BENKELMAN BEAM TESTING OF SHOULDER AND PAVEMENT RECYCLING PROJECTS

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

BENKELMAN BEAM TESTING OF SHOULDER AND PAVEMENT RECYCLING PROJECTS

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Research Laboratory Section
Testing and Research Division
Research Project 81 TI-727
Research Report No. R-1217

Lansing, March 1983

OFFICE MEMORANDUM

DATE: November 10, 1983

TO: A. P. Chritz
Chairman, Bituminous Advisory Committee

FROM: J. H. DeFoe

SUBJECT: Research Report No. R-1217
"Benkelman Beam Testing of Shoulder and Pavement Recycling Projects"
(attached), R.P. 81 TI-727

The method of comparing the two base constructions (stabilized-in-place and hot plant mix) involved elastic layer theory and used in conjunction with pavement deflection analysis. Results of the study were expressed as estimated stiffness modulus values for the two base materials. This general method of analysis is a recent inovation in pavement thickness design and is currently being modified and improved as experience dictates.

Results summarized in Table 4 are average values and apply only to the eleven projects investigated. Because of the inovative nature of the analysis method, the measured variability within each project and the limited scope of the study, the results should not be used for the design of pavement sections until the results have been verified by further tests.

The AASHTO layer coefficients shown in Table 4 are approximations based on an empirical relationship with stiffness modulus and were included only to provide perspective to the results for those familiar with the AASHTO Interim Guide procedure.

TESTING AND RESEARCH DIVISION

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INTRODUCTION

The purpose of this study was to evaluate the strength and load carrying capacity of stabilized in-place recycled bases as compared with conventional hot plant-mixed bases used for constructing bituminous shoulders and pavements.

This research project was initiated in January 1981 in response to a request from the Construction Division for technical assistance in establishing guidelines for selecting projects for recycling. A technical advisory committee was formed upon initiation of the study to guide the investigation and to select appropriate projects where the two types of bases could be compared.

Many shoulder reconstruction projects seem to be appropriate for either cold in-place recycling to create a stabilized base or for a hot plant-mixed base. Some projects may, however, require some form of high quality base because of heavy traffic, along with the presence of water in the subbase or subgrade layers. For certain projects where either type of base may seem adequate, it was felt that the two methods should be allowed as alternates in the bidding process and further, if the two are approximately equal in strength, they should be constructed to approximately the same thickness.

In this study, Benkelman beam deflection measurements were made on shoulders constructed of the two base types, cold recycled and hot mix black base, in order to compare their relative strengths. The shape and magnitude of the deflection basins were used along with a computerized layer analysis program to determine the strength of the two bases.

Core samples of the bituminous layers (surfacing and base) were obtained for laboratory testing to measure tensile strength of the two materials.

RESEARCH PROGRAM

Eleven test locations were selected for Benkelman beam deflection measurements involving shoulders at eight locations and roadways at three locations (Fig. 1). Black base shoulders were tested on I 275 in Monroe County and M 14 in Washtenaw County with stabilized shoulders tested on I 96, US 27, and US 31 in Muskegon, Isabella, and Ottawa Counties, respectively. Deflections were also measured in traffic lanes of the selected roadways as recommended by the project's technical advisory committee.

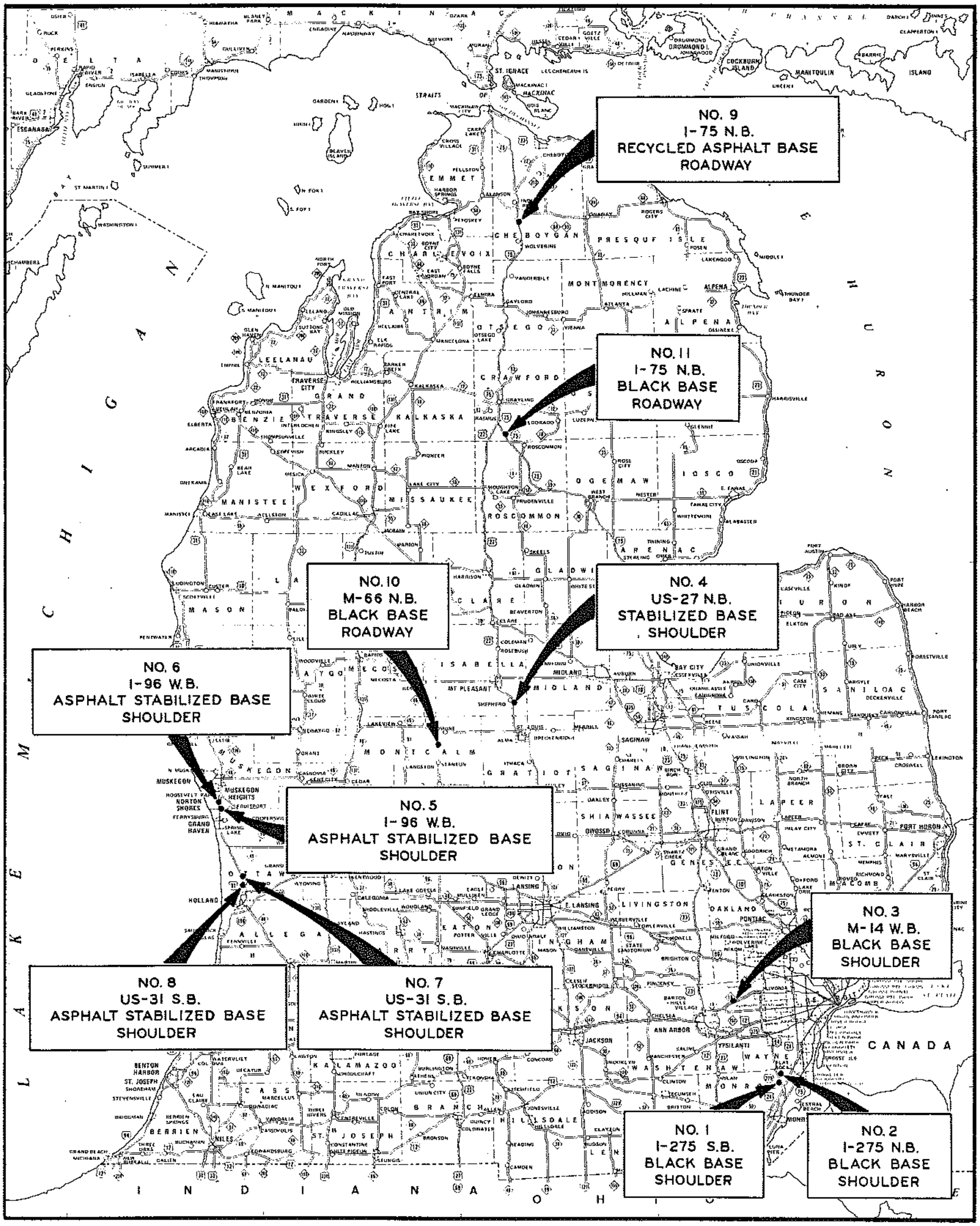


Figure 1. Benkelman beam deflection test locations.

Black base deflections were measured on M 66 in Montcalm County and I 75 in Crawford County as well as a stabilized base roadway section of I 75 in Cheboygan County. Table 1 summarizes the 11 Benkelman beam test locations and describes the base, subbase, and subgrade layers. Figure 2 shows the layer thicknesses for the different sections including both road (traffic lane) and shoulder sections.

TABLE 1
DESCRIPTION OF BENKELMAN BEAM TEST SECTIONS

	Location	Base Type	Subbase	Subgrade
Shoulder	1. I 275 Monroe County	black base	crushed limestone	clay
	2. I 275 Monroe County	black base	crushed limestone	clay
	3. M 14 Washtenaw County	black base	sand	clay
	4. US 27 Isabella County	stabilized	sand	clay
	5. I 96 Muskegon County	stabilized	sand	sand
	6. I 96 Muskegon County	stabilized	sand	sand
	7. US 31 Ottawa County	stabilized	sand	sand
	8. US 31 Ottawa County	stabilized	sand	sand
Traffic Lane	9. I 75 Cheboygan County	stabilized	sand	sand
	10. M 66 Montcalm County	black base	sand	sand
	11. I 75 Crawford County	black base	sand	sand

Deflection Measurements

Benkelman beam rebound deflections were measured using an 18-kip single-axle load. The Benkelman beam was equipped with a displacement transducer connected to a strip chart recorder so that the rebound deflection was continuously recorded as the load truck moved away from the beam pointer. The truck speed averaged 1/2 mph during the tests. Equipment and test procedures which were involved are shown in Figure 3 and are more fully described in Ref. (1).

Deflection basins for each of the comparative shoulder types are shown in Figure 4. Each curve represents the average deflection measured for the sections tested on the designated highways. Deflections were also measured in the traffic lanes of three roadways. Results of these measurements are compared with shoulder deflections in Figure 5.

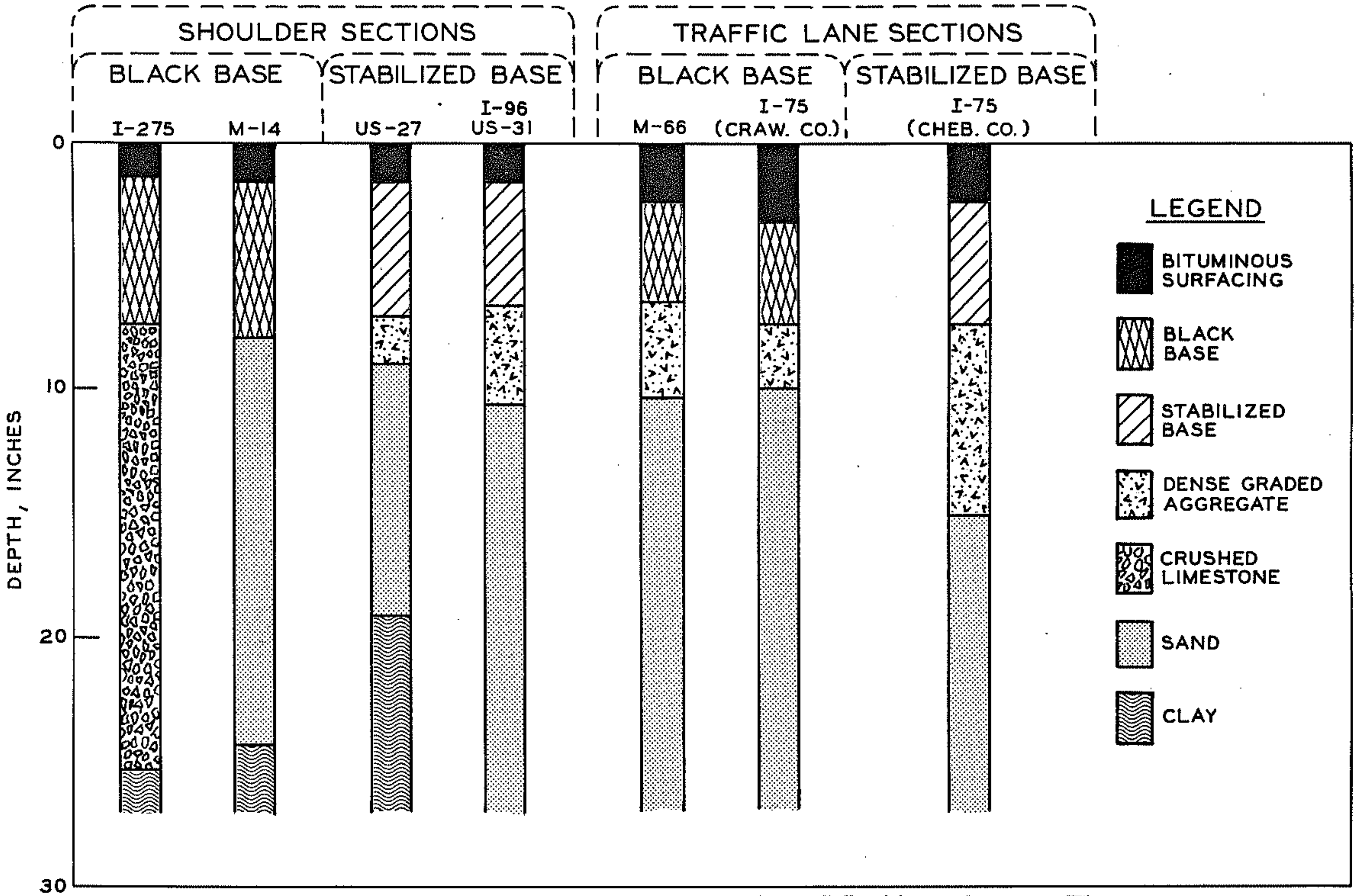
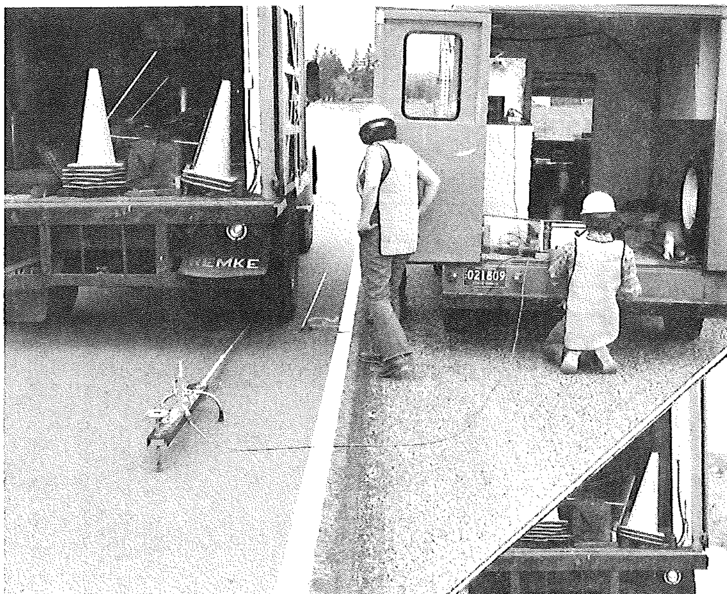
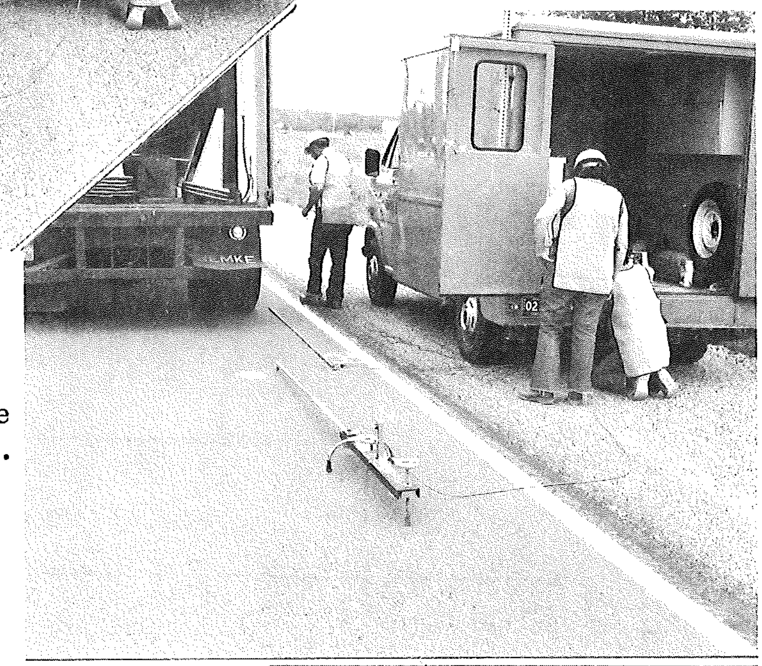


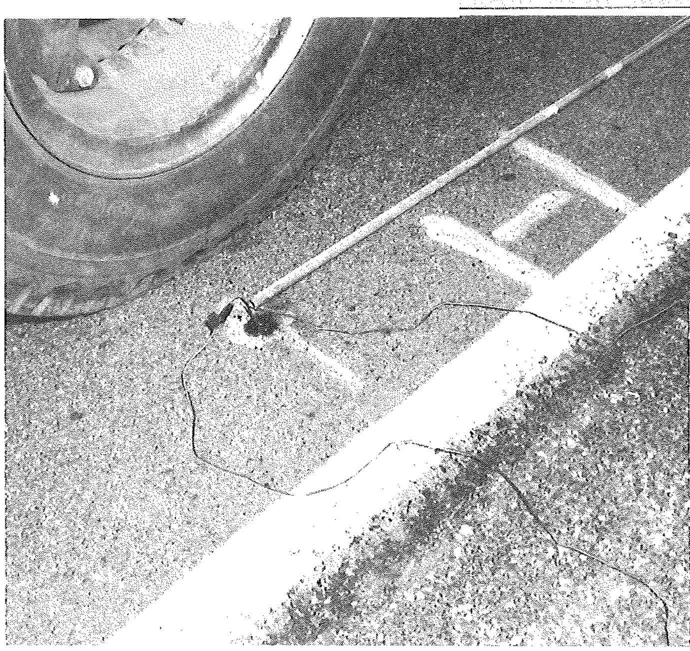
Figure 2. Layer thicknesses of comparative test sections.

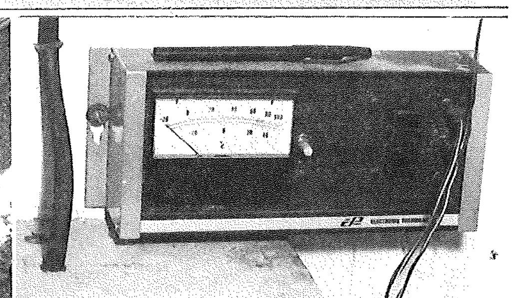


Recording the initial deflection with probe between the dual wheels of the load truck.



Recording deflections while the load truck is creeping forward.





Oil-filled hole for pavement temperature measurements. Temperature recorder above.

Figure 3. Benkelman beam deflection testing.

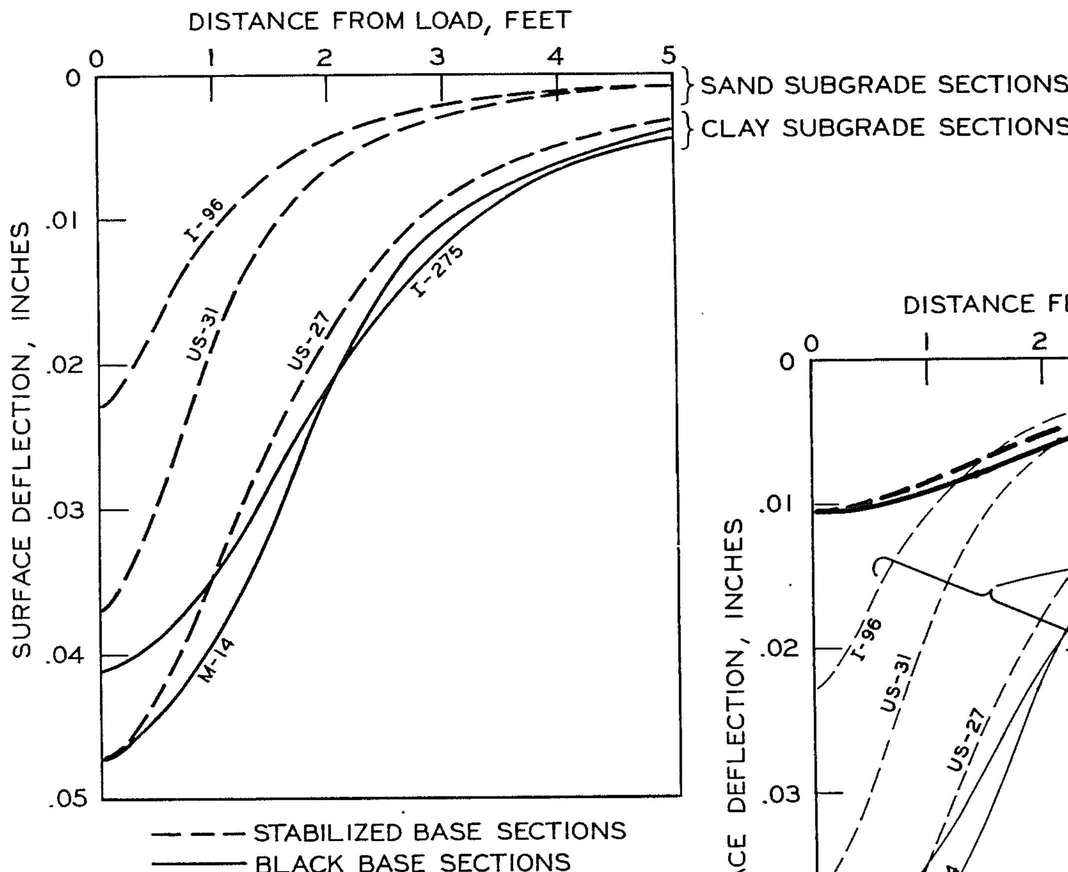


Figure 4. Deflection basins measured on the comparative bituminous shoulder types, as averaged for each type of base.

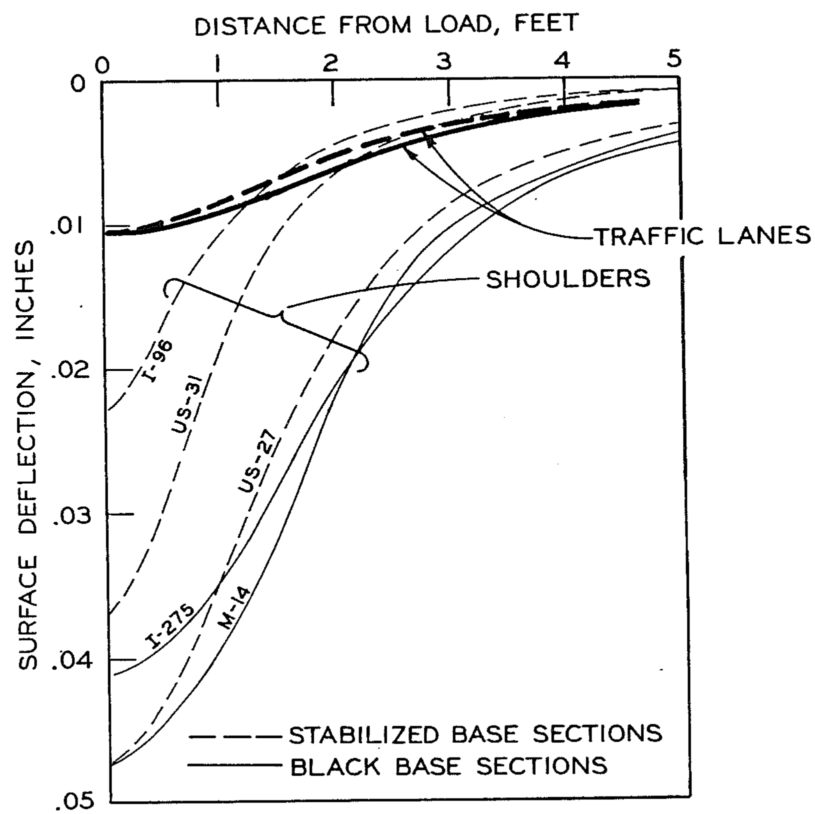


Figure 5. Comparison of shoulder and traffic lane deflection basins as averaged for each highway measured.

Deflection values, as represented by the deflection basin, can be used in several ways in evaluating the structural capacity of the shoulder sections. The shape, or curvature, of the deflection basin as well as the maximum deflection are used in this comparison of black base and stabilized base sections and involves the following three factors.

Maximum Deflection, d_0 — The maximum deflection indicates the stiffness of the entire layered section, including that of the subgrade, bituminous base and surfacing as well as the stiffness of the granular materials in between (2).

Radius of Curvature, R — The radius of curvature (3, 4) of the deflection basin in the vicinity of the wheel load (i.e., within 24 in.) is a measure of the stiffness of the surface and base course layers and correlates strongly with the tensile strain at the bottom of the bituminous base layer (Fig. 6). Radius of curvature was determined from the Benkelman beam deflection recordings using the equations and procedures given in Ref. (4).

$$R = \frac{1}{2ad_0}$$

where a is related to deflection measurements by

$$d(X) = \frac{d_0}{1 + aX^2}$$

where:
- R = radius of curvature
- a = radius of wheel load contact area
- X = distance from wheel load to deflection pointer
- d(X) = deflection at distance X from load
- d_0 = maximum deflection.

Spreadability, S — Spreadability is a measure of the ability of the section to distribute the load over a wide area (5). The concept of spreadability considers the shape as well as magnitude of the deflection basin and is computed as follows:

$$S = \frac{d_0 + d_1 + d_2 + d_3 + d_4}{5d_0} \times 100$$

where: S = spreadability in percent and d_0 through d_4 are the deflections at 1-ft intervals from the wheel load beginning with d_0, the maximum deflection.

Maximum deflection (d_0), radius of curvature (R), and spreadability (S) values measured for the comparative sections are summarized in Table 2 and are compared graphically in Figures 7 through 9.

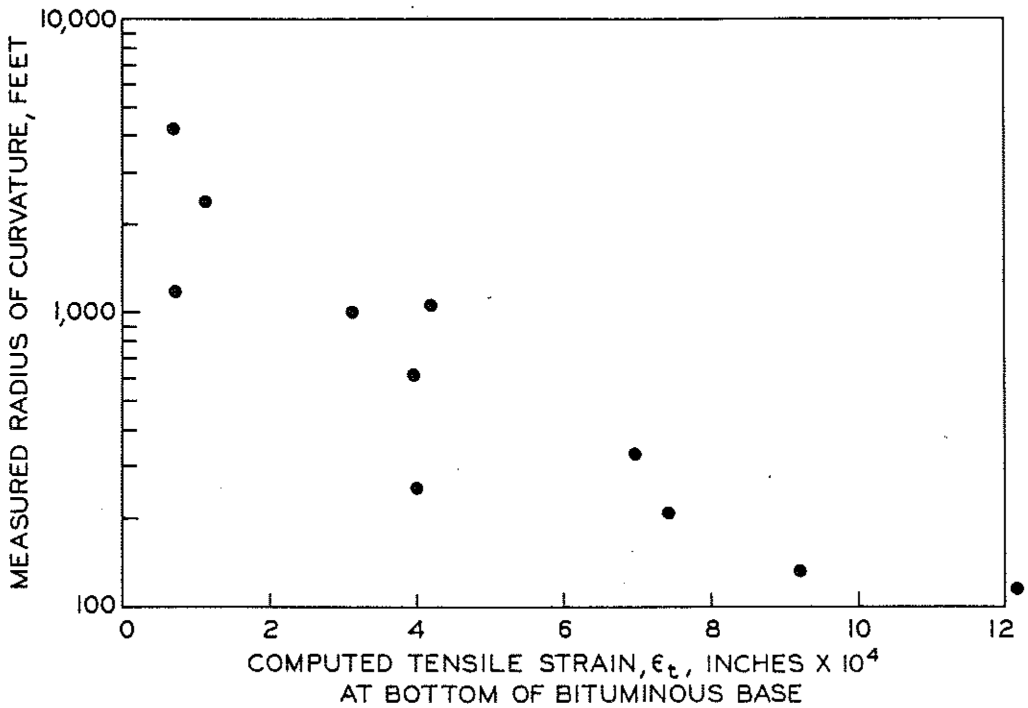


Figure 6. Relationship between radius of curvature measured with the Benkelman beam and tensile strains in the bituminous base layer.

TABLE 2
DEFLECTION BASIN PARAMETERS FOR
BLACK BASE AND STABILIZED BASE TEST SECTIONS

	Location	Base Type	Maximum Deflection, d_0, in.	Spread-ability, (S), percent	Radius of Curvature, (R), ft
Shoulder	1. I 275 Monroe County	black base	0.0365	55.9	978
	2. I 275 Monroe County	black base	0.0468	54.0	611
	3. M 14 Washtenaw County	black base	0.0447	57.2	1,061
	4. US 27 Isabella County	stabilized	0.0472	47.8	326
	5. I 96 Muskegon County	stabilized	0.0262	34.9	208
	6. I 96 Muskegon County	stabilized	0.0193	36.0	257
	7. US 31 Ottawa County	stabilized	0.0332	33.4	130
	8. US 31 Ottawa County	stabilized	0.0403	36.9	119
Traffic Lane	9. I 75 Cheboygan County	stabilized	0.0109	55.8	2,368
	10. M 66 Montcalm County	black base	0.0102	60.8	4,149
	11. I 75 Crawford County	black base	0.0093	65.6	1,161

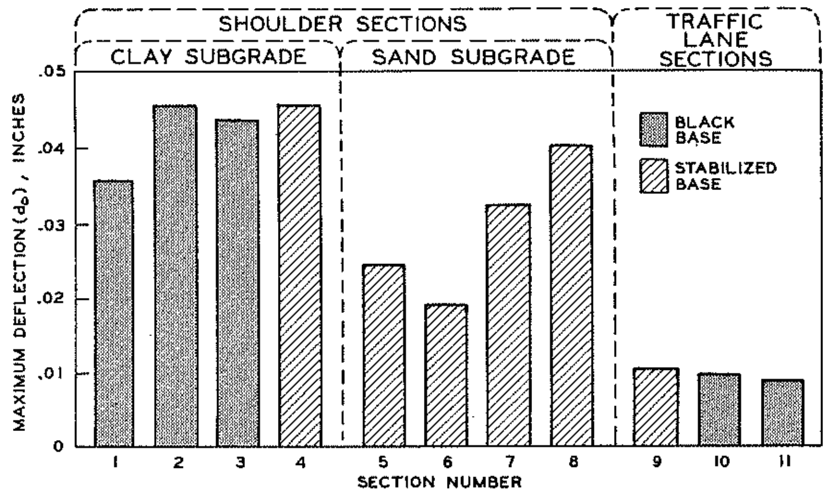


Figure 7. Comparison of maximum deflections measured at the wheel load for black base and stabilized base sections.

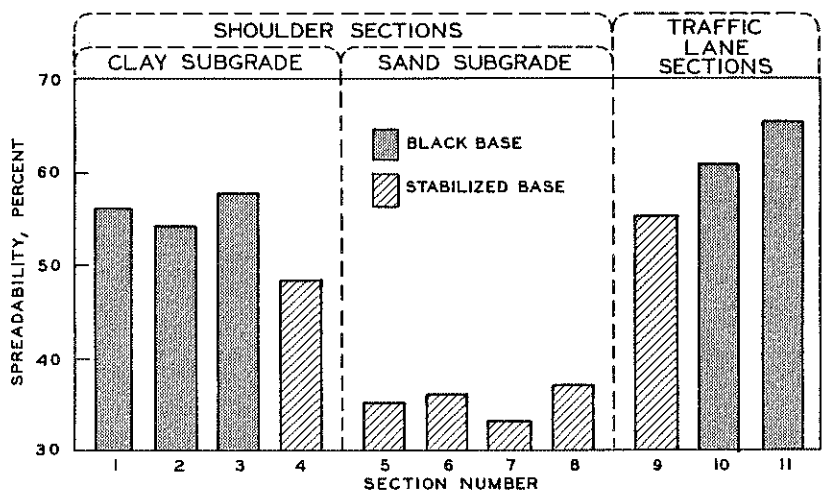


Figure 8. Comparison of spreadability values measured by the Benkelman beam for black base and stabilized base sections.

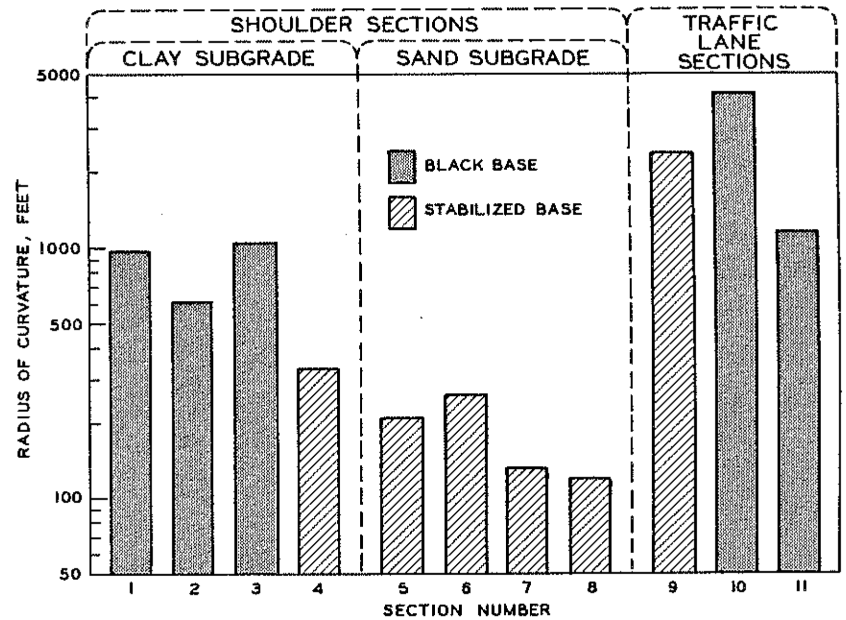


Figure 9. Comparison of radii of curvature in the vicinity of the wheel load as measured by the Benkelman beam for black base and stabilized base sections.

TABLE 3
LABORATORY TEST RESULTS COMPARING
BLACK BASE AND STABILIZED BASE MATERIALS

	Location	Base Type	Stiffness Modulus, E, psi	Tensile Strength, psi
Shoulder	1. I 275 Monroe County	black base	14,500	46.5
	2. I 275 Monroe County	black base	15,100	54.2
	3. M 14 Washtenaw County	black base	25,800	87.6
	4. US 27 Isabella County	stabilized	--	5.5
	5. I 96 Muskegon County	stabilized	1,600	4.2
	6. I 96 Muskegon County	stabilized	1,100	4.2
	7. US 31 Ottawa County	stabilized	2,200	4.8
	8. US 31 Ottawa County	stabilized	2,100	7.6
Traffic Lane	9. I 75 Cheboygan County	stabilized	28,500	55.0
	10. M 66 Montcalm County	black base	--	--
	11. I 75 Crawford County	black base	--	--
	Average for black base shoulders		18,500	62.8
	Average for stabilized base shoulders		1,750	5.3

TABLE 4
BASE LAYER CHARACTERISTICS
ESTIMATED FROM DEFLECTION BASIN ANALYSES

	Location	Estimated Stiffness Modulus, psi (thousands)	AASHTO Layer Coefficient, a
Shoulder	1. I 275 Monroe County	200	0.42 black base
	2. I 275 Monroe County	200	0.42 black base
	3. M 14 Washtenaw County	140	0.36 black base
	4. US 27 Isabella County	50	0.22 stabilized base
	5. I 96 Muskegon County	40	0.20 stabilized base
	6. I 96 Muskegon County	100	0.31 stabilized base
	7. US 31 Ottawa County	50	0.22 stabilized base
	8. US 31 Ottawa County	20	0.15 stabilized base
Traffic Lane	9. I 75 Cheboygan County	180	0.40 stabilized base
	10. M 66 Montcalm County	250	0.47 black base
	11. I 75 Crawford County	250	0.47 black base
	Average for black base shoulders	180,000	0.40
	Average for stabilized base shoulders	52,000	0.22

Laboratory Tests

The indirect tensile test method (6) was used to measure the tensile strength and stiffness modulus of the base materials. The laboratory test conditions (temperature, loading time, and confinement) did not duplicate conditions during deflection testing so the results, shown in Table 3, are not comparable to those obtained in the field and shown in Table 4. The values do, however, provide a relative measure between black base and stabilized base materials.

RESULTS

A comparison of the deflection basins measured on the shoulders (Fig. 4) show greater deflections for the black base sections than for those with stabilized bases. Deflections measured for traffic lane sections, however, are nearly identical for the two types of bases (Fig. 5).

Radius of curvature and spreadability values for each of the sections are summarized in Table 2 and are compared graphically in Figures 8 and 9, respectively. Radius of curvature values in Figure 8 are greater for black base sections than for the stabilized base sections. The larger radii of curvature measured for black base sections would result in lower tensile strains at the bottom of the bituminous base layer.

The deflection results were also influenced by the underlying subgrade. Sections constructed over clay subgrades resulted in larger deflections than those built on granular subgrades. The influence of subgrade type on deflection and curvature values can be seen in Figures 5, 7, and 8. Figures 5 and 7 show that deflection values are approximately equal for both bases when the clay subgrades are involved. Spreadability values are also nearly equal for the two bases in the clay subgrade sections (Fig. 8). Radius of curvature values (Fig. 9) were not as great, however, for the stabilized base section as compared with black base sections in the clay subgrade; this would result in higher tensile strains for the stabilized base section.

The results of this study have thus far been evaluated by directly comparing deflection measurement parameters made on layered pavement systems. A comparison of the two bases can also be made by computing the stiffness modulus of the bituminous base layers using deflection basin analysis methods recently developed (1). Modulus values thus estimated are presented in Table 4. Departmental procedures for thickness design of flexible pavements are based on AASHTO procedures (7) involving layer coefficients; Table 4 also lists layer coefficient values which correspond to tabulated modulus values. The relationship used to arrive at the layer coefficients is shown in Figure 10 and is an approximation based on limited field correlations (8).

Laboratory tests show that stiffness modulus and tensile strength values are greater for black base materials than for stabilized materials (Table 3). Data from section 9 also show, however, that stabilized material can be as stiff and strong as black base material. Section 9 is a portion of the first cold recycling project in Michigan involving large portions of bituminous materials, asphalt cements, and a high level of quality control in construction.

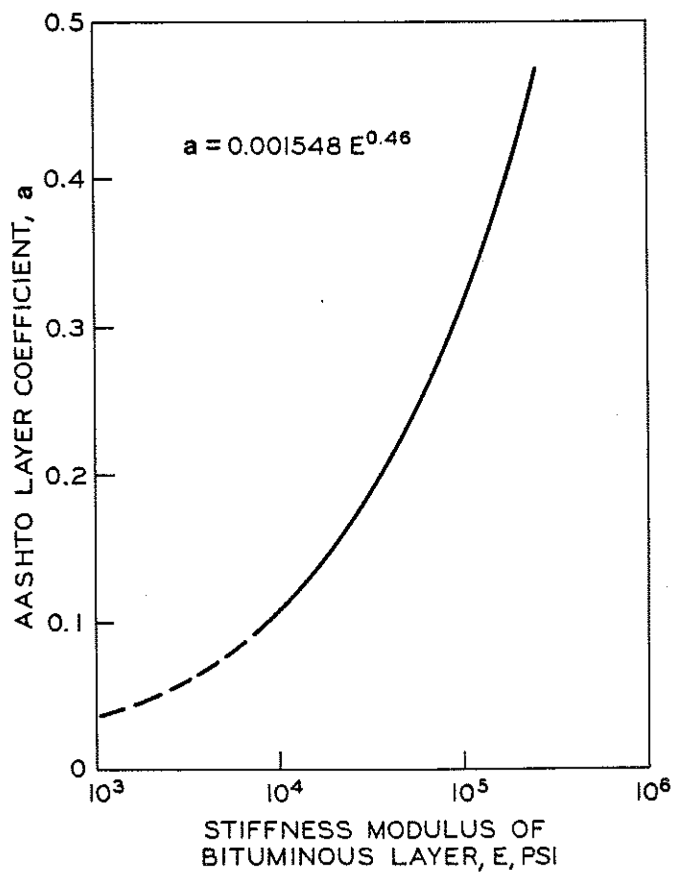


Figure 10. Relationship between AASHTO layer coefficient and stiffness of bituminous mixtures for base and surface courses (after Takeshita (8)).

CONCLUSIONS

1) The shape of the deflection basin is a more meaningful measure of the performance capabilities of the two types of construction than is maximum deflection alone.

2) The black base sections measured in this study were stiffer on the average than the comparable stabilized base sections. Average stiffness moduli for black base and stabilized base layers were 180,000 and 52,000 psi, respectively. AASHTO layer coefficients were estimated to be 0.40 for the black bases and 0.22 for the stabilized bases investigated.

3) Stabilized bases can be as stiff and have the equivalent structural capacity of black bases as demonstrated by the modulus and layer coefficient values obtained for section 9, of 180,000 psi and 0.40, respectively.

4) Both black base and stabilized base sections constructed on clay subgrades experienced greater deflections than those constructed on sand. Greater radii of curvature, i.e., lower tensile strain, were measured for the black bases than for the stabilized bases on the clay subgrades.

5) The tensile strength and stiffness modulus of stabilized base materials can be as great as for black bases as shown for section 9 in Table 3, even though the values measured for the stabilized shoulder bases in this study were approximately 10 percent of the black base values.

RECOMMENDATIONS

Black bases rather than stabilized bases should be used under shoulders along highways having heavy commercial traffic; and where medium to heavy volumes of commercial traffic occur along with saturated layers of subbase or subgrade, e.g., usually over clay subgrades.

REFERENCES

1. DeFoe, J. H., "Use of Deflection Basin Characteristics for Flexible Pavement Analysis and Overlay Design," MDOT Research Report No. R-1204, September 1982.

2. Rufford, P. G., "A Pavement Analysis and Structural Design Procedure Based on Deflection," Proceedings, Fourth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1977.

3. Miura, Y. and Tobe, T., "Evaluation of Existing Pavement Based on Deflection and Radius of Curvature and Overlay Design," Proceedings, Fourth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1977.

4. Leger, P. and Autret, P., "The Use of Deflexion Measurements for the Structural Design and Supervision of Pavements," Proceedings, Third International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1972.

5. Kuo, S. S., "Evaluation of Existing Pavement and Overlay Design on M 38 in Ontonagon County," MDOT Departmental Memorandum, June 1980.

6. Maupin, G. W., Jr. and Freeman, J. R., Jr., "Simple Procedure for Fatigue Characterization of Bituminous Concrete," Federal Highway Administration, Report No. FHWA-RD-76-102, June 1976.

7. AASHTO Interim Guide for Design of Pavement Structures, 1972.

8. Takeshita, Harumi, "Considerations on the Structural Number," Proceedings, Second International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1967.