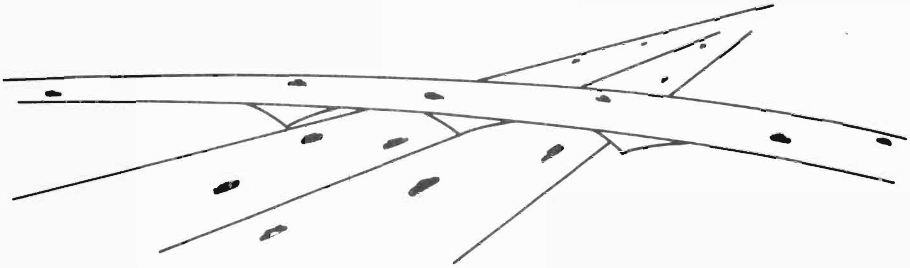
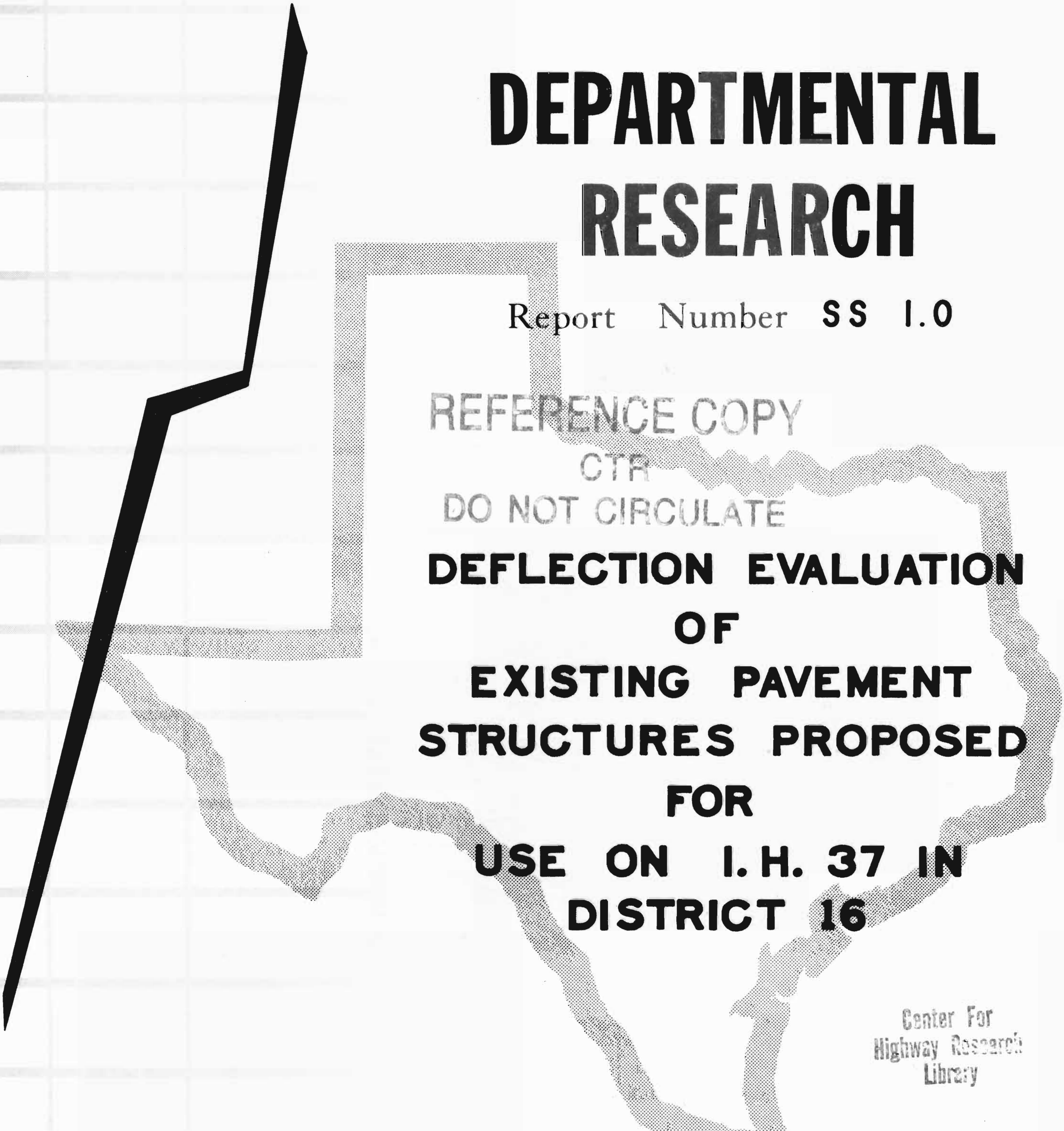


DEPARTMENTAL RESEARCH

Report Number **SS 1.0**



DEFLECTION EVALUATION OF EXISTING PAVEMENT STRUCTURES PROPOSED FOR USE ON I. H. 37 IN DISTRICT 16

TEXAS HIGHWAY DEPARTMENT

DEFLECTION EVALUATION OF EXISTING PAVEMENT STRUCTURES PROPOSED FOR USE ON IH 37 IN DISTRICT 16

By

B. F. McCullough
Supervising Design Research Engineer
and
James L. Brown
Engineering Assistant II

Report Number No. SS 1.0

THE STATE OF TEXAS

Conducted by
The Research Section of
The Highway Design Division
The Texas Highway Department
March, 1966

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CONCLUSIONS

1. Deflection measurements can be used as a basis for determining the strength of existing flexible pavements and the pavement structure required for future traffic.
2. Variation in subgrade strength contributes more to variation in total strength than any other layer of the pavement structure.
3. Three essentially different design methods give similar amounts of overlay required to upgrade the existing pavements to Interstate standards.
4. This study can be used as a basis for developing a complete design procedure to evaluate existing pavement structures and to select reconstruction needed to handle future traffic.

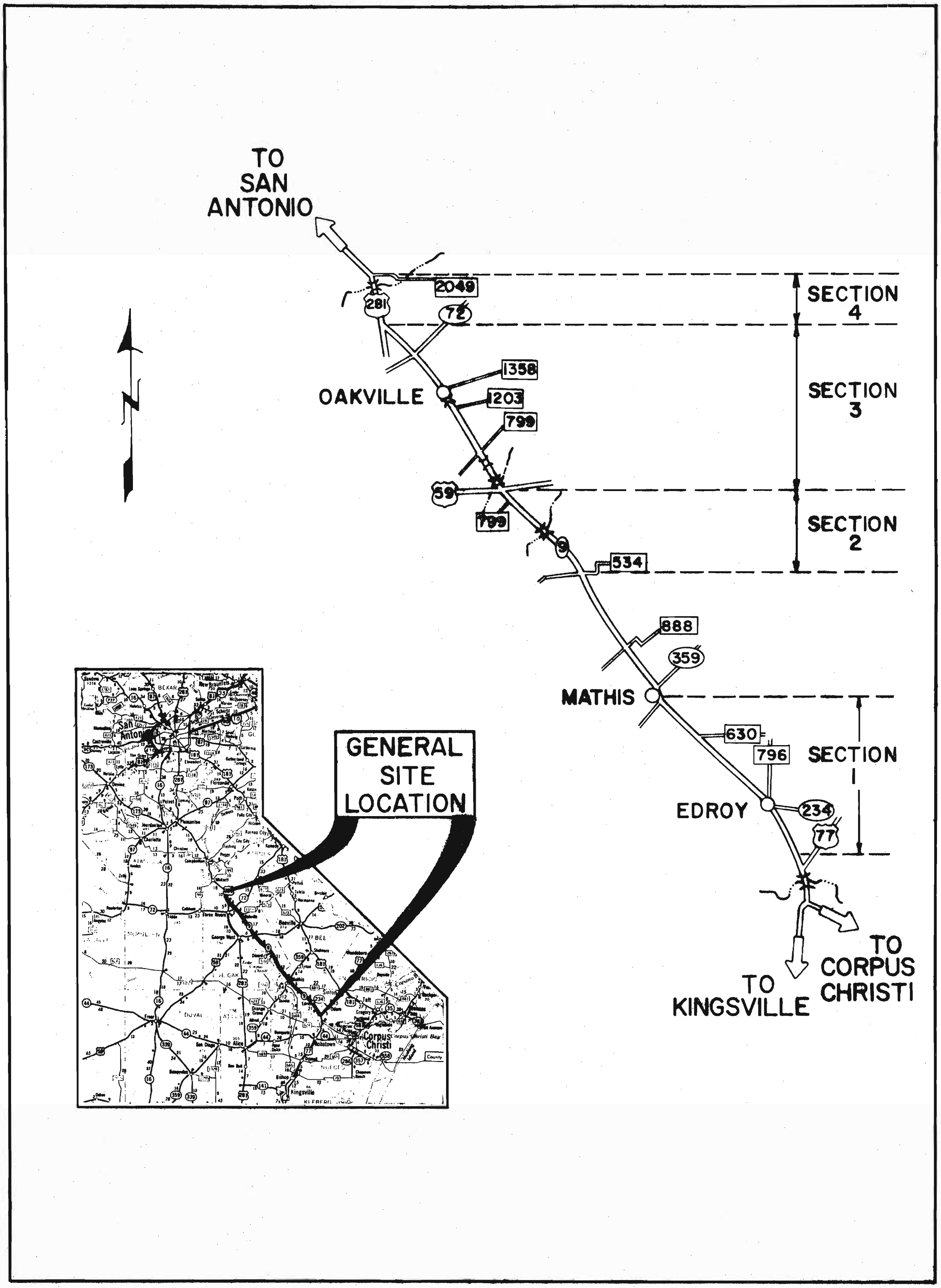
INTRODUCTION

The objective of this study was to use deflection measurements for evaluating four existing sections of highway in order to arrive at a satisfactory overlay of asphaltic concrete. The pavements are proposed for use as main lanes of Interstate Highway 37. Figure 1 shows the general location of the four sections. Figures 2.1 thru 2.4 portray the typical pavement sections.

EQUIPMENT AND PROCEDURES

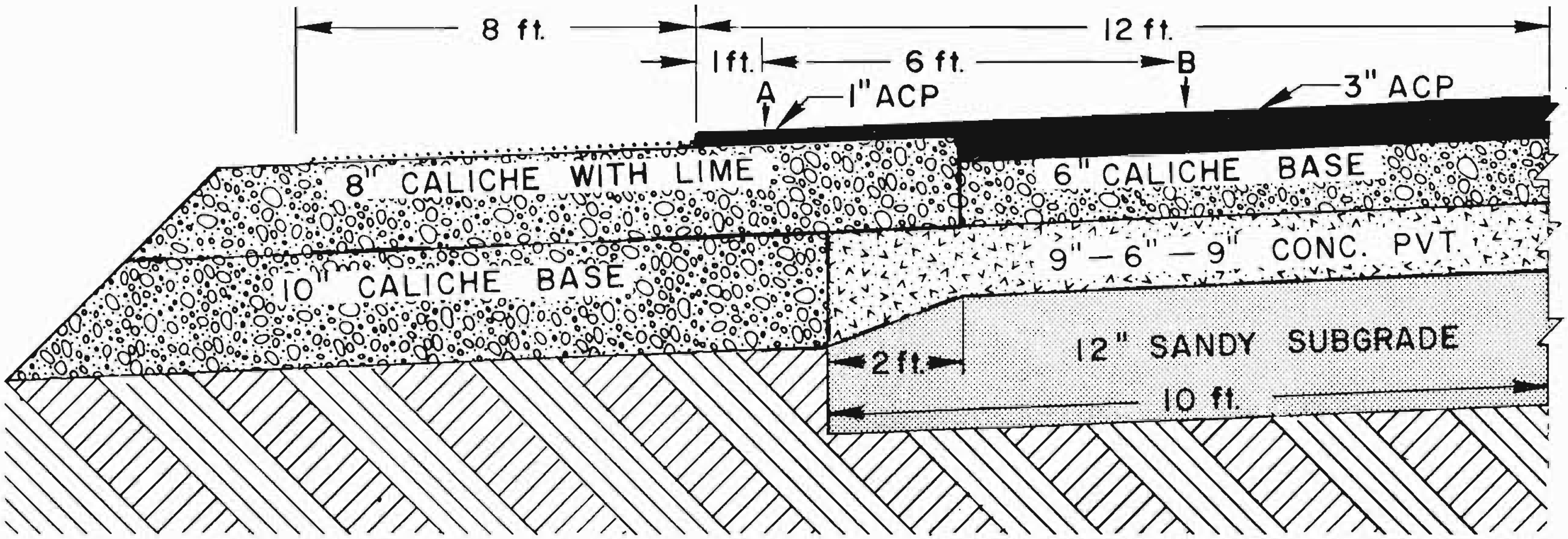
Prior to collection of the primary data the following preliminary measurements were made:

1. A Benkelman Beam was placed between the dual tires of a two axle truck which was loaded to 18 kips on the rear axle. A second Benkelman Beam was placed at the fulcrum of the first beam. As the truck was driven away the deflection was measured at both points. This check for basin effect was made both over the old concrete pavement and on the flexible portions of all four sections. In no case was the length of the basin found to extend to the fulcrum of the first beam.



LOCATION AND LAYOUT OF PROJECT

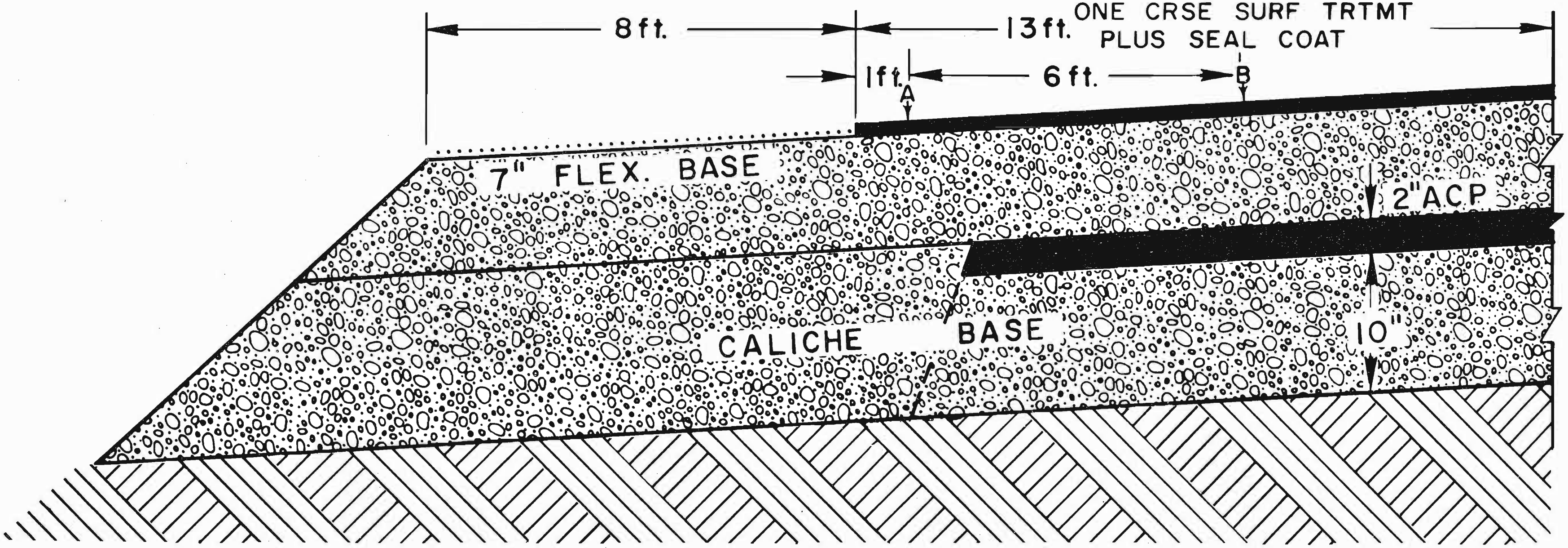
FIGURE I.



A–POINT OF OUTSIDE DEFLECTION MEASUREMENT
B–POINT OF INSIDE DEFLECTION MEASUREMENT

EXISTING PAVEMENT – SECTION I

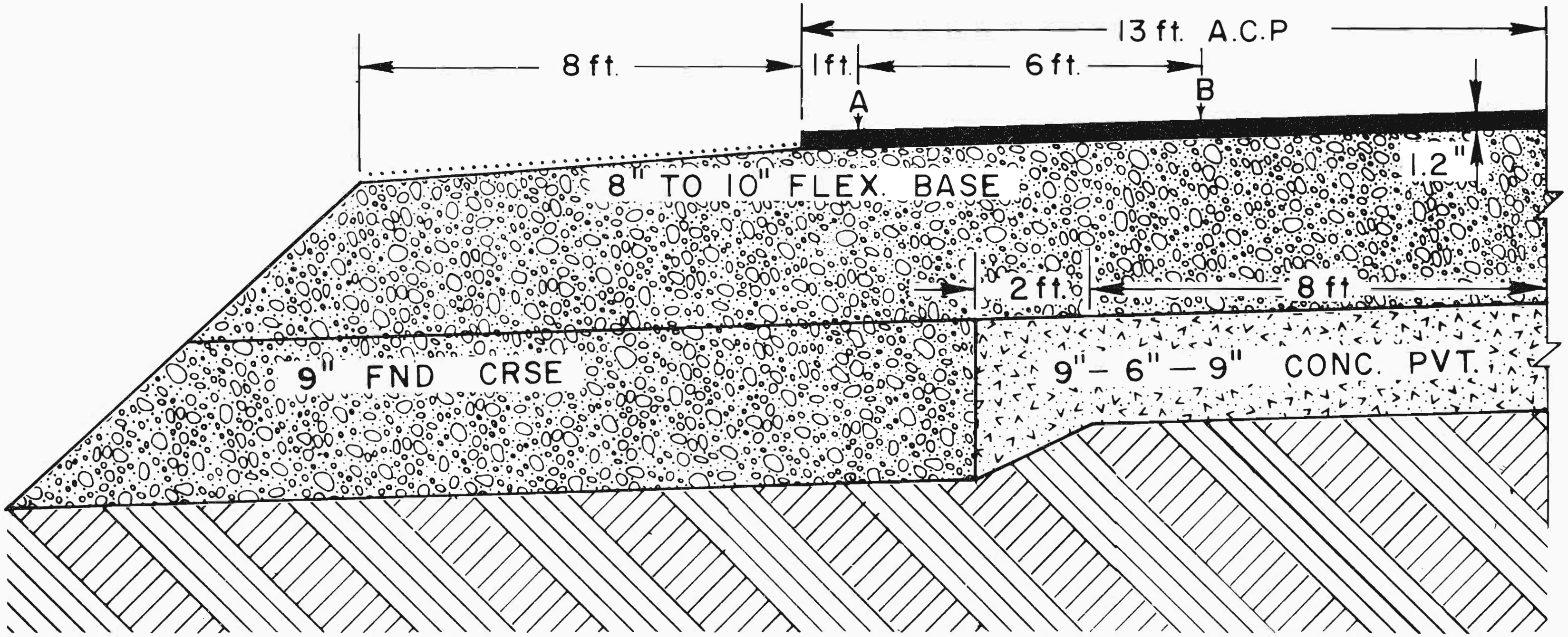
FIGURE 2.1



A—POINT OF OUTSIDE DEFLECTION MEASUREMENT
B—POINT OF INSIDE DEFLECTION MEASUREMENT

EXISTING PAVEMENT – SECTION 2

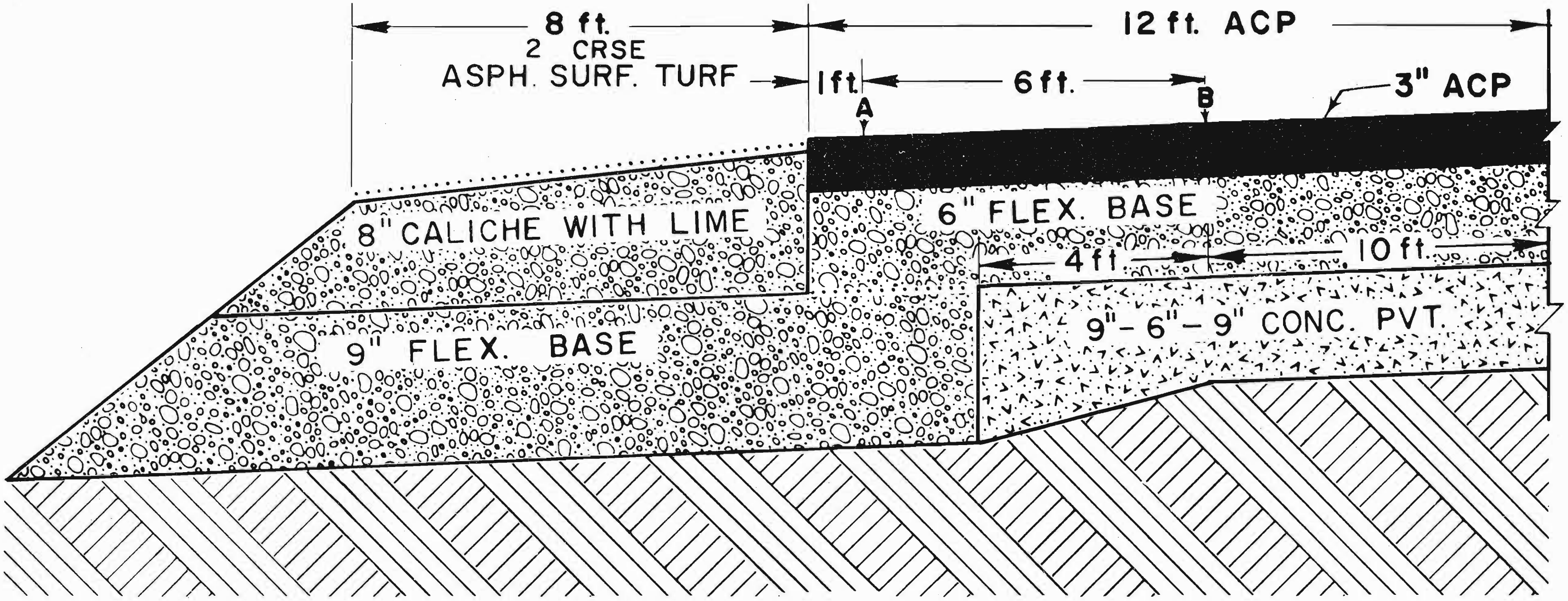
FIGURE 2.2



A–POINT OF OUTSIDE DEFLECTION MEASUREMENT
B–POINT OF INSIDE DEFLECTION MEASUREMENT

EXISTING PAVEMENT – SECTION 3

FIGURE 2.3



A POINT OF OUTSIDE DEFLECTION MEASUREMENT
B - POINT OF INSIDE DEFLECTION MEASUREMENT

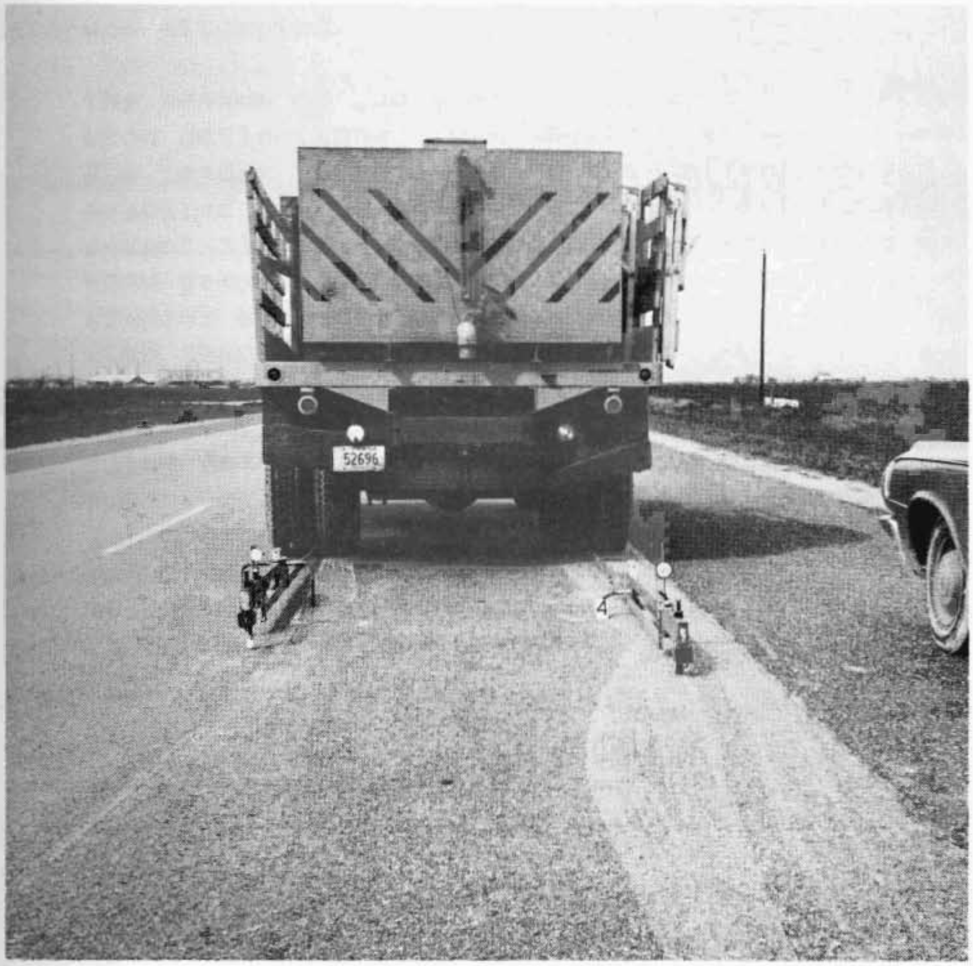
EXISTING PAVEMENT - SECTION 4

FIGURE 2.4

2. In all sections, deflection was found to increase with distance from the present centerline. The future centerline is to be two feet either right or left of the present centerline.

The operating procedure chosen for the primary part of this investigation was as follows:

1. Benkelman Beam readings were taken under both duals using AASHO procedure.[1]
2. The outside dual tires were placed at the edge of the present surfacing. Thus, the outside measurement was taken at the weakest point in the existing section (excluding the present shoulder which will always be outside the future wheel path). Figure 3 shows the position of the truck and the beams.
3. A reading was taken every one-tenth mile as measured and recorded from the speedometer of an automobile.
4. In addition to the outside and inside deflection the following data was recorded:
    a. Time
    b. Speedometer reading
    c. Located in cut, fill, or neigher
    d. Roadway flat or on grade
    e. Roadway super elevated or not



LOCATION OF BEAMS

FIGURE 3

METHOD OF ANALYSIS

The following assumptions were made before an analysis of the data was attempted.

1. The season of the year has a neglectable effect upon deflection. In support of this hypothesis, the reader is referred to the deflections measured at the AASHO Road Test which remained essentially constant except for the spring thaw period.[1] Furthermore, the temperature studies showed minor changes in deflection with temperature when asphaltic concrete was a small portion of the overall pavement. In addition, California has considerable experience using deflection measurements to determine reconstruction requirements and this assumption is apparently made.[2] It should be noted that District personnel commented during the data collection that "the ground is the wettest that it has been in seven years."

2. While a corrective method other than overlaying with asphaltic concrete might be more economical, it was considered beyond the objective of this study to investigate alternate solutions.

3. The point where outside deflection measurements were taken is considered the weakest point in the section. The analysis is based upon these outside deflection measurements. Unless stated otherwise, the deflections referred to throughout the remainder of this report are these outside measurements.

Essentially three methods of analysis were used. The "Texas Design Index" (TDI) Method was based upon research presently being conducted by the Texas Transportation Institute.[3] This research is sponsored by the Texas Highway Department and the Bureau of Public Roads. The second method, termed the "California Method," was a modification of a method being used by California.[2] Last was the "Triaxial" Method using Texas Test Procedure Tex-117-E and the strengths found in the TDI Method.[4]

The Texas Design Index Method (TDI)

The Texas Design Index (TDI) is a numerical expression for the overall strength of a pavement in terms of the layer strengths and their thicknesses. See Appendix A for further explanation. This index can be determined for an existing pavement by measuring the deflection and using the equation shown below:

$$\mathrm{TDI}_{(\text{existing})} = 112.8 - 30 \operatorname{Log} U$$

Where: U = deflection in thousandths of an inch.

Note: This equation contains a regional factor and is therefore only applicable to the District 16 region.

It was felt desireable to subdivide this overall strength into existing layer strengths. Figure 4.1 - 4.4 shows that correlation exists between the outside deflection and inside deflection for all four sections. The only pavement layers that are common to both inside and outside deflections are the subgrade and the thin asphaltic concrete surfacing. It therefore appears reasonable to assume that this correlation is caused by similar subgrade at any point longitudinally within a section. This

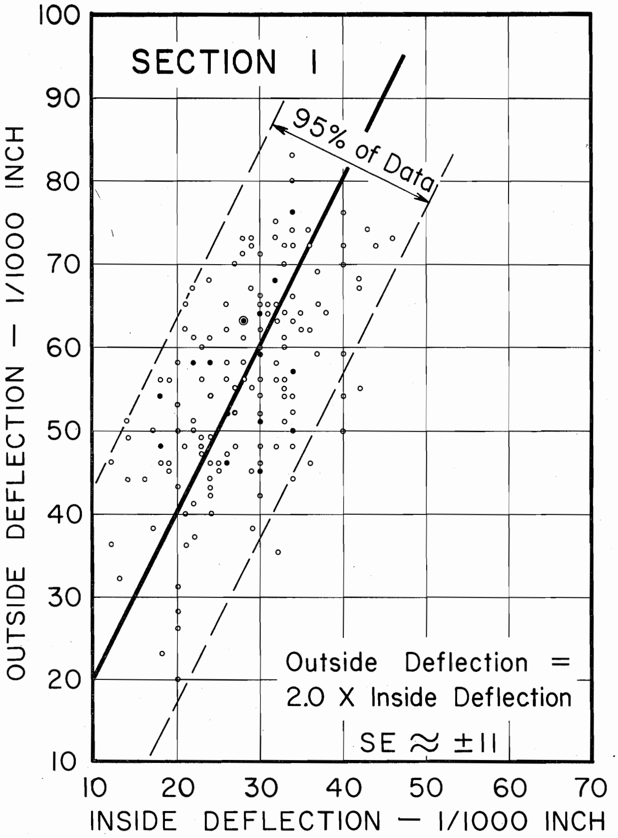


FIGURE 4.1

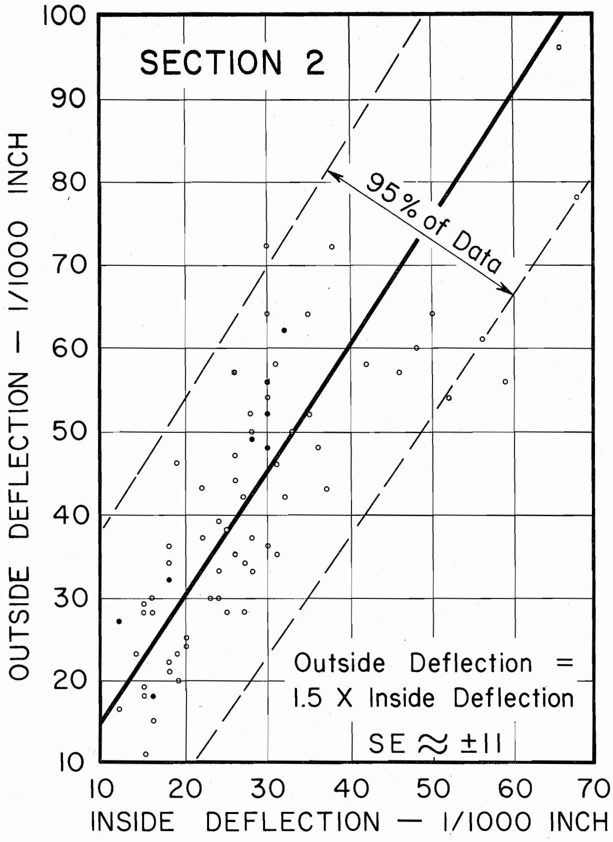


FIGURE 4.2

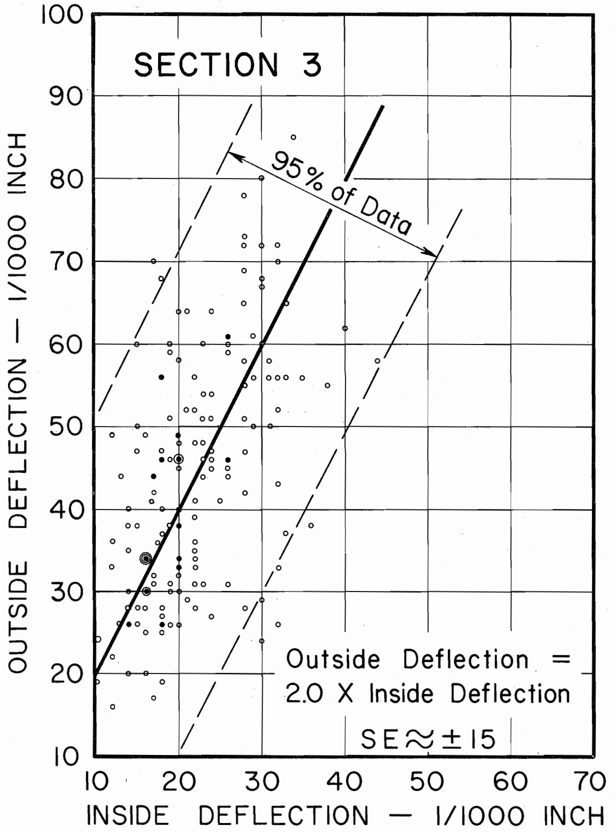


FIGURE 4.3

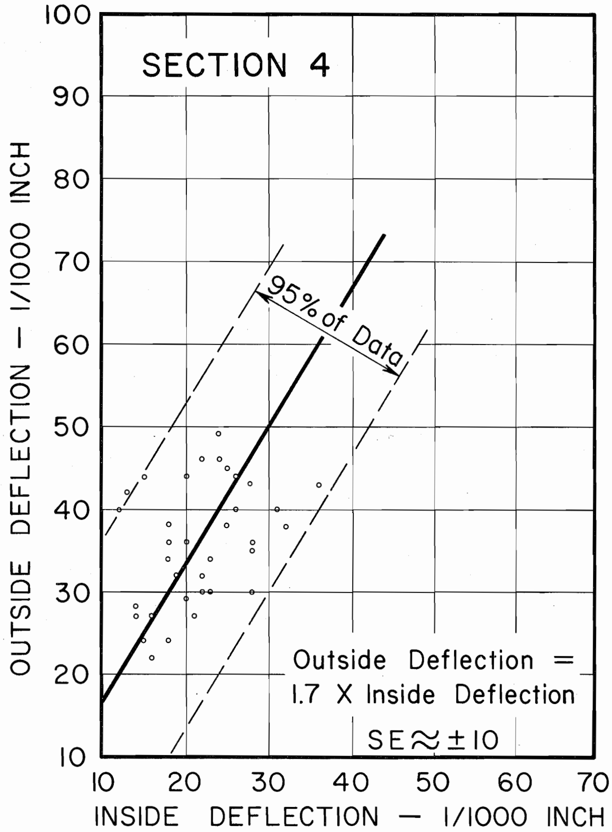


FIGURE 4.4

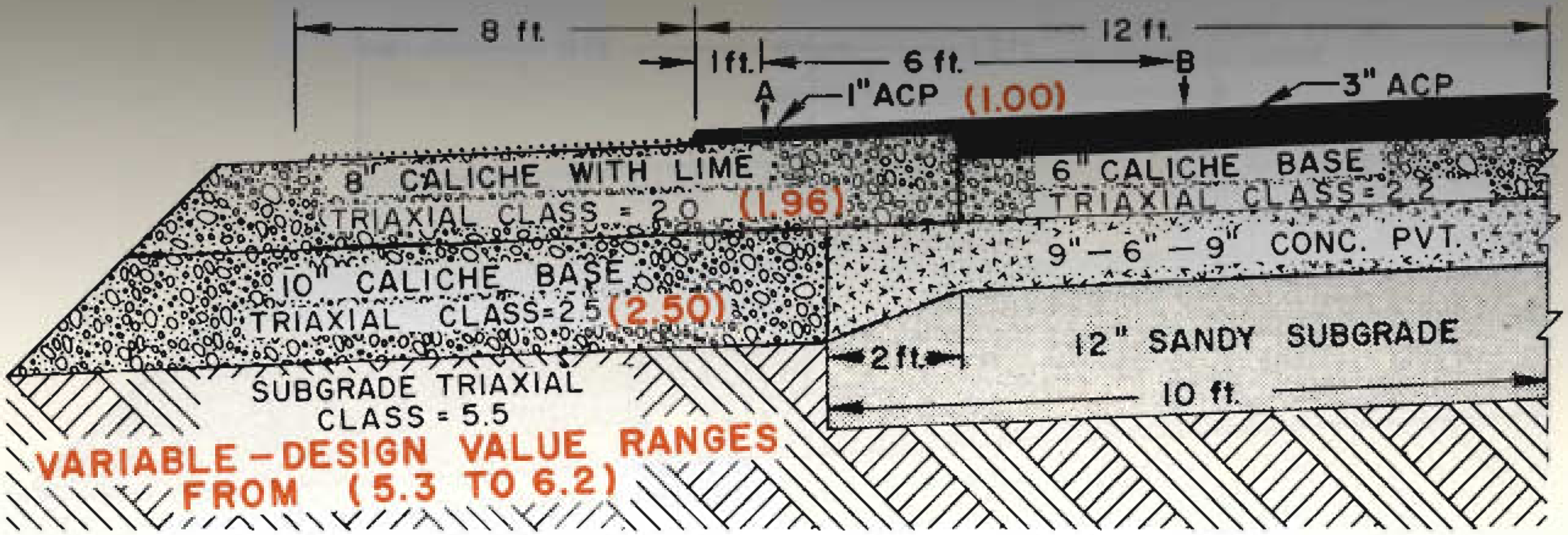
CORRELATION OF OUTSIDE DEFLECTION TO INSIDE DEFLECTION assumption stated in another way says that longitudinal variation in deflection is caused largely by variation in subgrade strength only. By assigning strengths and thicknesses to all layers except subgrade, it now becomes possible to calculate the subgrade strength existing at any deflection measurement. The strengths assigned to the layers of each section are shown in Figures 5.1 thru 5.4. The equations used for calculating subgrade strength (Sq) are shown below:

Section 1 $Sq = 156.3 - 77.1 \text{ Log } U$
Section 2 $Sq = 165.6 - 74.3 \text{ Log } U$
Section 3 $Sq = 164.4 - 75.5 \text{ Log } U$
Section 4 $Sq - 152.5 - 73.8 \text{ Log } U$

Figure 6 is a graphical presentation of these equations when the defining relationship (see Appendix A) for Texas Triaxial Class is substituted for subgrade strength.

The design TDI is a function only of serviceability loss desired for the design period and the expected traffic. Design traffic was furnished by the Planning Survey Division. The desired serviceability loss for the design period was chosen as a drop from the initial serviceability, Po, to 0.59Po. The equations in Appendix A were used to calculate a Design TDI and a Design Deflection for each section. This information is summarized in Table 1.

After calculating the existing strengths of each layer and the Design TDI, it is only a matter of adding enough thickness to the surfacing layer to bring the existing TDI to the Design TDI.

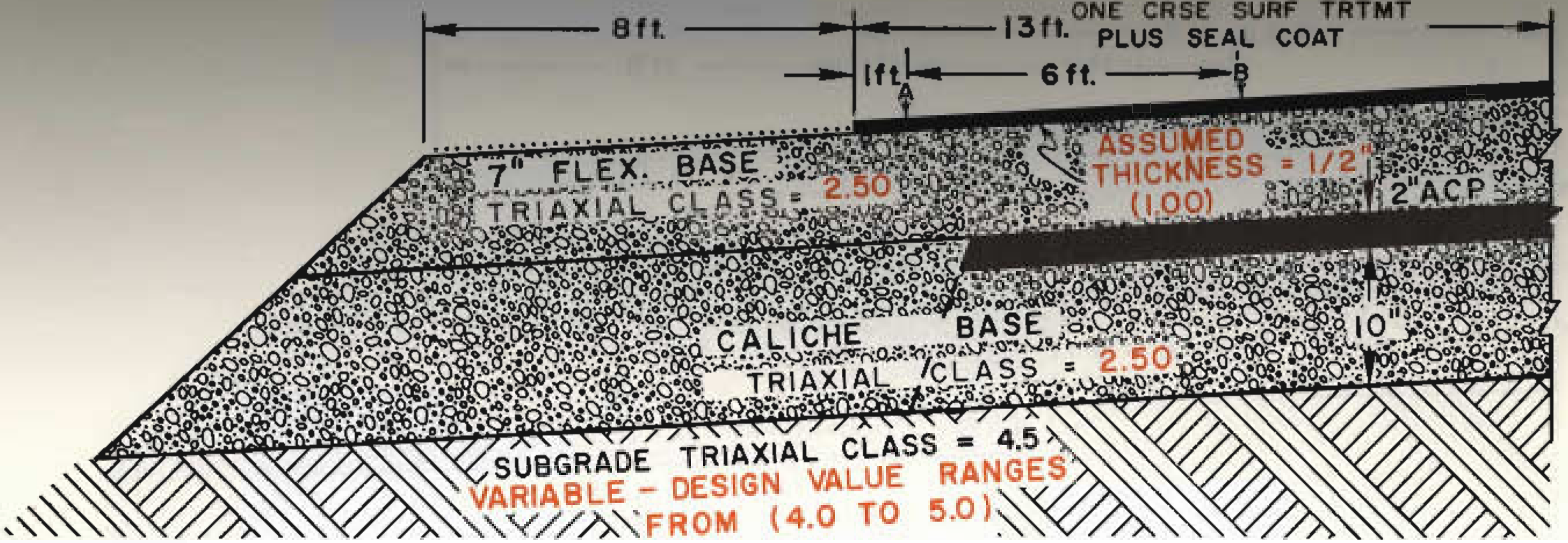


A – POINT OF OUTSIDE DEFLECTION MEASUREMENT
B – POINT OF INSIDE DEFLECTION MEASUREMENT

TRIAXIAL CLASS ASSIGNED TO EACH LAYER IS IN RED
TRIAXIAL CLASS ESTIMATED BY DISTRICT PERSONNEL IS IN BLACK

EXISTING PAVEMENT – SECTION I
SHOWING STRENGTHS OF LAYERS

FIGURE 5.1

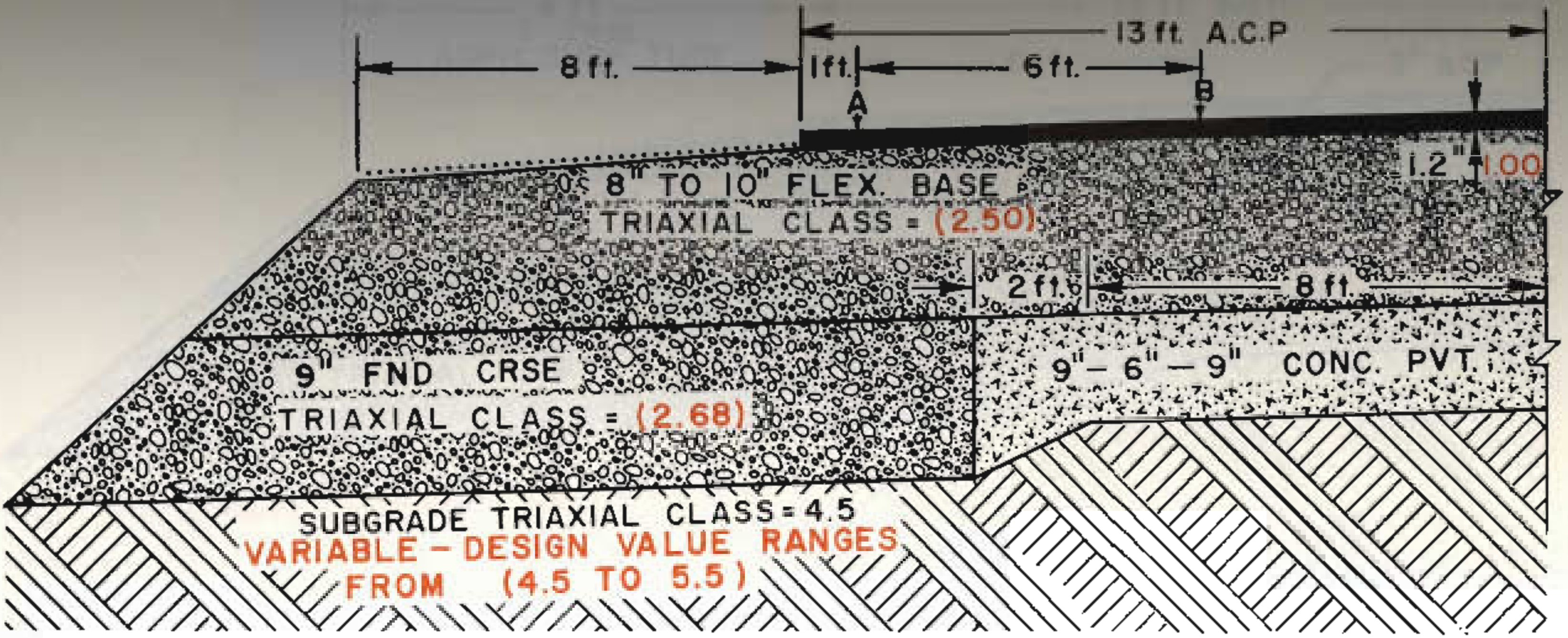


A—POINT OF OUTSIDE DEFLECTION MEASUREMENT
B—POINT OF INSIDE DEFLECTION MEASUREMENT

TRIAXIAL CLASS ASSIGNED TO EACH LAYER IS IN RED
TRIAXIAL CLASS ESTIMATED BY DISTRICT PERSONNEL IS IN BLACK

EXISTING PAVEMENT—SECTION 2
SHOWING STRENGTHS OF LAYERS

FIGURE 5.2

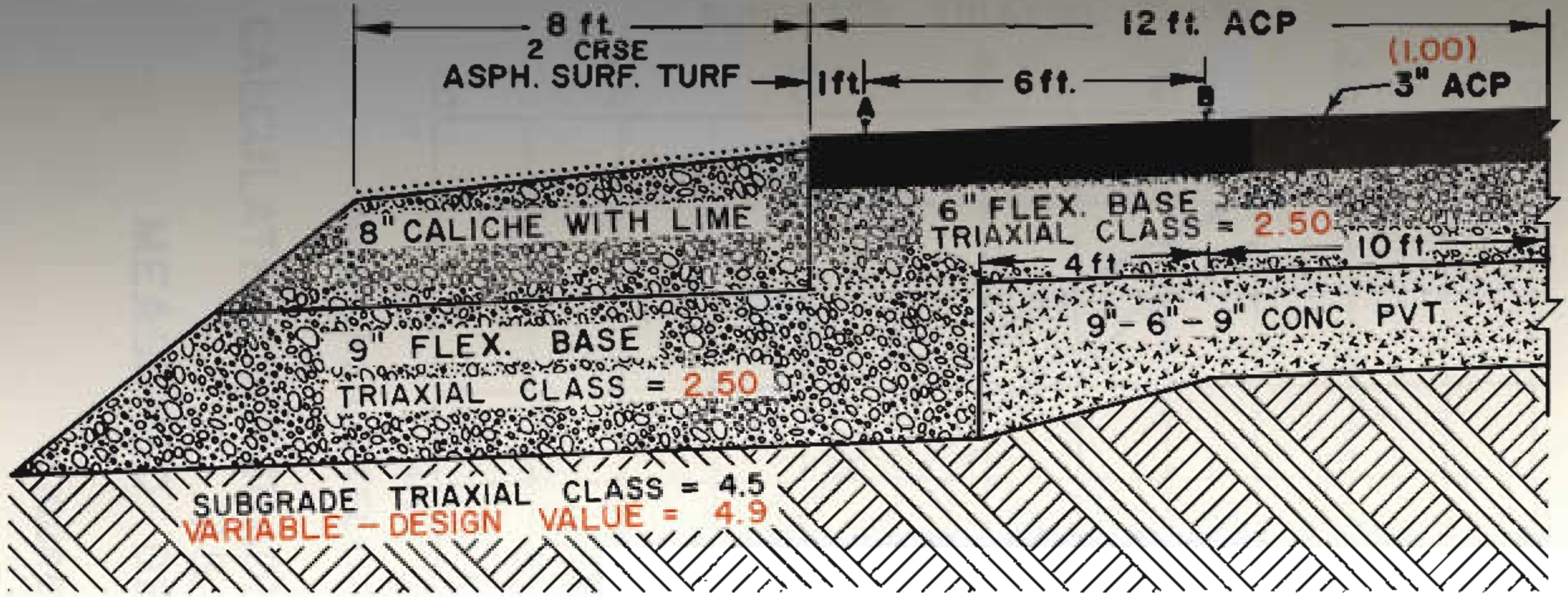


A—POINT OF OUTSIDE DEFLECTION MEASUREMENT
B—POINT OF INSIDE DEFLECTION MEASUREMENT

TRIAXIAL CLASS ASSIGNED TO EACH LAYER IS IN RED
TRIAXIAL CLASS ESTIMATED BY DISTRICT PERSONNEL IS IN BLACK

EXISTING PAVEMENT – SECTION 3
SHOWING STRENGTHS OF LAYERS

FIGURE 5.3

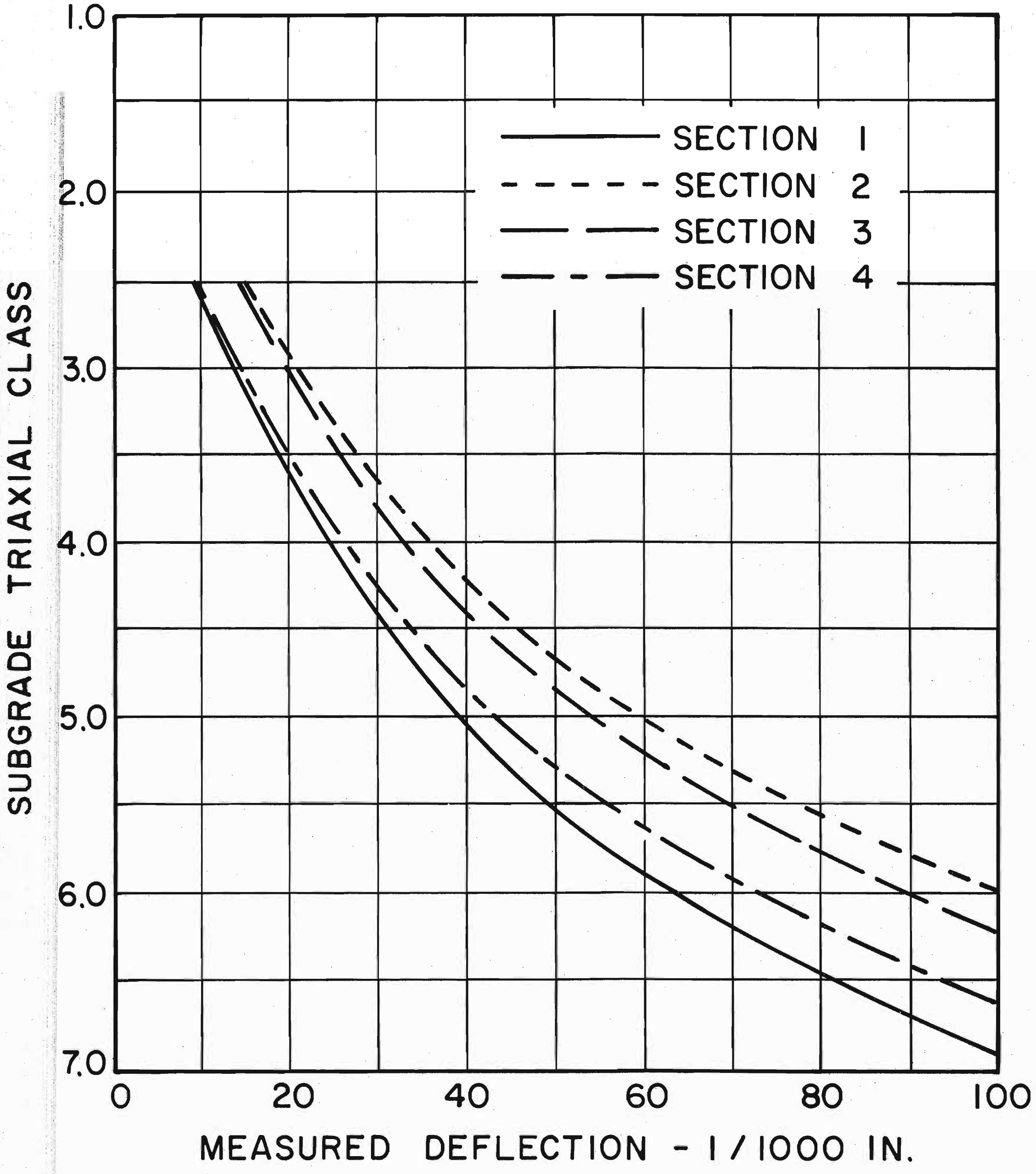


A - POINT OF OUTSIDE DEFLECTION MEASUREMENT
B - POINT OF INSIDE DEFLECTION MEASUREMENT

TRIAXIAL CLASS ASSIGNED TO EACH LAYER IS IN RED
TRIAXIAL CLASS ESTIMATED BY DISTRICT PERSONNEL IS IN BLACK

EXISTING PAVEMENT – SECTION 4
SHOWING STRENGTHS OF LAYERS

FIGURE 5.4



CALCULATED SUBGRADE TRIAXIAL CLASS
V.S.
MEASURED DEFLECTION

FIGURE 6

Section	1965 ADT	Equiv. 18 KSA For Design Period (One Way)[a]	Design TDI[b]	Design Deflection (Maximum)[c]
1	3000	3,200,000	75.7	0.017"
2	2200	3,050,000	75.3	0.017"
3	2000	2,870,000	74.8	0.019"
4	2300	2,711,000	74.2	0.020"

a. Used in the "Triaxial" and the "TDI Method"
b. Used in the TDI Method
c. Determined in the "TDI" Method and used in the "California Method"

TABLE I

Summary of Design Data

The California Method

Appendix B gives a simplified version of a method used by California to determine reconstruction requirements.[2] The method used in this report consists of using the design deflections calculated in the TDI Method (Shown in Table 1) and California's Percent Reduction Chart, Figure 2 of Appendix B. The Design Deflections used are quite close to those California would use when (1) modified for a 15 kip single axle deflection truck and (2) 18 kip equivalent single axle design traffic is converted to California's Traffic Index.

The Triaxial Method (Tex-117-E)

The Triaxial Method consists of using Texas Test Method Tex-117-E[4] and the existing subgrade triaxial strengths found by the TDI Method to obtain an overall depth of cover required on the subgrade. No reduction for cohesiometer strength of the asphaltic concrete was allowed. At some points the "Suggested Thickness of Surface Courses," Figure 19 of Tex-117-E controlled the overlay required.

PRESENTATION OF RESULTS

Figure 8 summarizes the results of the three analyses described above. As can be seen, sections of roadway exhibiting like deflections have been selected as units where the ACP overlay will be constant. The 20th percentile, the median, and 80th percentile deflection is shown for each of these sections. California designs on the 80th percentile. In essence, this provides for an adequate overlay on eighty percent of the roadway. This was selected as the value to use in the other two methods also. Note that in most of the sections, the median is closer to the 80th percentile than to the 20th percentile. This was caused by a few very low deflections which in turn may have been caused by any of the following conditions:

1. Thicker pavement existing at the point of measurement due either to construction expedient changes or maintenance patches.
2. Low moisture contents existing at localized spots.
3. High densities existing at localized spots. For example, old county road crossings sometimes exhibited low deflections.

The calculated existing subgrade triaxial class is shown again by the 20th, 50th, and 80th percentiles. Having calculated the existing subgrade strength by assigning values to the strength of the other layers it now appears pertinent to look at the assumptions and results to see if they are reasonable. The following points verify the results:

1. As stated previously all variation in deflection longitudinally within a section was considered as variation within subgrade strength. The primary reason for making this assumption was the correlation between inside and outside deflection.
2. Examination of the expression for TDI in terms of the layer strengths and thicknesses (See Appendix A) shows that varying the strengths or layer thicknesses of the other layers within expected construction tolerances could not have caused the variation in TDI that was shown by the deflection measurements.
3. The District personnel estimated a subgrade triaxial class for Section 1 to be 5.5. The average class calculated for the 169 points was 5.55.
4. The District personnel estimated a subgrade triaxial class for Sections 2, 3, and 4 to be 4.5. The average class calculated for the 279 points was 4.30.
5. There is a pronounced change in deflection measurements between Sections 3 and 4. As stated above, the District personnel had

estimated the subgrade strength to be the same for both sections. The subgrade strength calculated from deflections shows no change at the break between these sections.

The bottom portion of Figure 8 shows the additional asphaltic concrete required by each of the three methods using the 80th percentile deflection.

Figures 7.1 to 7.4 show a comparison of the additional asphaltic concrete required by the three methods for each of the four different sections. Note that the TDI Method requires more overlay than the other two methods.

RECOMMENDATIONS

As stated earlier in this report, it is considered beyond the objective of this study to determine the most economical pavement design for the four sections studied. It is believed that the existing strengths of the pavement layers have been determined at the weakest point in the cross-section with greater accuracy than could have been determined by any other method. It is also believed possible to determine a strength value for the old concrete pavement by utilizing the inside deflection data in the same manner as the outside data was used. A copy of all the data is being furnished to the District so that a follow through on Recommendations 1 and 2 below can be accomplished.

1. Determine the most economical solution to the upgrading problem considering the construction materials available. Possible solutions

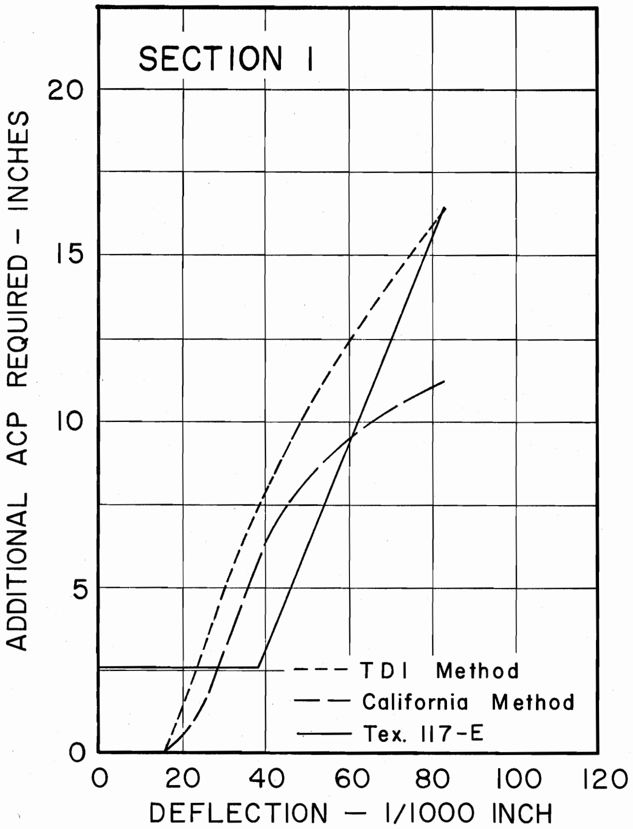


FIGURE 7.1

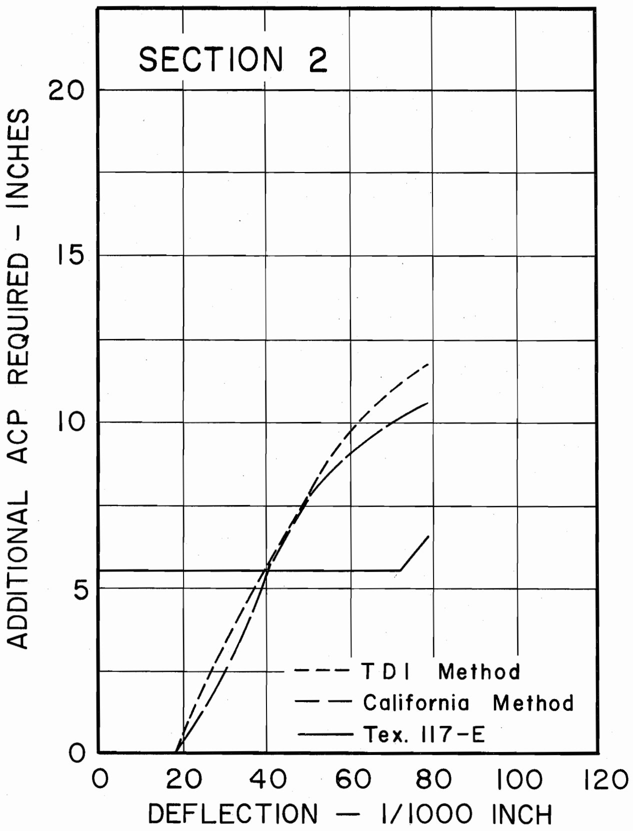


FIGURE 7.2

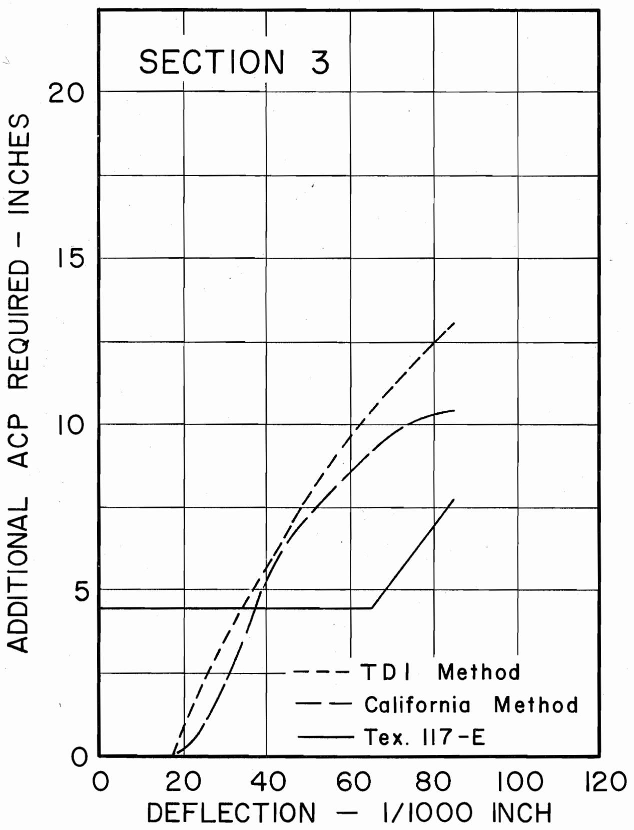


FIGURE 7.3

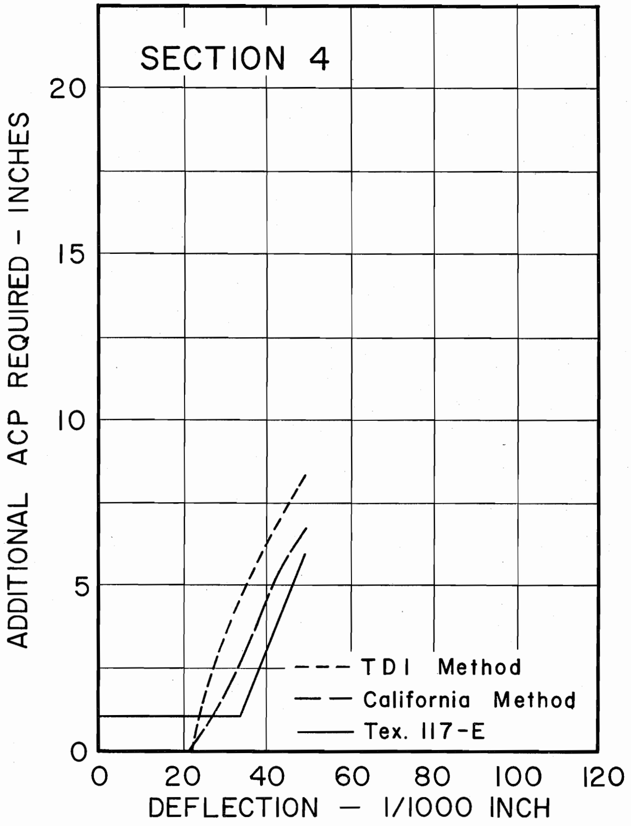


FIGURE 7.4

ADDITIONAL ACP SURFACING REQUIRED
AS DETERMINED BY THREE METHODS

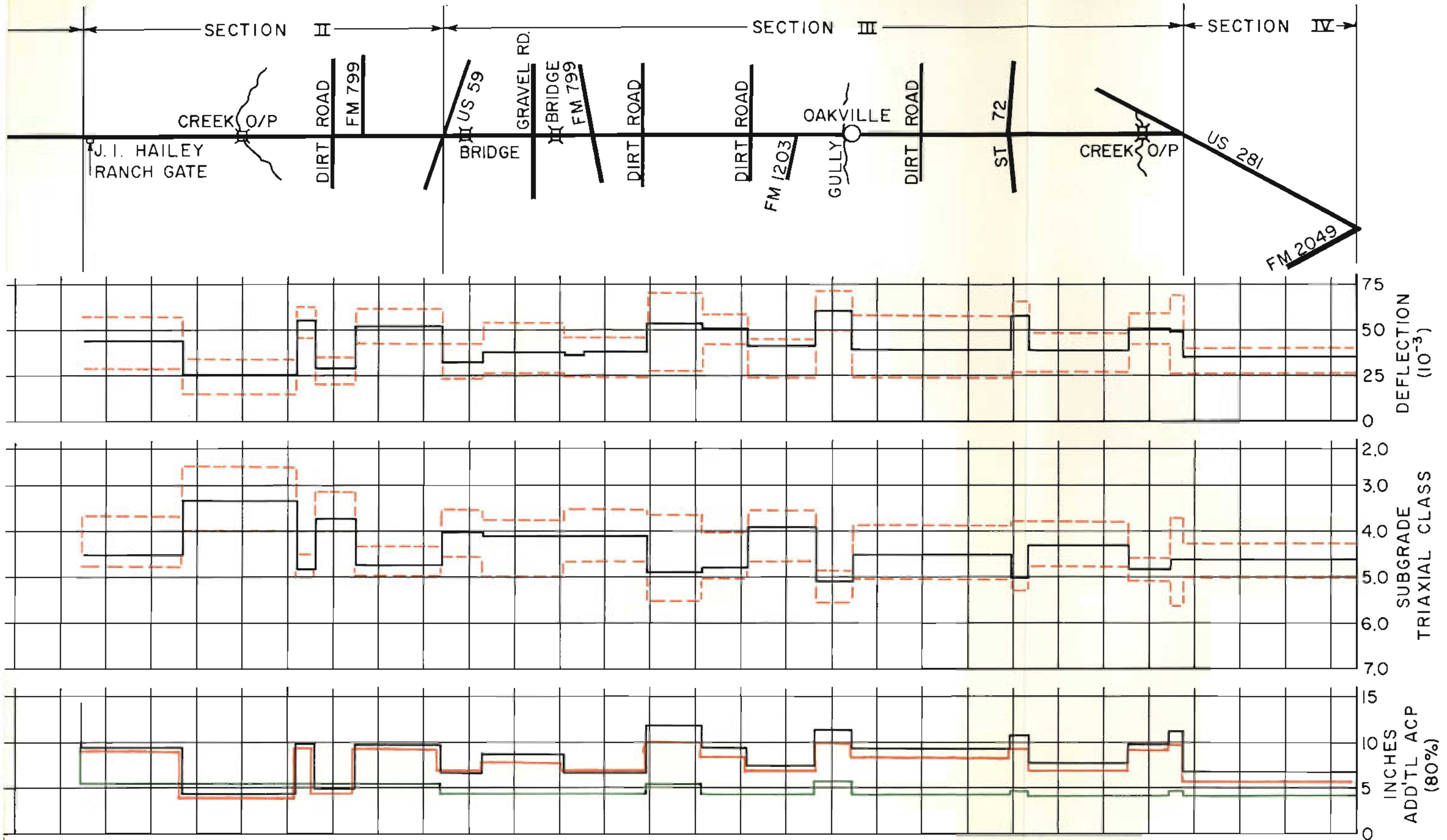
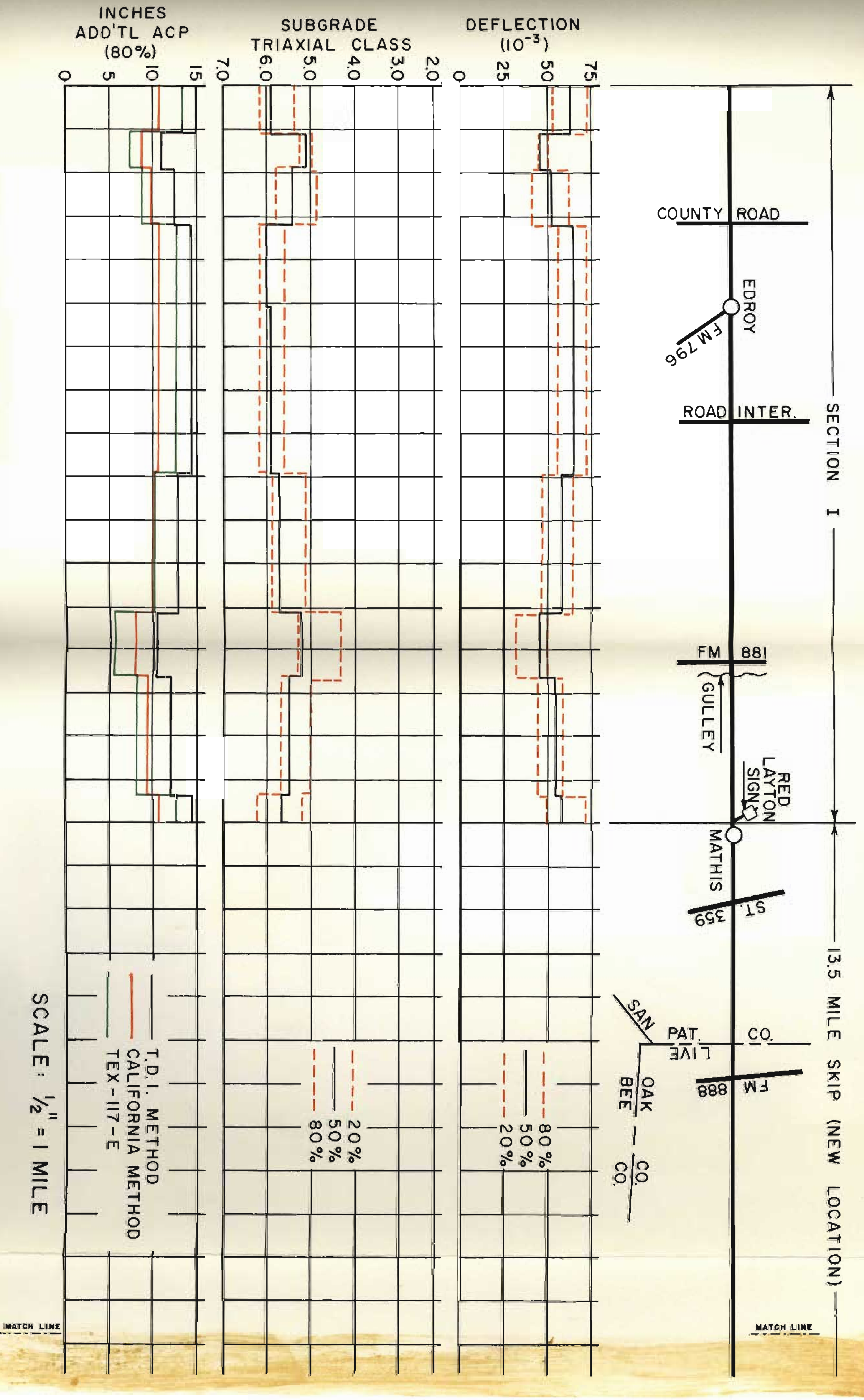


FIGURE 8 SUMMARY SHEET


INCHES ADD'TL ACP (80%)
0
5
10
15
SUBGRADE TRIAXIAL CLASS
7.0
6.0
5.0
4.0
3.0
2.0
DEFLECTION (10^{-3})
0
25
50
75
COUNTY ROAD
EDROY
FM 796
ROAD INTER.
FM 881
GULLEY
RED LAYTON SIGN
MATHIS
ST. 359
SAN PAT. CO.
LIVE OAK CO.
BEE CO.
FM 888
SECTION I
13.5 MILE SKIP (NEW LOCATION)
T.D.I. METHOD
CALIFORNIA METHOD
TEX-117-E
20%
50%
80%
80%
50%
20%
SCALE: ½" = 1 MILE
MATCH LINE
MATCH LINE

are outlined below:

a. Overlay present pavement. Design considering point of outside deflection as weakest point.
   - (1) Asphaltic Concrete Overlay
   - (2) Flexible Base Overlay plus AC Surfacing
   - (3) Concrete Pavement Overlay

b. Remove pavement outside old concrete and overlay middle portion. Design on inside deflection for overlay. Design on existing subgrade triaxial for the outside excavation. Calculate existing strength of concrete pavement, by using the existing subgrade strength found in this report and the inside deflection measurements.
   - (1) Asphaltic Concrete Overlay
   - (2) Flexible Base Overlay

c. Remove all base and surfacing down to the old concrete pavement. Excavate adjacent to the old concrete pavement. Design an overlay for the old concrete pavement using the existing strengths found in "b" above. Design the excavated portion for the existing subgrade triaxial strength.

(1) Asphaltic Concrete Ovelay

(2) Concrete Pavement Overlay

2. Study the soil tests, topography, and maintenance history of the four sections to see if an explanation exists for any of the variation in existing strengths found in this study.
3. As is well known to all practicing highway engineers, the problem of upgrading an existing roadway is being encountered at an increasing rate. It is therefore recommended that a complete design procedure for the Texas Highway Department be developed to handle this problem. This report and California's experience can be utilized as a basis for such a procedure.

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2. Zube, Ernest and Forsyth, Raymond, Flexible Pavement Maintenance Requirements as Determined By Deflection Measurements, Presented at the 45th Annual Meeting of the Highway Research Board, January, 1966.

3. Schrivner, F. H., A Pavement Design Formula and Its Research Background - (A tentative, unpublished report based on Research Project 2-8-62-32, Application of the AASHO Road Test Results to Texas Conditions).

4. Volume I, Texas Highway Department, Manual of Testing Procedures.

Acknowledgements

The research reported in this paper was conducted under the supervision of Mr. R. L. Lewis, Research Engineer, and the general supervision of Mr. T. S. Huff, Chief Engineer of Highway Design.

The authors wish to acknowledge the foresight of Mr. Travis A. Long, District Engineer of District 16, and Mr. E. J. Wilson, Highway Designing Field Engineer of the Highway Design Division; shown in requesting this study.

We are also indebted to Mr. H. W. Hass, District Design Engineer, and Mr. H. E. Lawson, who is in charge of the District Laboratory. Their cooperative assistance in the data collection for the study was invaluable.

APPENDIX A

THE TEXAS DESIGN INDEX (TDI) METHOD

Current research[3] (Research Project 2-8-62-32) that is aimed at translating AASHO Road Test results to Texas conditions is the basis for the equations presented below. These equations are only tentative. It is beyond the scope of this appendix to present any of the assumptions or derivations of them. The reader is asked to wait until they are published.

Q is defined as $\text{Log } W - \text{Log Log} \frac{P_o}{P}$

$$Q = \frac{1}{20} \text{ TDI} + Cr$$

$$Q = 9 - 3/2 \text{ Log } U$$

$$\text{TDI} = S_1 + \frac{1000\,(S_2 - S_1)}{1000 + S_1 D_2} + \frac{1000\,(S_3 - S_2)}{1000 + S_1 D_1 + S_2 D_2}$$

$$\ldots . + \frac{1000\,(S_q - S_{q-1})}{1000 + S_1 D_1 + S_2 D_2 + \ldots . S_q D_{q-1}}$$

Where:

W = Equivalent 18 kip single axles expected for a design period.

P_o = Initial Serviceability Index

P = Serviceability Index at the end of the design period

Cr = 3.36, A regional factor applicable only to the District 16 region.

U = Deflection in thousandths of an inch under an 18 kip single axle

S_1 = Strength of the top pavement layer

S_2 = Strength of the second pavement layer

S_{q-1} = Strength of the layer above the subgrade pavement layer

S_q = Strength of the subgrade layer

D_1 = Thickness in inches of the top pavement layer

D_2 = Thickness in inches of the second pavement layer

D_{q-1} = Thickness in inches of the layer above the subgrade

For nontreated, flexible pavement layers; S is found by the use of the following formula:

$$S = 50/3\ (7-T)$$

Where T is the standard Texas Triaxial Class <u>using the modified</u> "Chart For Classification of Subgrade and Flexible Base Material" shown herein.

For other materials no test procedure is available to determine S. The S value for the hot-mix asphaltic concrete at the AASHO Road Test is 100. This data plus an intuitive comparison of any material with a triaxial test on a flexible material must be used as a basis of judgment for assigning strength values (S) to stabilized materials.

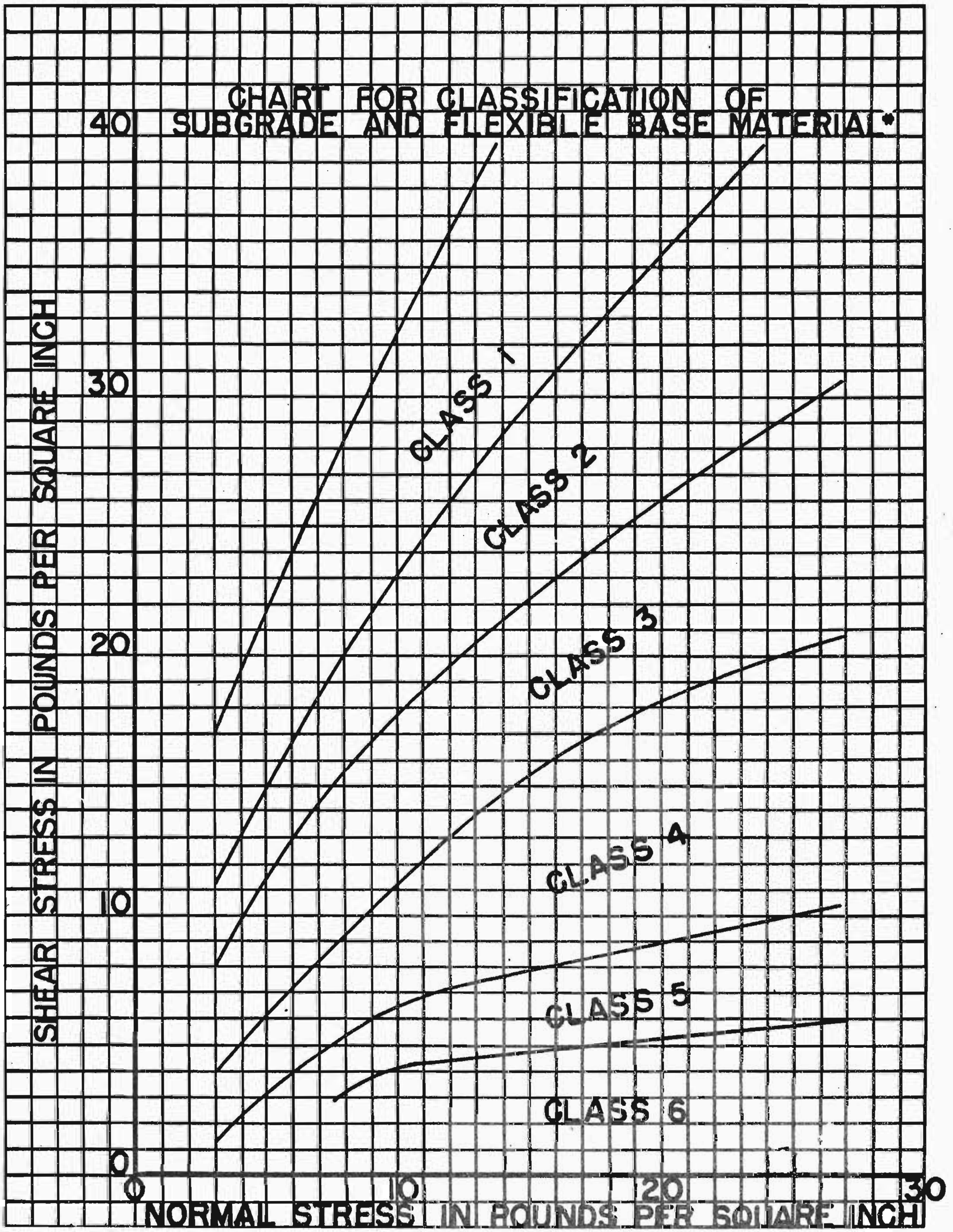

CHART FOR CLASSIFICATION OF SUBGRADE AND FLEXIBLE BASE MATERIAL*

* Modified by Texas Transportation Institute, Pavement Design Department, December, 1965

APPENDIX B

THE CALIFORNIA METHOD

California[2] has considerable experience using deflection measurements to evaluate existing flexible pavements in order to make recommendations as to suitable reconstruction. Basically, the method consists of the following steps:

1. Measure the deflection for the roadway in question.
2. Determine a desireable deflection level for the type pavement proposed (considering traffic).
3. Calculate the percent reduction in deflection needed.
4. Use the graph shown in this appendix as Figure 2, to determine the amount of overlay required to effect the desired percent reduction.

Figure 2

REDUCTION IN DEFLECTION RESULTING FROM PAVEMENT RECONSTRUCTION