature transverse cracking of flexible pavements, including:

1) Mixtures should be made with softer asphalts than those used on these projects. Current Bituminous Design Guidelines call for penetration grades of 85/100 and 120/150 which should be satisfactory.

2) The temperature susceptibility (PI) of asphalt cements should be limited to less than -1.5 as measured by the modified Heukelom method.

3) Hardening potential of the asphalts should be controlled through strict enforcement of the current specification requirement for penetration of residue in the Thin Film Oven Test.

4) In-service hardening can be reduced by achieving adequate compaction during construction (i.e., 5 to 6 percent air voids).

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2. Haas, R. C. G., "A Method for Designing Asphalt Pavements to Minimize Low-Temperature Shrinkage Cracking," The Asphalt Institute Res. Rep. 73-1, January 1973.

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