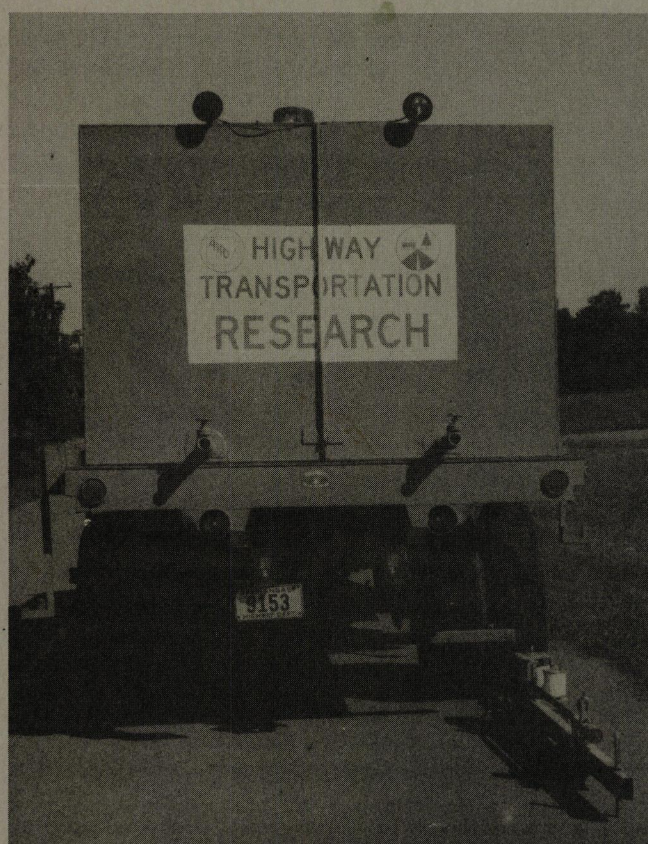
Design of ACHM Overlays by Deflection Analysis



TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
HRC-30		

4. Title and Subtitle

DESIGN OF ACHM OVERLAYS BY DEFLECTION ANALYSIS

5. Report Date

May 15, 1974

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

9. Performing Organization Name and Address

Arkansas Highway Department
Division of Planning and Research
P.O. Box 2261
Little Rock, Arkansas

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

Department of Transportation
Federal Highway Administration

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Asphaltic concrete hot mix overlays used for improving load carrying quality of a roadway have not been designed according to specific criteria. Of the design procedures available, only deflections take into account structural strength of the in-situ pavement.

Eight test sections were tested during each season for a period of four years. Data was collected, reduced, and plotted on a series of graphs of temperature (pavement & ambient) vs. deflection (total & rebound). Regression analyses were performed on each set of data to fit a trend line and determine the relationship between temperature and deflection.

In most cases, ambient temperature influenced deflections to a greater degree than pavement temperature. For this reason, a flexible pavement design procedure should utilize ambient temperature.

17. Key Words

Flexible Pavement Design, Deflections, Benkleman Beam

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassfied			

Form DOT F 1700.7 (8-69)

DESIGN OF ACHM OVERLAYS BY DEFLECTION ANALYSIS

Final Report

HRC-30

Prepared by the Arkansas Highway Department
Division of Planning and Research
in cooperation with the Federal Highway Administration

SUMMARY

Asphaltic concrete hot mix overlays used to upgrade the load carrying qualities of an existing pavement structure have not been designed according to specific criteria. Of the procedures available, only deflections take into consideration in-situ structural strength.

Eight test sections were chosen for testing and evaluation. Test data included ambient temperature, pavement temperature, total deflection, and rebound deflection. Field data was reduced and plotted on a set of graphs. These graphs illustrate the relationships between temperature (both ambient and pavement) and deflection (both total and rebound). In order to establish these relationships, regression analyses were performed to fit a line to each plot.

Through investigation of these trend lines, it was determined that ambient temperature influences deflections to a greater extent than does pavement temperature. For this reason, ambient temperature should be used in lieu of pavement temperature in flexible pavement design utilizing deflections.

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INTRODUCTION

Asphaltic concrete hot mix overlays used to improve the load carrying capacity of an existing roadway have not been designed by specific criteria. Most states base overlay design on experience only. The remaining states use some form of the AASHO guide or a deflection method.

From the many published reports it is apparent that much work has been done concerning flexible pavement and overlay design. There is, however, no design method which stands out as being "the best." Of the procedures available, only those using pavement deflections take into account structural strength and load carrying capacity of the in-situ pavement structure.

The primary objectives of this study were: (1) to provide some method for determining thicknesses of bituminous overlays, and (2) to evaluate the effectiveness of the selected procedure. A secondary objective was to determine what effect temperature had on deflections and apply a "correction factor" to the design if needed.

A previous literature search revealed several different types of equipment used. Benkleman Beams were the instruments predominately used to measure deflections of the roadway, and procedures varied only slightly from state to state. The most significant differences, however, were in the load vehicle. Most states filled a dump truck to 18,000 lbs with sand or some other type of bulk material. Roadway cross-slope as a weight variable was neglected. Evidently none of the load vehicles were weighed at each test section to determine whether the load remained constant or whether it had changed due to changes in slope.

After thorough study and much discussion, the Arkansas Highway Department research personnel concluded that the load vehicle should be equipped to redistribute the 18,000 lb load as required to correct for roadway crown. To accomplish this, a 25,000 gvw truck was equipped with a twin-compartment water tank. A pump enabled water to be transferred between compartments as needed to keep the required 9,000 lbs on each side of the rear axle. Loadometer scales were used to weigh the truck at each test site to lessen the chance of measurement errors due to weight differences. Figure 1 shows the water truck and beam used in data collection.

The Benkleman Beam used in the study was built by the University of Arkansas' Department of Civil Engineering. An Ames dial capable of measuring deflections to .001 inches was mounted on the beam as was a Helmer recorder used to get a trace of the deflection.

Serviceability ratings were to be made in conjunction with the deflection data collection. A Wisconsin Roadmeter manufactured by Rainhart was acquired for this purpose. The roadmeter, however, malfunctioned making serviceability ratings difficult and the results questionable.

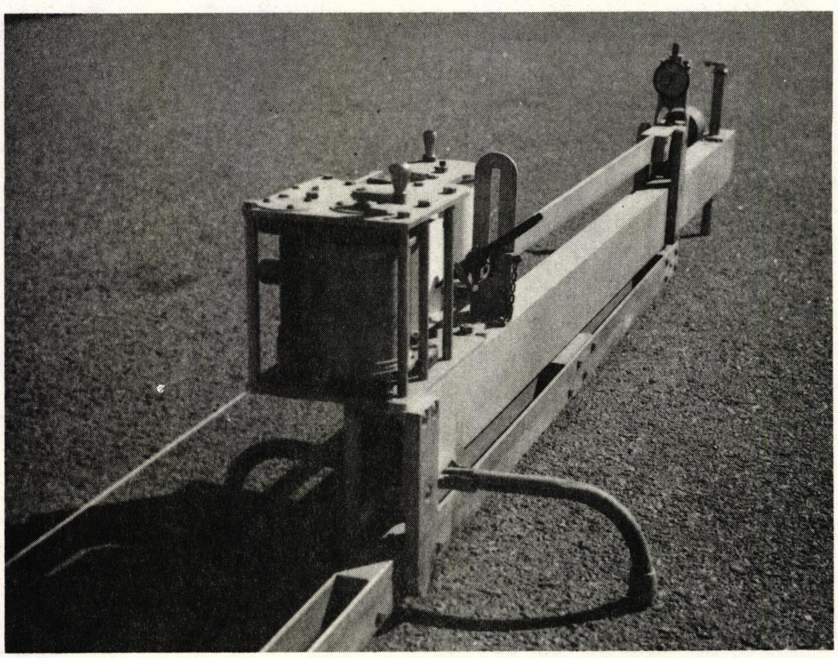


FIGURE 1: TRUCK & BEAM USED FOR DATA GATHERING

SELECTION OF TEST SITES

Nine sections of highway were originally selected for testing and evaluation during the study. These sections were selected on the basis of classification, surface type, asphalt thickness, and location. Classifications range from primary arterial highways with high traffic volumes traveling at high speeds to secondary highways with low volumes and low speeds.

These nine original sections were tested and the data catalogued by route, section, and log mile. One section was sealed after data collection began and had to be eliminated from the test sequence, leaving eight sections for study and reporting.

Each section was approximately 400 feet in length with five deflection sites 100 feet apart marked with white paint. Each site was repainted as testing took place to enable the crew to gather data in the exact spot each time. Table 1 enumerates each test section showing highway route number, highway section number, beginning log mile of test section, and classification. Appendix A shows the test sections with a brief description of their physical characteristics.

Deflections and temperatures were measured at least once during each season at each test site. At various other times, deflections were measured on other highways throughout the State where overlays were to be placed as regular maintenance work. Data collected at these highways was reduced and recommendations were made as to the thickness of overlay required for suitable structural strength as governed by deflections and traffic. Since deflections were taken on these highways only once, the data was not in-

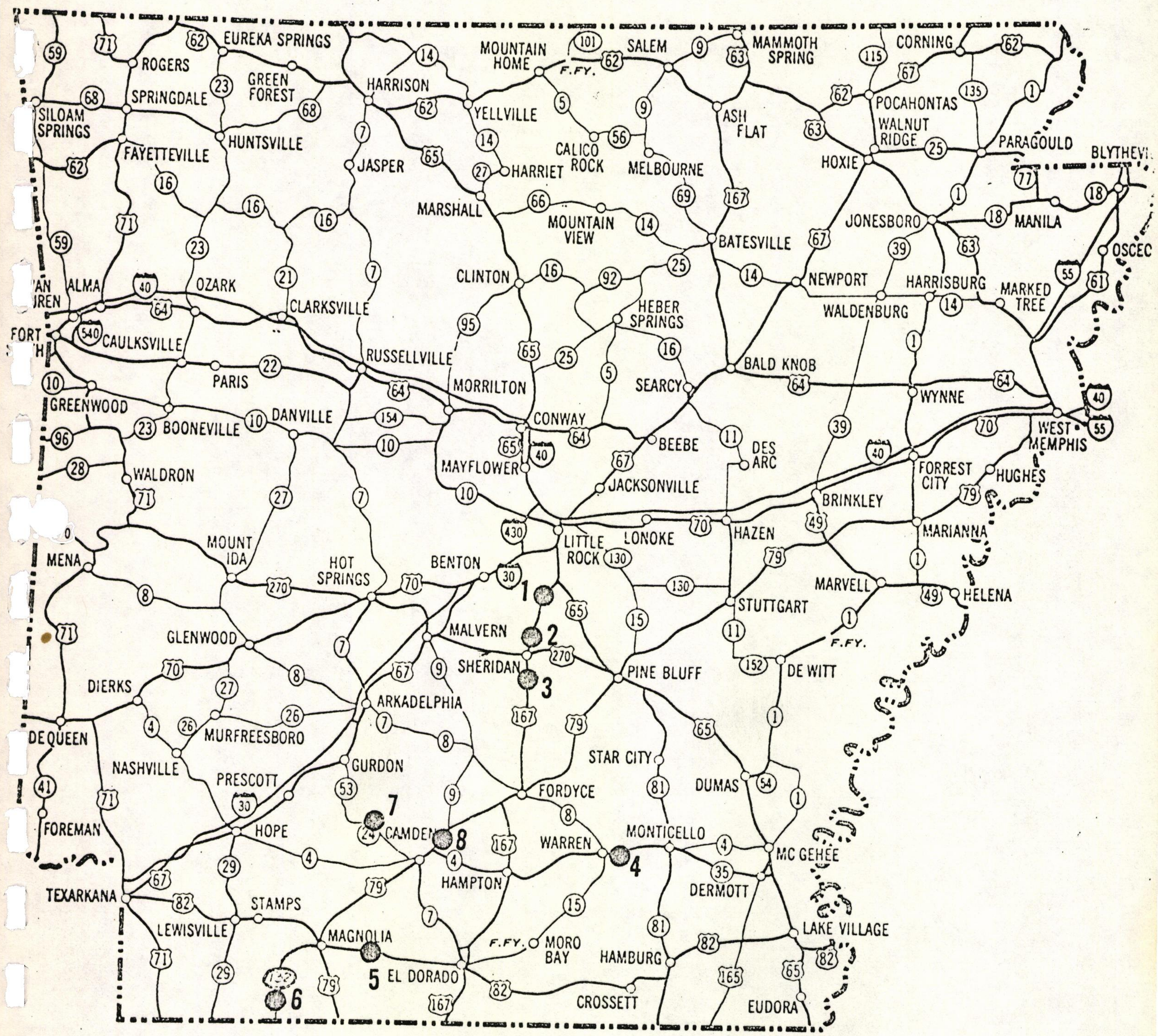
TABLE 1

Test Sections

	RT.	SEC.	BEG. LM	COUNTY	CLASSIFICATION
Sec 1	167	12	3.5	Saline	F.A. Primary
Sec 2	167	11	9.5	Grant	F.A. Primary
Sec 3	167	10	11.62	Grant	F.A. Primary
Sec 4	4	13	3.2	Bradley	F.A. Primary
Sec 5	82	4	8.79	Columbia	F.A. Primary
Sec 6	132	1	11.4	Columbia	F.A. Secondary
Sec 7	24	6	5.96	Ouachita	F.A. Secondary
Sec 8	79	4	10.3	Ouachita	F.A. Primary
*Sec 9	128	1		Dallas	F.A. Secondary

* Eliminated because new seal coat was placed on section.

Fig. 2. Location of Deflection Test Sections



cluded in analysis for this report. Procedures used for designing overlays on these sections will be considered for purposes of determining a desirable overall design method.

METHOD OF ANALYSIS

The basic problem of selecting a method of fitting a trend line is deciding upon a criterion for measuring goodness of fit. The Least Squares fitting method is widely used to fit a line to a set of data.

If the points to which a line is being fitted do not all fall on a straight line, certainly no straight line can fit perfectly. Thus the problem is reduced to defining what is meant by "best fit line." One criterion for defining best fit line might be "is the sum (disregarding signs) of the deviations from the trend line a minimum?" If so, then the trend line may be regarded as a best fit line since the trend values come closer to the actual data than any other line.

Inasmuch as it is illogical to disregard the signs, another criterion could be "is the sum of the squares of the deviations a minimum?" This would seem to have an advantage over the first criterion. The name "Least Squares" is derived from the second criterion.

Derivation of the equations for the theoretical best fit line for each of the eight test sections are listed in Appendix B.

ROADMETER

Although deflection analysis will provide an indication of structural strength, no amount of analysis will enable the isolation of single components to determine the effects they have on the total pavement structure. A Wisconsin ML-500 Roadmeter was obtained by the Arkansas Highway Department to provide a method of evaluation to determine serviceability ratings on each of the test sections. These evaluations were to continue until a decline in PSI could be measured.

The roadmeter was mounted in a standard size passenger car operated by an employee of the Division of Planning and Research. As the car moved over the pavement, surface roughness moved the rear axle. The number of movements was measured on eight digital counters each of which register in 1/8 inch increments, i.e. a 1/2 inch movement would be registered on counters 1-4. A one inch movement would be registered on counters 1-8. Through use of formulas provided by the manufacturer, surface roughness per distance traveled was calculated.

As was mentioned previously, the roadmeter malfunctioned and its use in this study was discontinued. Aside from numerous mechanical and electrical problems with the unit, it was found that the accuracy was questionable. Several different instances caused the undermining of confidence in the results obtained from the roadmeter.

First of all, the roadmeter could not be zeroed as required before testing began. After repairs were made, a second, very puzzling, problem surfaced. Upon completion of a run, the numbers on the counters are recorded. The very nature of the device requires that each successive counter display a number less than the preceding counter. However, this was not always the case. At times, the roadmeter displayed a higher number on counter number 8 than on number 7. This implied that the movement of the test axle reached 1 inch without reaching 7/8 inch which is, of course, ridiculous. For these reasons, use of the roadmeter was discontinued.

DATA ANALYSIS

Data gathered at each test site included both ambient and pavement temperature. Ambient temperature was measured by suspending a thermometer in the air away from the truck for a sufficient period of time to allow the maximum temperature to be determined. Pavement temperature was then measured by placing the thermometer in a hole approximately 1½" deep in the pavement. Both temperatures were recorded before deflections were measured.

The deflection measuring procedure was established before extensive testing began and therefore remained unchanged throughout the entire study period. After the load vehicle was positioned correctly, the Benkleman Beam was placed with the probe between, and approximately four feet in front of, the dual tires in the outer wheel path. The Helmer Recorder drive string was then hooked to the truck in order to obtain traces of each site deflection. This being done, the initial Ames dial reading was recorded on the data sheet before the load vehicle moved forward. As the load vehicle moved forward at creep speed, the maximum dial reading was recorded. The final dial reading was recorded after all dial movement had ceased. At this point, the pavement had rebounded as much as possible. The load vehicle then moved forward to the next site and the above deflection measuring procedure was repeated.

Data reduction included averaging total deflections (Maximum D.R. - Initial D.R.)x2) and rebound deflections (Maximum D.R. - Final D.R.)x2) at each site. All dial readings are multiplied by 2 to take into account the mechanical advantage of the lever arm. Average total deflection

($\bar{x}_T$) and average rebound deflection ($\bar{x}$) were plotted against both ambient and pavement temperature. Regression analyses were performed for each set of data in order to establish any trends. An example of the regression analysis and a short summary of the analysis procedure are included in this report under the heading "Method of Analysis" and in Appendix B.

With few exceptions, trend lines show that ambient temperature affects both total deflection and rebound deflection more than does pavement temperature. Evidence of this fact was found by comparing the slopes of the trend lines of deflections vs. ambient temperature against trend lines of deflections vs. pavement temperature (see Figures 3 & 4). The difference of influence of ambient temperature is more pronounced for low-type pavements, (i.e. SH 132, SH 24). This can be at least partly accounted for by the fact that the three low-type pavements (except for SH 4 which is the exception to this premise) have markedly shallower base and surface courses than do the high-type pavements.

In most cases, ambient temperature seems to affect deflections more than pavement temperature. Therefore, any design procedure should utilize ambient temperatures for determining a temperature adjustment factor. Use of the ambient temperature in the Asphalt Institute procedure for designing pavement overlays would yield a higher adjustment factor and therefore help guard against underdesign. This procedure is set forth in Appendix C.

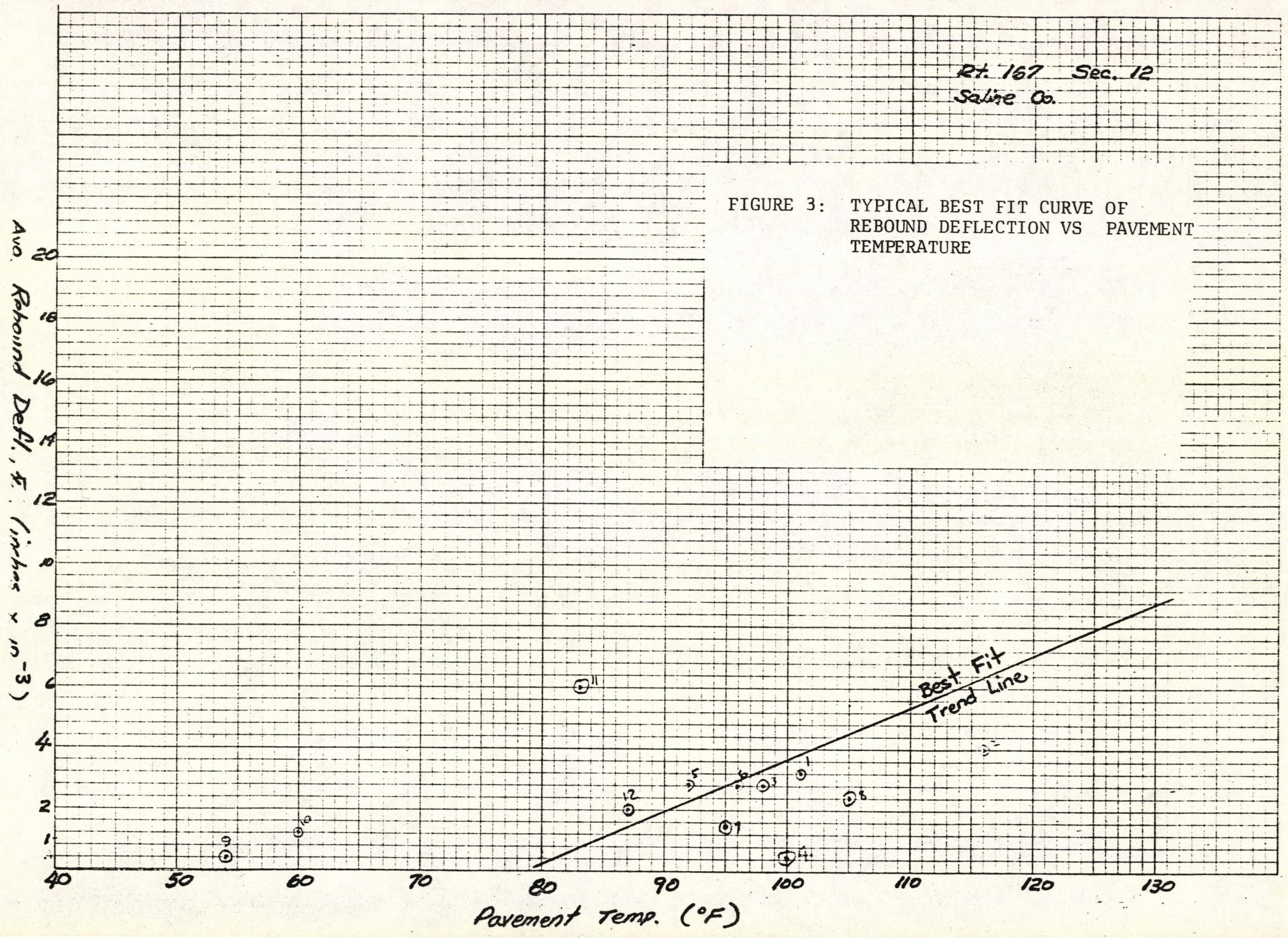


FIGURE 3: TYPICAL BEST FIT CURVE OF REBOUND DEFLECTION VS PAVEMENT TEMPERATURE

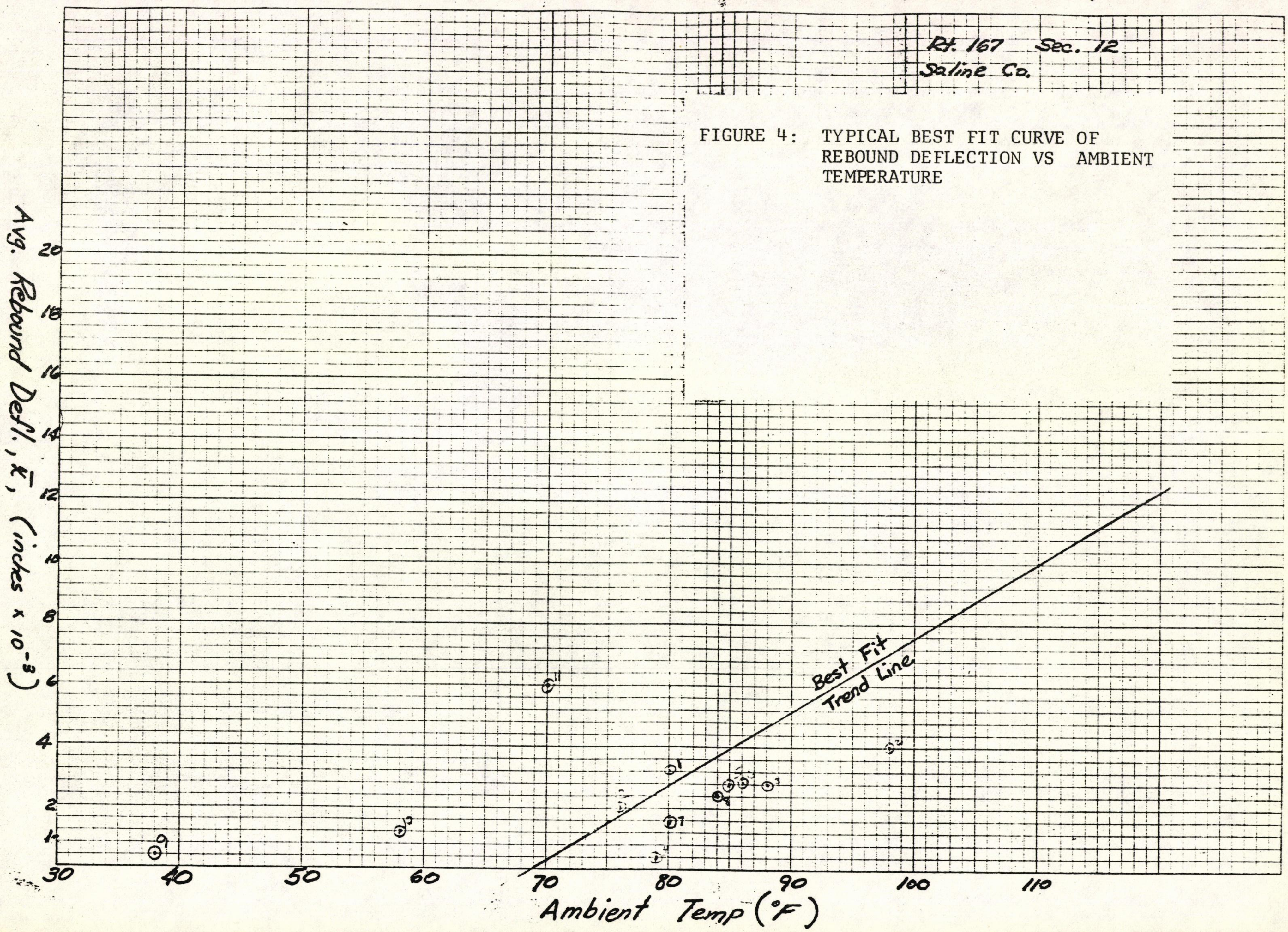
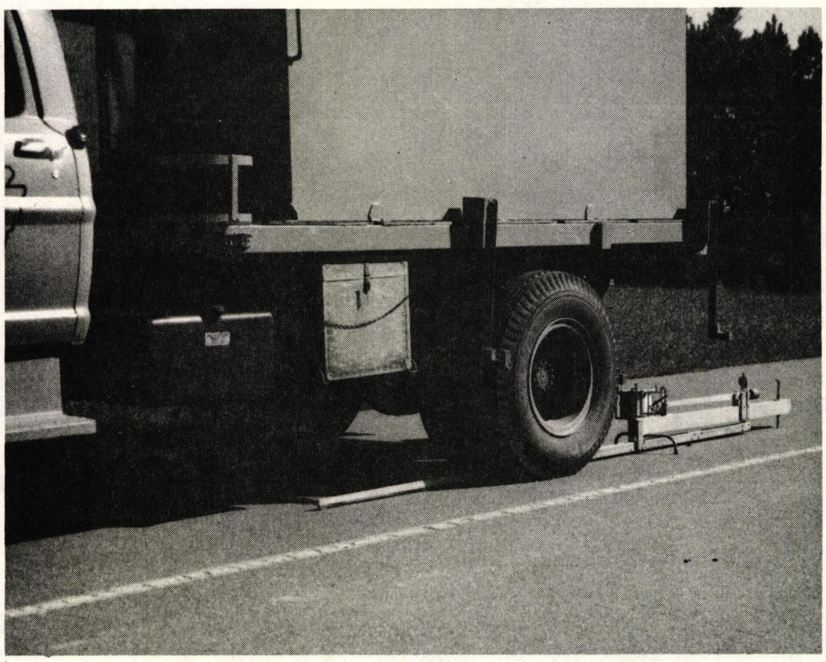


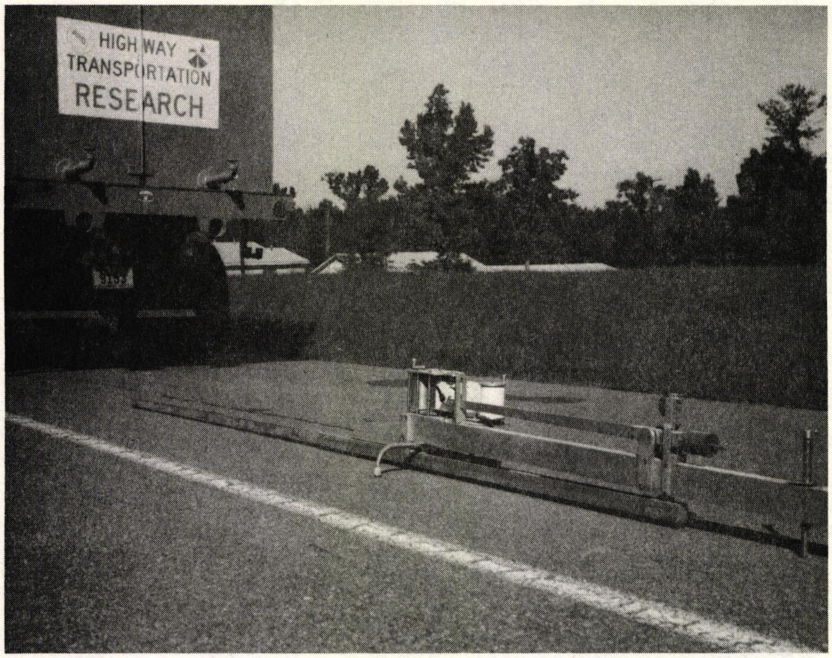
FIGURE 4: TYPICAL BEST FIT CURVE OF REBOUND DEFLECTION VS AMBIENT TEMPERATURE

STEP 1: WEIGH TRUCK

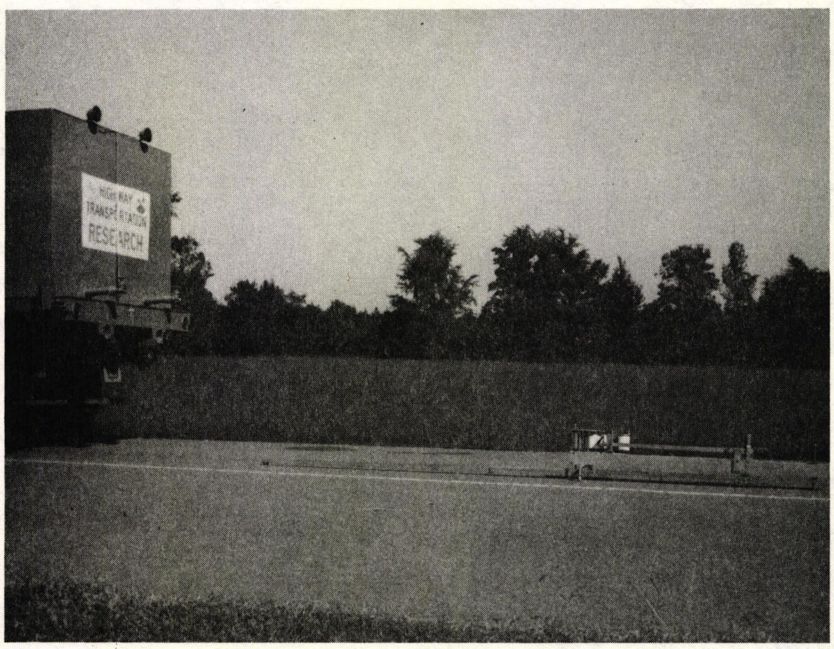


STEP 2: PLACE BEAM

FIGURE 5: STEP-BY-STEP MEASUREMENT PROCEDURE



STEP 3: PULL FORWARD AT CREEP SPEED



STEP 4: STOP BEYOND POINT OF MAX REBOUND

FIGURE 5

CONCLUSIONS & RECOMMENDATIONS

1. Ambient temperature influences deflections more than pavement temperature. This is especially true on pavements consisting of shallow surface courses (0.3 ft. or less).

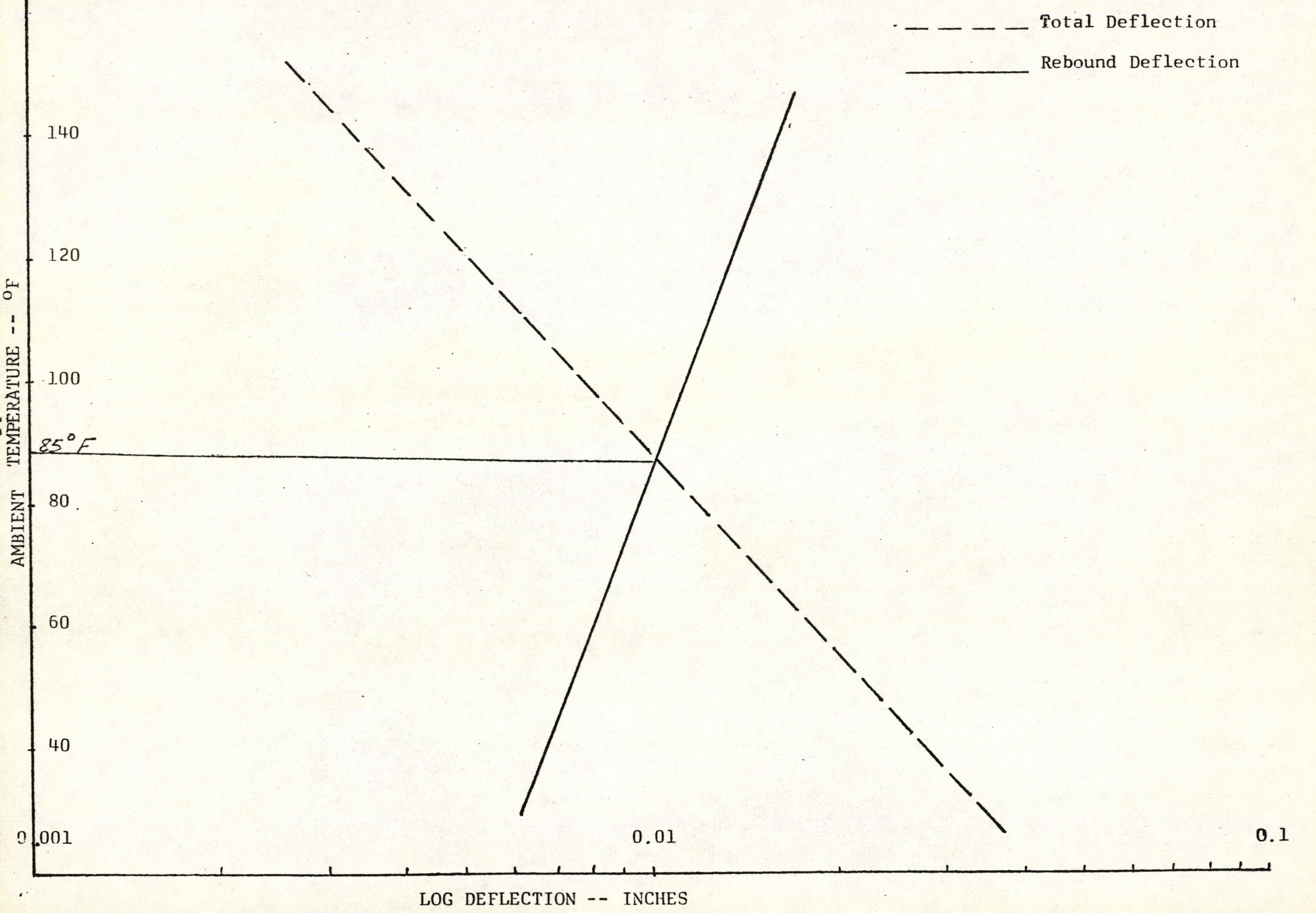
2. A design procedure based on ambient temperature would result in better overlay design. (See Figure 6)

3. At or above 85°F (ambient), rebound deflections should be used as the design criteria. Below 85°F, total deflection should be the design criteria.

4. The use of The Asphalt Institute's overlay design method as set forth in Manual Series No. 17, "Asphalt Overlays and Pavement Rehabilitation", is recommended except that ambient temperature should be used in lieu of pavement temperature. This procedure is set forth in Appendix C.

5. These conclusions are based on a somewhat limited amount of data. Perhaps additional testing would enhance the reliability of the conclusions.

Fig. 4. Ambient Temperature vs. Deflection



APPENDIX A

Each of the test sections were slightly different in regard to terrain, drainage, and overall condition of the roadway. Bad drainage characteristics quite possibly could adversely affect deflections by keeping the subgrade soil in the plastic range virtually year round. There is, however, insufficient data to adequately substantiate this premise.

A brief description of each test section is included in order to detail any pertinent aspects of a section's physical features.

TEST SECTION 1:

Highway: 167 Section: 12 Log Mile: 3.50

County: Saline

Terrain: Gently rolling hills

Drainage: Good drainage. No standing water along or beside roadway.

Profile: Shallow cut section.

TEST SECTION 2:

Highway: 167 Section: 11 Log Mile: 9.50

County: Grant

Terrain: Gently rolling hills

Drainage: Good drainage. No standing water.

Profile: Located on a fill section approximately 2 feet.

TEST SECTION 3:

Highway: 167 Section: 10 Log Mile: 11.62

County: Grant

Terrain: Gently rolling hills

Drainage: Good drainage. No standing water.

Profile: Roadway is about the same grade as natural ground level.

TEST SECTION 4:

Highway: 4 Section: 13 Log Mile: 3.20

County: Bradley

Terrain: Bottom area between two bridges

Drainage: Deep pools of standing water within 50 feet on each side of section.

Profile: Located on fill section approximately 12 feet with timber on each side.

TEST SECTION 5:

Highway: 82 Section: 4 Log Mile: 8.79

County: Columbia

Terrain: Flat between two creeks

Drainage: Swampy area. Two ditches take water to the creeks.

Profile: Located on fill section approximately 10 feet which seems to be dry.

TEST SECTION 6:

Highway: 132 Section: 1 Log Mile: 11.40

County: Columbia

Terrain: Flat with lots of timber on each side.

Drainage: Adequate. No standing water.

Profile: Slight fill section approximately 1 foot.

TEST SECTION 7:

Highway: 24 Section: 6 Log Mile: 5.96

County: Ouachita

Terrain: Rolling hills.

Drainage: Adequate with some standing water after rainfall.

Profile: Roadway is about the same grade as natural ground level.

TEST SECTION 8:

Highway: 79 Section: 4 Log Mile: 10.30

County: Ouachita

Terrain: Flat

Drainage: Some standing water in ditches year round.

Profile: Located on shallow fill approximately 1 foot.

APPENDIX B

The normal equations for a least squares trend line are derived as follows: Let the predictive equation for the required line be $X = a + bY$. The values of X on this line corresponding to $Y_1, Y_2, \ldots, Y_n$ are $a + bY_1$, $a + bY_2, \ldots, a + bY_n$, while the actual values are $X_1, X_2, \ldots, X_n$ respectively. The difference between the trend values and the actual values then are $(a + bY_1 - X_1), (a + bY_2 - X_2), \ldots, (a + bY_n - X_n)$. The least squares line, then, is such that $S = (a + bY_1 - X_1)^2 + (a + bY_2 - X_2)^2 + \ldots + (a + bY_n - X_n)^2$ is a minimum. From calculus, S is a minimum when the partial derivitives of S with respect to a and b are zero. Then,

$$\frac{\delta S}{\delta a} = 2((a + bY_1 - X_1) + (a + bY_2 - X_2) \ldots + (a + bY_n - X_n)) = 0$$

$$\frac{\delta S}{\delta b} = 2((a + bY_1 - X_1)\, Y_1 + (a + bY_2 - X_2)\, Y_2 + \ldots (a + bY_n - X_n)\, Y_n = 0$$

These equations reduce to:

$NA + b\Sigma Y - \Sigma X = 0$ or $\Sigma X = Na + b\Sigma Y$

$aEY + b\Sigma Y^2 - \Sigma XY = 0$ or $\Sigma XY = a\Sigma Y + b\Sigma Y^2$

which are the desired normal equations for a straight line or linear trend.

APPENDIX C

The method selected for determining thicknesses of bituminous overlays was selected on the basis of simplicity, relevance, and how quickly results can be obtained.

The first step toward thickness design by the Asphalt Institute Method is determining the average rebound deflection of the total set of data. This average is referred to as $\bar{x}$. Next, the rebound deflections are summed to provide $\sum x$ which, in turn, is squared to obtain $(\sum x)^2$. The next step is to square each of the individual rebound deflection values and add each one to obtain $\sum x^2$. After calculating $\bar{x}$, $\sum x$, $(\sum x)^2$, and $\sum x^2$, the standard deviation of the data must be determined. This is found by the equation

$$S = \sqrt{\frac{n(\sum x^2) - (\sum x)^2}{n(n-1)}}$$

where S = standard deviation
n = number of individual test values

The final calculation is now to determine the Representative Rebound Deflection (RRB). This value is the arithmetic average of the individual rebound deflections plus two standard deviations, multiplied by a temperature adjustment factor for reference to 70°F (21°C) and a critical time adjustment factor. The temperature factor is obtained from a graph (Fig. III-4 or III-5) in the MS-17 handbook. The critical time factor is simply a factor used to relate the RRB to the time period during which the pavement is most likely to be damaged by heavy loads. The value of the factor is a judgment decision and is considered as 1.25 in all deflection analysis in Arkansas.

The next step in deflection analysis is obtaining proper traffic data for determining the Design Traffic Number (DTN). The DTN should be calculated and projected to some future date to guard against instant obsolescence of the new design. Traffic data must include the number of trucks, weight distribution of the axles, and axle configuration. This data is then reduced to the number of equivalent 18 kip loads through use of the equivalent axle load factors found in the HRB Special Report No. 73, "The AASHO Road Test."

With the Representative Rebound Deflection and the Design Traffic Number now determined, the final step in the design procedure is determination of required overlay thickness. The required thickness is taken from another graph (Fig. IV-3) in the MS-17 manual. Entering the graph with the known values of RRB and DTN assigns a thickness, to be rounded upward to nearest 1/2 inch, which is required for proper rehabilitation of the existing pavement system.

Several sections have been designed with this method since the beginning of the study. One section of approximately 24 miles in length was designed in 1971 utilizing this method. This section is now three years old and in excellent condition with no sign of structural distress. Other more recently designed sections are exhibiting the same good qualities so far in their short service lives.

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