DEFLECTION TESTING AND ITS APPLICATION TO PAVEMENT REHABILITATION IN ALASKA

FINAL REPORT

By

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January 1985

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16. Abstract

Considering the need to operate Alaska's paved highway system at the lowest possible long term cost, it has become necessary to constantly rebalance the economics of continued maintenance versus reconstruction versus rehabilitation alternatives on all existing pavement structures. Such economic analyses require rational methods for estimating remaining vehicle load life combined with the ability to assess the long term performance of rehabilitation or maintenance options on any given section of existing road. Both the initial pavement load life estimates and the rehabilitation performance projections should be based on the very best of available engineering technology. Both should also have a similar theoretical basis. Data and experience accumulated from Alaskan research projects since 1977 have led to the conclusion that deflection basin shape, as measured by the Falling Weight Deflectometer, is a key factor through which pavement rehabilitation economics can be determined.

The report focuses on selection and operation of the FWD in Alaska. It also discusses methods for applying FWD data to alternative rehabilitation designs for asphalt concrete pavements and for vehicle load-life estimates.

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FOREWARD

Research represented by this final report began in 1977 as an effort to optimize the structural evaluation of paved roads in Alaska. This study, primarily involving evaluations of deflection testing equipment, has provided the State with several engineering tools which are now routinely used in rehabilitation, planning and designs for existing highway pavements. Pavement deflection data has become, in fact, an indispensible element in the management of existing pavements throughout the United States; but one which is not necessarily well understood by the average highway engineer.

The original objective of this report was to present, very specifically, the evaluation and selection of deflection testing equipment for use in Alaska. However, I have considered that the principally targeted readership is not (or should not be) other research engineers. Bearing this in mind I have attempted to discuss deflection testing equipment by placing it within a more general context. To this end I have tried to draw a total picture of what deflection testing is, how it is done, and how it is applied. I would hope that the entire report is readable, without prior research literature grounding, by staff-level materials and design engineers of the Alaska Department of Transportation and Public Facilities.

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Fairbanks, Alaska 99701
January 11, 1985

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ACKNOWLEDGEMENTS

Funding for this project was provided by the Federal Highway Administration through the Highway Planning and Research (HPR) program. The Federal project coordinators have shown genuine interest in the application of modern design methods and equipment systems to the betterment of Alaska's highway system.

IMPLEMENTATION RECOMMENDATIONS

Implementation steps necessary to incorporate findings and suggestions contained in this report are beginning to become an integral part of rehabilitation design procedure for the Department of Transportation and Public Facilties.

This implementation includes:

1) Selection of deflection basin shape as the basis for vehicle load-life estimations, for estimation of in situ materials properties and for rehabilitation designs.

2) Selection of the Falling Weight Deflectometer as the means of deflection testing throughout Alaska.

3) Adoption of mechanistic design methods as they are applicable to analyses of Falling Weight Deflectometer data.

4) Incorporation of remaining load life as a pavement management ranking tool.

5) A routine (yearly) collection of Falling Weight Deflectometer data on essentially all State owned, paved roads in Alaska.

6) Application of deflectometer data to the control of spring load restrictions on selected sections of Alaskan highways.

The State of Alaska presently owns and operates two Falling Weight Deflectometer units which collect data during every spring season on Alaskan roads. This level of effort now allows repeated springtime coverage of each 1-mile long paved highway section approximately once every four years.

Implementation measures have been progressing vigorously since the time initial deflectometer research was being done, although the process is by no means complete at this time. Suggestions for further implementation actions include:

1) Purchase of 2-4 additional Falling Weight Deflectometer units so that individual road sections can be structurally characterized at least every two years.

2) Conversion of the Department of Transportation and Public Facilities overlay design procedure (reference; "Guide for Flexible Pavement Design and Evaluation," August, 1983) from its present form to one based on "back calculation" of material properties and "forward calculation" of stresses, strains and vehicle load life.

3) Development and adoption of a formalized pavement management system (PMS) which will help insure an optional allocation of highway funds throughout Alaska.

It is PMS development which is perhaps the strongest and most long term form of implementation of research represented by this report. It is only through a well established PMS with its structured data bank and the ability to compare actual and predicted performance that the true economic advantage of the Falling Weight Deflectometer will be documented.

INTRODUCTION

Rising costs of materials, equipment and manpower associated with new highway construction have focused increasing attention on existing pavement structures. The key to properly protecting these investments is application of correct and timely maintenance, rehabilitation or reconstruction actions based on a rational, long term management strategy. It has been repeatedly demonstrated that thoughtfully formulated highway management practices actually do minimize long term costs of both the transportation agency and road user.

This report describes how the Alaska Department of Transportation and Public Facilities (DOT&PF) structurally evaluates existing pavements, and the selection of equipment used for this purpose. The report also discusses ways in which these evaluations are applied to pavement rehabilitation designs. At the present time structural data, i.e., deflection measurements, are gathered from the approximately 2000 miles of interconnected asphalt concrete road which constitutes the State's paved highway network. These roads are located in the Interior, South Central and Southeastern areas of the State where climatic variations range from moderate to severe. Rehabilitation oriented structural evaluations now rely on field data collected with the Falling Weight Deflectometer (FWD). These data are processed making increasing use of the so called mechanistic design methods. Such methods key on the shape of the deflection basin produced by the FWD. Information gained through this form of non-destructive testing is used to compute load response or performance characteristics of the existing pavement or of proposed rehabilitation alternatives.

Although Alaska presently has no formal pavement management program, life estimation and rehabilitation schemes based on the FWD and deflection basin analysis are, in fact, applied to nonformalized management functions at both the project and network level. Project level management is possible through the ability to compare cost/benefit ratios of specific designs via mechanistic computations. Some useful network management has resulted from the ability to prioritize rehabilitation requirements on a large number of road sections through a ranking process according to estimates of remaining vehicle load life.

newly marketed FWD, such as a higher loading capability and basic mechanical simplicity suggested that the objectives of the study be changed so that the RR and FWD systems could be directly compared through intensive side-by-side field tests. Accumulated information from the first study titled "Evaluation of Road Rater Test Methods," subsequently became incorporated into a second and more comprehensive research effort. The second project titled "Correlating Dynamic Deflections with Pavement Performance," provided funding for a comparison of both systems in terms of their operating characteristics and their relative abilities to distinguish pavement performance through deflection basin shape. By the time that all project data had been collected a decision to purchase the FWD system had been made based on equipment dependability and its ability to simulate actual vehicle loadings. The research effort summarized here was unusual in that implementation was actually accomplished during the course of the project itself. At the time field comparisons were being conducted between deflection systems, there was an immediate need to begin gathering yearly deflection inventory data. The decision to purchase an FWD and to continue on with equipment operation and data acquisition procedures utilized <u>during</u> the research project began a process of routine implementation which now continues. This summary includes project findings which have supported present FWD implementation by the Alaska DOT&PF.

CHARACTERIZATION OF THE PAVEMENT STRUCTURE

The pavement structure addressed here is defined as the upper portion of the roadway which supports vehicle loadings in a true structural sense. With even large truck axle loads, vehicle induced stresses are significant to a depth of only about 4 to 5 feet in normally constructed pavements. For practical purposes, therefore, the pavement structure will subsequently be defined as all material lying between the road surface and a depth of 5 feet.

The Deflection Basin:

Application of a vehicle load to the pavement surface produces a bowl shaped depression known as the deflection basin. Many engineers agree that

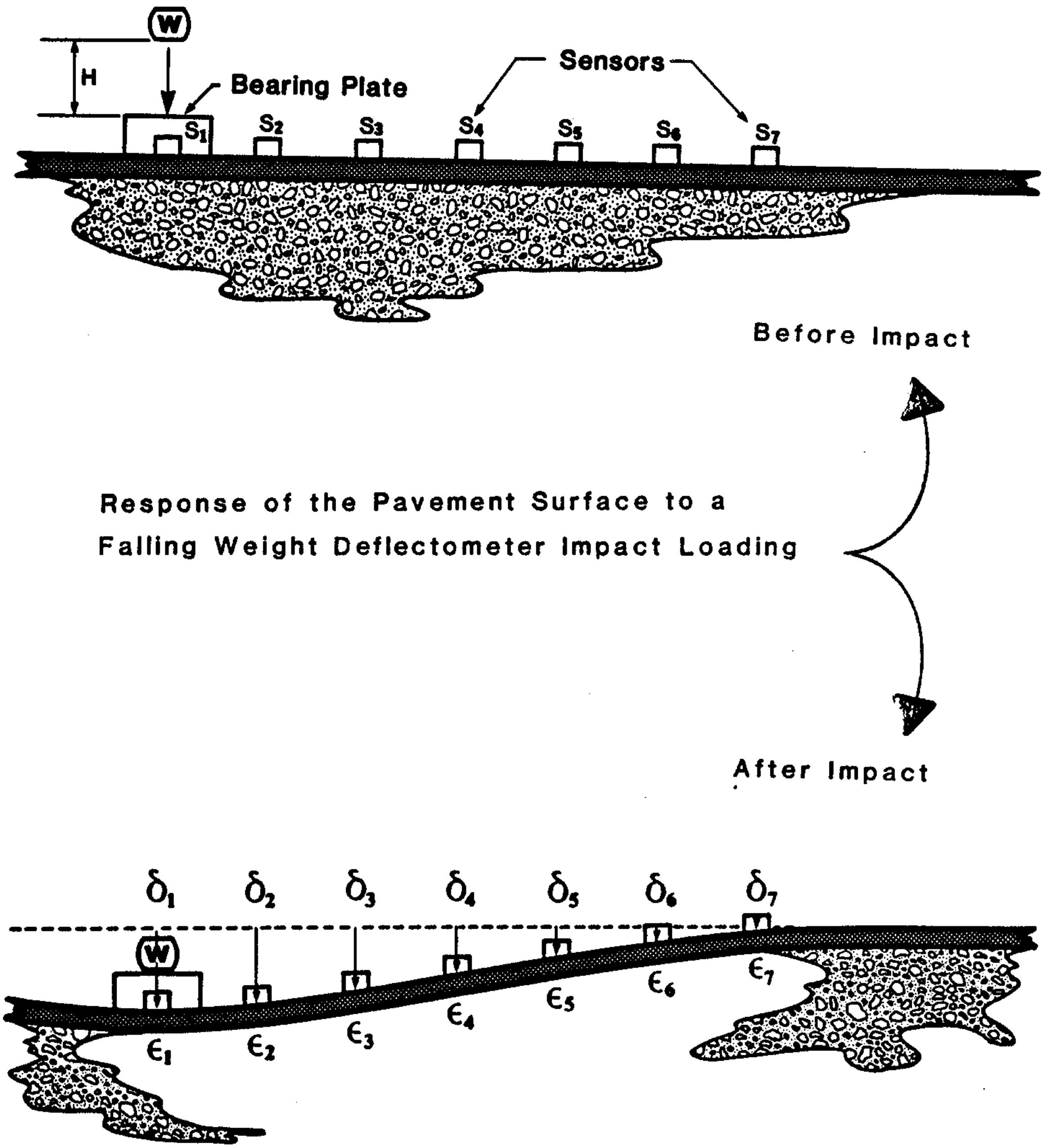

FIGURE 1. "S" Shaped Deflection Curve Generated by a Test Load Application

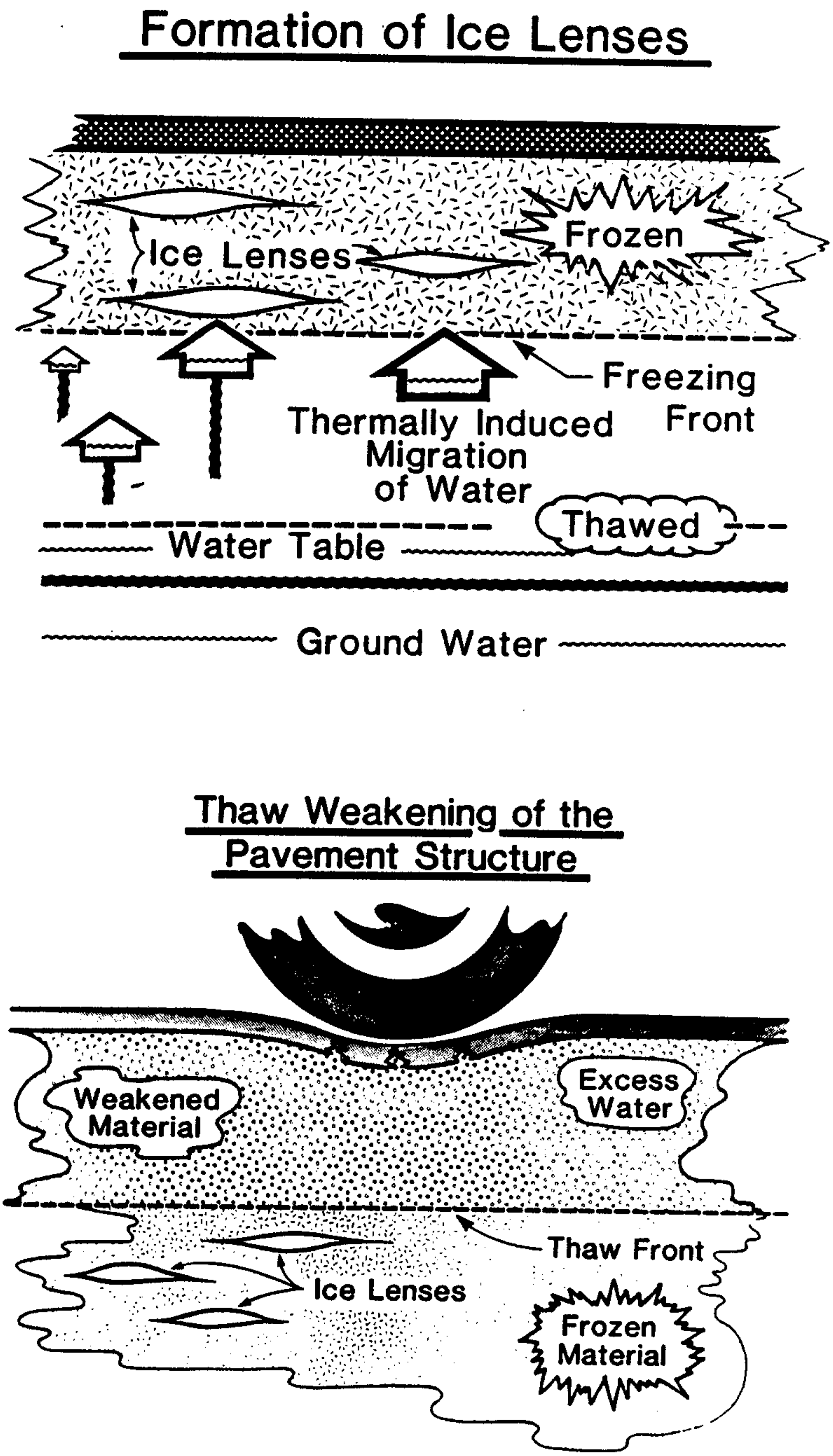

FIGURE 2. The Physical Nature of Freezing and Thawing Pavements

Examples of poor correlations between pavement stress-strain environment and load center deflections are easily found in Alaskan field data. A discussion of this relationship in terms of Alaskan data is presented in reference 4 which further substantiates the need to record and analyze overall deflection basin shape as opposed to the use of Benkelman Beam-type single point deflections.

Non-Destructive Testing:

Non-destructive testing (NDT) of paved roads is a method by which in situ pavement structural properties can be estimated, in response to a surface load, without causing significant pavement damage at or near the load site. More specifically NDT systems are used to collect deflection curve data from which structural properties can be inferred. The guiding principal behind any test method or device used for NDT is that it must provide a reasonably accurate assessment of a pavement's response to real traffic loads. The following are necessary elements:

1) Load application and intensity should mimic actual highway traffic.

2) The test method should be rapid and safe, causing minimal traffic interference.

3) The testing device must be mechanically robust so that excessive maintenance is not necessary. It must also be simple enough so that routine repair and servicing can be done without extensive special training.

4) Load intensity and mode of load application to the pavement surface must not cause significant damage to any portion of the pavement structure.

5) Equipment must supply enough deflection sensing points to insure good characterization of the deflection basin's shape.

INVENTORY OF REMAINING PAVEMENT LIFE AND REHABILITATION NEEDS

General Considerations:

Alaskan highways lie within a wide range of climate zones which include the moderate, maritime conditions along southeastern coastal portions of the State, to the extreme temperature variations common to the these data describe only the center points of deflection basins, they provide some useful insight about the general characteristics of the deflection basin as a whole. The Canadian data, based on 828 observations, indicates that even for similar subgrade types, spring/fall deflection ratios vary by a factor of 3-4. Furthermore, for about half the subgrade types listed, at least a few spring/fall ratios were found to be as low as 1.0 or less, indicating cases where pavement strength actually decreased during the summer or fall.

Using measurements from 105 Alaskan pavement sections, 95% of the observed spring/fall deflection ratios were between 0.5 and 2.2. Multiple regression analyses were unsuccessful in determining which, if any, climatic variables or material properties could be used to successfully predict the ratio. Correlation analyses were performed to look at the strength of the relationship between: 1) the spring maximum versus fall maximum deflection, 2) the spring/fall deflection ratio versus the spring maximum deflection, and 3) the spring/fall deflection ratio versus the fall maximum deflections. Index of determination values (R^2) were 0.57, 0.34, and 0.02 respectively. These R^2 values further indicate that the concept of predicting spring from fall deflection has little if any validity in the case of Alaskan roads.

Based on consideration of Canadian and Alaskan Benkelman Beam data it appears that the spring/fall ratio concept is not useful. It is concluded that repeated springtime measurements are absolutely necessary in order to accurately characterize thaw-weakened pavement structures. This conclusion is assumed to apply, in principle, to general deflection basin shapes as well as the deflection center point deflections from which it was derived.

The size of Alaska is such that "spring" begins at different times in different areas, although the total length of the spring season in any given area is about the same, i.e., about 5-6 weeks. On a routine inventory basis, every mile of paved road is deflection tested during this springtime period, about every 3 to 4 years. The State now owns and operates two FWD units, each of which can routinely test approximately 50 centerline miles of road per day. This testing rate allows the machines to cover, together, about 500 miles during a normal work week. To achieve the 50 mile per day per machine rate, deflection samplings are normally obtained at intervals of about 1/5 mile. Details of the FWD deflection sampling procedure are included in a following section of this report.

indicated these conditions to be optimal on Alaskan pavements. In terms of cyclic load, 1,200 pounds was approximately the highest RR setting which did not require frequent readjustment between test load applications. It was primarily this load instability which discouraged operation of the RR at or near its maximal load capability. Using the 1,200 pound loading it was possible to obtain a measurable pavement response up to a frequency of about 35 Hz, past which natural damping rapidly reduced surface deflections to about zero. It is within the frequency range of 10-35 Hz that pavement structures are said to respond to cyclic loadings as simple mass-spring-dashpot systems (6). A frequency of 15 Hz was finally settled upon because it produced optimum pavement response, i.e., at or near maximum deflections, with the 1,200 pound load. The frequency was also high enough to simulate at least slow moving traffic and lie within the frequency range of simple elastic response.

Figures 4, 5, and 6 show various aspects of the RR, Model 400A System which was until recently, owned by the State of Alaska. Information concerning the RR can be obtained from the manufacturer at the following address:

Foundation Mechanics Inc.
421 East El Segundo Blvd.
El Segundo, California 90245

Impact (Impulse) Load NDT systems are mechanically more simple in nature than the steady state type. An impulse signal is generated at the pavement surface, such as by impact of a falling weight and the magnitude of the vertical response is measured at various distances from the load center. The major design feat of such a system is data acquisition circuitry which "reads" motion transducer output only at the proper time with respect to the pavement's impulse load response. It is the first wave, i.e., the initial response which is recorded and provides useful design information. The test method normally used by Alaska for its FWD equipment involves a 9,000 pound impact force with a loading time of about 27 milliseconds. This combination of load time and intensity has been found to closely imitate the actual load signature of a moving 18,000 pound truck axle. The Dynatest Model 8000 is capable, however, of impact loads ranging

FIGURE 6. Road Rater Control and Data Acquisition Unit

FIGURE 7. Falling Weight Deflectometer in Operation

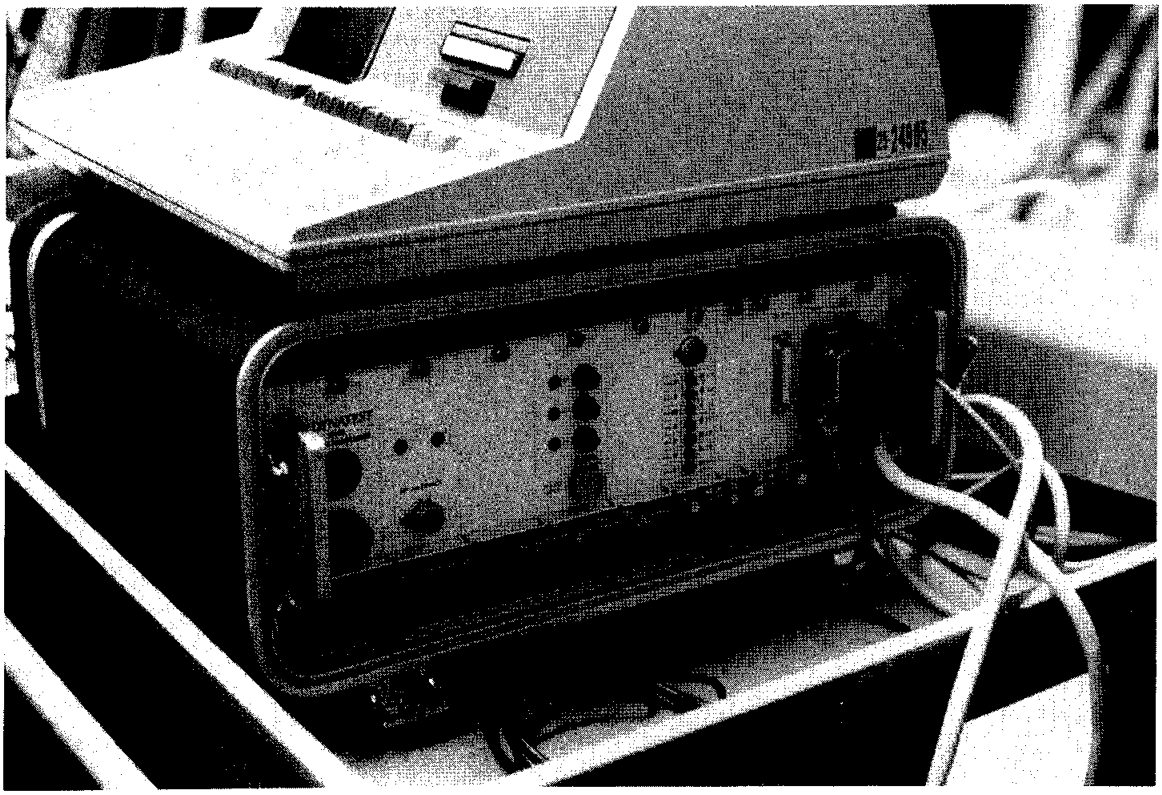

FIGURE 8. Falling Weight Deflectometer Control Computer and Data Acquisition Unit

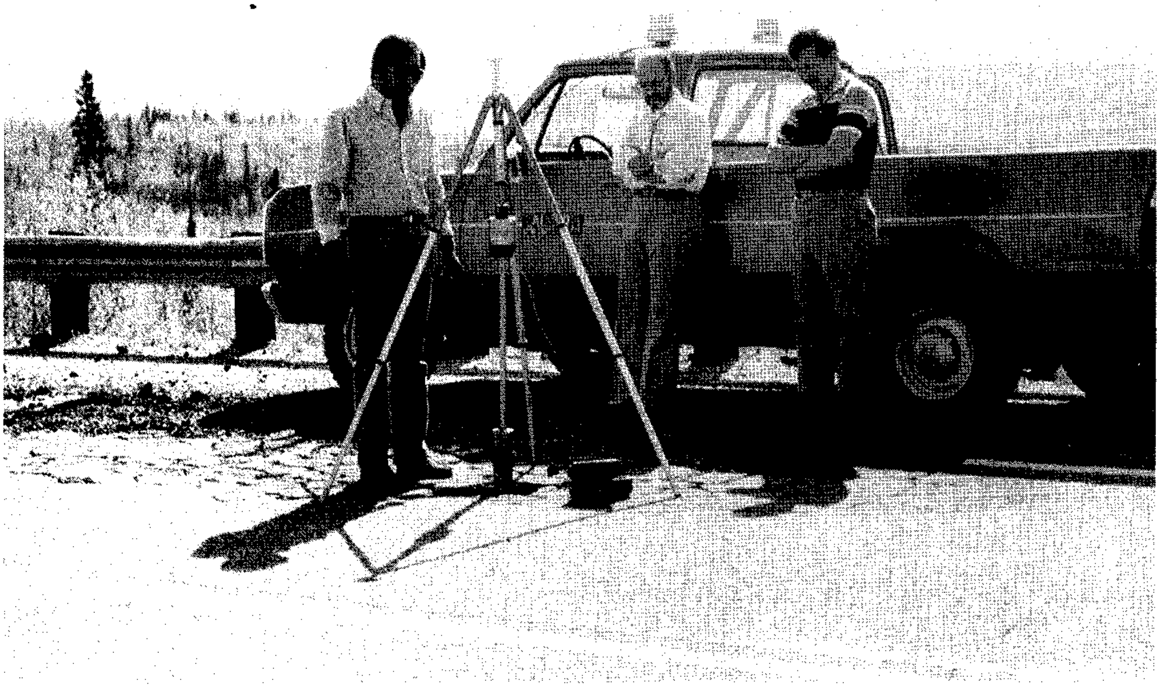

FIGURE 9. Testing Base Course Materials with a Small Falling Weight Deflectometer

To get a better grasp on the RR/FWD data comparison a statistical 1-way analysis of variance (ANOVA) was conducted to determine if changes in pavement condition with time could be discriminated on the basis of minimum springtime spreadability values. A statistical hypothesis was formulated stating that the variation in spreadability values was so high within a particular pavement section on a given date that it was impossible to discern a change in that pavement's condition with time. The alternative hypotheses, required by the statistical test procedure, stated that a change in pavement condition with time could be detected. A description of the 1-way ANOVA test procedure is given in almost any elementary statistics text and is beyond the scope of this report. The critical statistic utilized in this analysis is the "F" ratio, i.e., the ratio of sample variances. In this case, the numerator in the F statistic represents the variance in spreadability values in a single roadway section for different dates. The denominator represents variance in spreadability values within a single roadway section on a single date. Conceptually, the F ratio can be thought of as the variability between samples divided by the variability within samples. Using this definition it is fairly obvious that a higher F ratio would be associated with a greater ability to discern a difference between samples. A low F ratio, on the other hand, would indicate so much "noise" within a sample that it is difficult to distinguish between samples. Working with these hypotheses and at a 90% confidence level, it became possible to objectively compare the abilities of RR and FWD systems to "see" structural differences in a given road section with time. Results of the ANOVA on 20 randomly selected road sections identified four distinct classes (groupings) of comparative discrimination capability which are shown on the following table:

Group #	Group Description	# of Cases in group
1	FWD able to discriminate changes in structural condition with time - RR not able to discriminate -	14
2	FWD & RR both able to discriminate -	3
3	FWD not able to discriminate - RR able to discriminate -	0
4	Neither the FWD nor the RR able to discriminate -	3

During emergency situations the FWD load plate can be manually raised and the machine moved from the test location without equipment damage. The RR load head could not be raised easily without hydraulic power. Loss of hydraulic pressure or actuation capability is a problem which could arise through either electronic or mechanical malfunction. Figure 10 illustrates the principal mechanical differences between RR and FWD load application mechanisms. It also shows details of the load configurations and motion sensor placements used during DOT&PF tests.

By the end of the 1982 spring season Alaska's DOT&PF had committed itself to continued use of FWD equipment.

Operation and sampling methods used with the Falling Weight Deflectometer:

Based on deflection testing experience accumulated in Alaska a workable field procedure for the FWD has been assembled. These methods are summarized on the following pages.

1) Sampling Interval - Except for general inventory work it is very difficult to suggest that the samples per centerline mile of road section can be limited to a specific number. DOT&PF has been satisfied with 5 sets of deflection tests per mile (taken in the outer wheel path of one lane only) for Alaska's yearly pavement structural inventory. However, for specific design work or in areas where a great deal of variation is noted, it may be necessary to repeat deflection measurements at closer intervals. Some project areas have been tested with sample spacings of no more than 20 feet. The need for extremely high density sampling is often not apparent until field testing is actually under way. As a field expedient it is possible to adjust the number of deflection tests per mile according to the amount of variation in load-center deflection which is assumed or has been measured.

   The sampling interval of 5 deflection measurements per mile previously noted was derived from a statistical analysis of data from 120 pavement sections described in reference 3. Sample size can be derived from the following definition:

$$t = (\overline{X}-\mu)\ N/S.D.$$

Where: t = students' "t" statistic (discussed in any basic statistics text), describes the distribution of sample means for small samples.

$\overline{X}-\mu$ = difference between sample average ($\overline{X}$) and population average (μ), or in this case the difference between the measured average deflection and the true average deflection - can be thought of as allowable error.

N = number of measurements per sample, i.e., per mile or other defined length of road section.

S.D. = standard deviation estimated for a sample size of "N".

The above formula can be manipulated in order to directly calculate a minimum sample size (N) such that specified confidence and error criteria ($\overline{X}-\mu$) are met.

$$N = [(t)(S.D.)/(\overline{X}-\mu)]^2$$

The error value is selected by the analyst and should be small enough to provide a reasonably accurate estimate of the true mean deflection, but not so small as to force N to an impractically large number. An allowable error on the order of 0.010 inch is reasonable for most purposes.

Examination of data from the 120 pavement sections indicated that the sample standard deviation (S.D.) increased with the average deflection of the section. At a confidence level of 90% and allowing an error in estimation of the true mean deflection of no more than 0.010 inch a required sample size (N) is computed based on the increasing S.D. values shown. The term "worst-week period" refers to the time of highest, i.e., worst-case deflections.

made, however, on pavement sections near Fairbanks where by the time daily air temperatures are averaging 32°F, considerable solar radiation heating of the pavement is occurring. Thaw may occur even in mid-late April with air temperatures averaging as low as 25°F because of radiation heat exchange. In the interior areas of Alaska, by the time 480 degree-days of thawing have accumulated, most pavement sections exhibit deflections at least 40% lower than their maximum values. The previous discussion applied only to load center deflections as measured by the Benkelman Beam. It should be realized that worst-case load effects, i.e., maximum deflection basin curvature may or may not have coincided with maximum Benkelman Beam deflections.

As a rule deflection testing in the geographical interior of Alaska, e.g., Fairbanks area, begins about the last week in April. To the south, in areas of the state known as Central and Southcentral Alaska (including the cities of Anchorage, Seward and Valdez) tests begin about a month earlier. In Southeast Alaska, typified by the Juneau area, testing may begin as early as mid February.

3) <u>Normal FWD Testing Configuration</u> - Alaska DOT&PF presently owns two FWD (Dynatest Model 8000) systems. Both were manufactured in Denmark, and were purchased through Dynatest Consulting Inc. of Ojai, California, at a cost of about $95,000.00 each. The units are of similar configuration and essentially all highway rehabilitation design assessments and normal inventory work has been performed using the same operational methods. As indicated in Figure 10, a 12 inch diameter load plate is placed on the pavement surface and then impacted by a falling mass of 440 lbs. The maximum impact dynamic force, delivered through a set of hard rubber bumpers is approximately 9,000 pounds. The rubber bumpers are designed such that a loading time of 25-30 milliseconds is attained. Each test location requires two drops of the FWD load, the first of which acts to firmly seat the load plate to the pavement surface. Seating-load deflections are not

6) Safety Requirements - FWD measurements, even including the two drop sequence, are rapidly done. The entire series of events from the time the FWD towing vehicle stops until the time it pulls away from the test location requires about 1 minute. Most sections of road in Alaska are tested without the aid of a second safety vehicle or safety flaggers. As far as maneuverability (traffic evasion) is concerned, the only time that the FWD cannot be moved quickly is approximately 45 seconds during the actual testing operation when the load plate has been lowered to the ground. During this period, any movement of the towing vehicle can severely damage the FWD's load assembly. No vehicle accidents have occurred during approximately 1,000 hours of highway FWD testing accumulated in Alaska.

   In the event of mechanical and/or electrical failure it is possible to raise the FWD load head manually in order that the FWD can be removed from the traveled area of the roadway without damage.

APPLICATIONS OF DEFLECTION DATA TO PAVEMENT DESIGN

Criteria Used in Estimating Pavement Service Life:

Modern pavement design methods usually rely on one or more of the following elastic structural response criteria for estimating pavement performance:

1) Tensile stress at the base of the asphalt concrete layer
2) Tensile strain at the base of the asphalt concrete layer
3) Compressional strains (or stresses) at the top of the subgrade

The first of the above items is an indicator of catastrophic load failure. The asphalt concrete layer will, of course, fail if the tensile stress at the base of that layer exceeds the tensile strength of the material, even with passage of a single vehicle loading. Strain criteria listed as numbers 2 & 3 are related to the long term cumulative type damage, i.e., fatigue life of the pavement in terms of fatigue cracking

State over the general range of climate and construction materials for which it was developed. The model predicts only fatigue cracking of the pavement and is of the form:

$$\log N_f = A \log FC + B \log BB + C$$

Where: FC = % of roadway section length which exhibits cracking

BB = the Benkelman Beam Deflection as measured by the rebound method (or FWD center-of-load deflection)

A, B, & C = empirically derived constants

Forward and Backward Computations Used in Pavement Structure Analysis:

As they apply to analyses of pavement structures, the terms forward and backward analysis are meant to describe two different ways that mechanistic design computation programs are used. The first, forward analysis, refers to application of the programs in their normal operational mode. The objective of forward analysis is to input elastic and thickness properties of the pavement structural layers and calculate the stresses, strains and deformations due to a specific load, at selected points within the pavement structure. Almost all elastic layer and finite element programs developed for pavement design were originally designed to operate this way.

Back calculation was briefly mentioned previously in this paper and is used to characterize elastic material properties of the pavement through an iterative matching of measured deflection basins with those calculated by a mechanistic program. This iteration is performed with successively refined estimates of elastic modulus values for each layer of the structure. Existing back calculation programs usually incorporate one of the available forward calculation programs such as CHEV or ELSYM 5 (2,1).

Documentation necessary to operate any of the following discussed computer programs is available through the Alaska DOT&PF Research Section upon request.

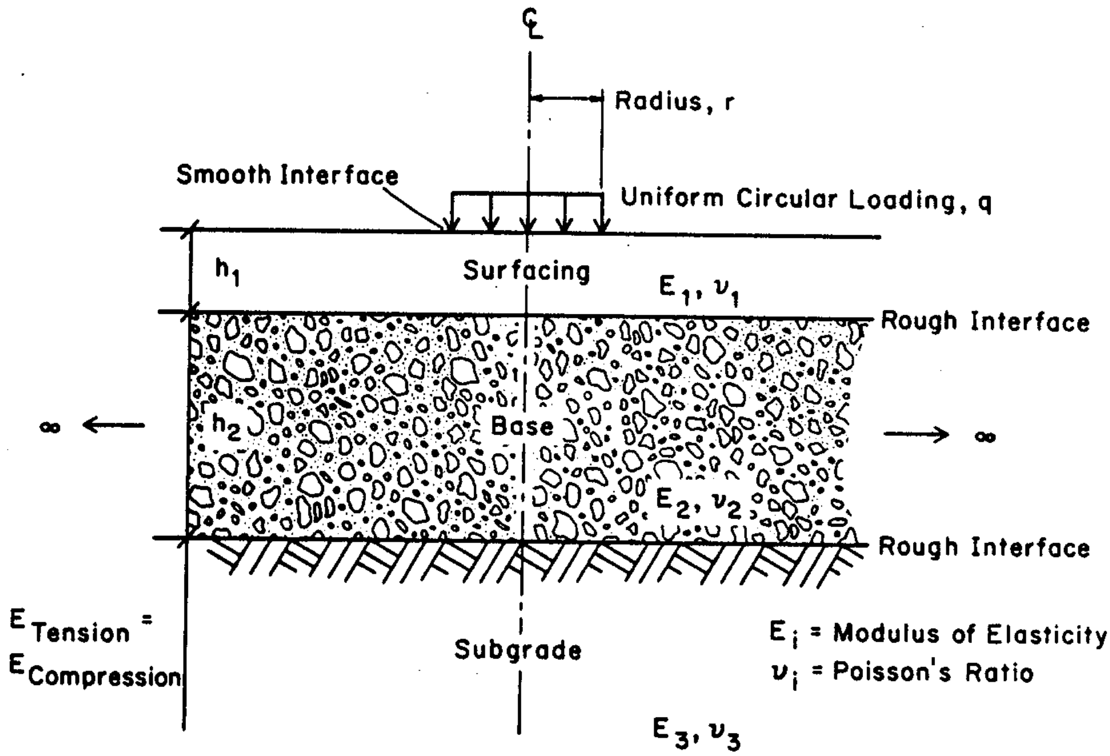

FIGURE 11. Pavement Structure Modeled by Programs Using Elastic Layer Theory

ISSEM IV. While this program has less general application than the other three methods, it can be quickly run on an HP-85 and the estimated tensile strain values provided by the program can be directly used in performance models for the determination of vehicle load life.

PAVEMENT LIFE ESTIMATION

Dynatest (Danish) Models:

Pavement load life estimates are based on two models which were empirically developed for pavement design work in Denmark. They have been recently discussed in a DOT&PF publication (15).

* for the asphalt concrete layer

$$\varepsilon = 2.28 \times 10^{-3} N_f^{-0.178}$$

Where: ε = the strain at the base of the asphalt concrete layer

N_f = the number of 18,000 lb axle loads before unacceptable cracking occurs.

* for the subgrade materials

$$\sigma = 4.42 \times 10^{-2} N_f^{-0.307} E \qquad \text{for } E > 23,000 \text{ psi or}$$

$$\sigma = 8.85 \times 10^{-3} N_f^{-0.307} E^{1.16} \qquad \text{for } E \leq 23,000 \text{ psi}$$

Where: σ = the vertical stress (psi) at the top of the subgrade

N_f = the number of 18,000 lb axle loads before unacceptable rutting occurs.

E = the dynamic elastic modulus of the subgrade material (psi)

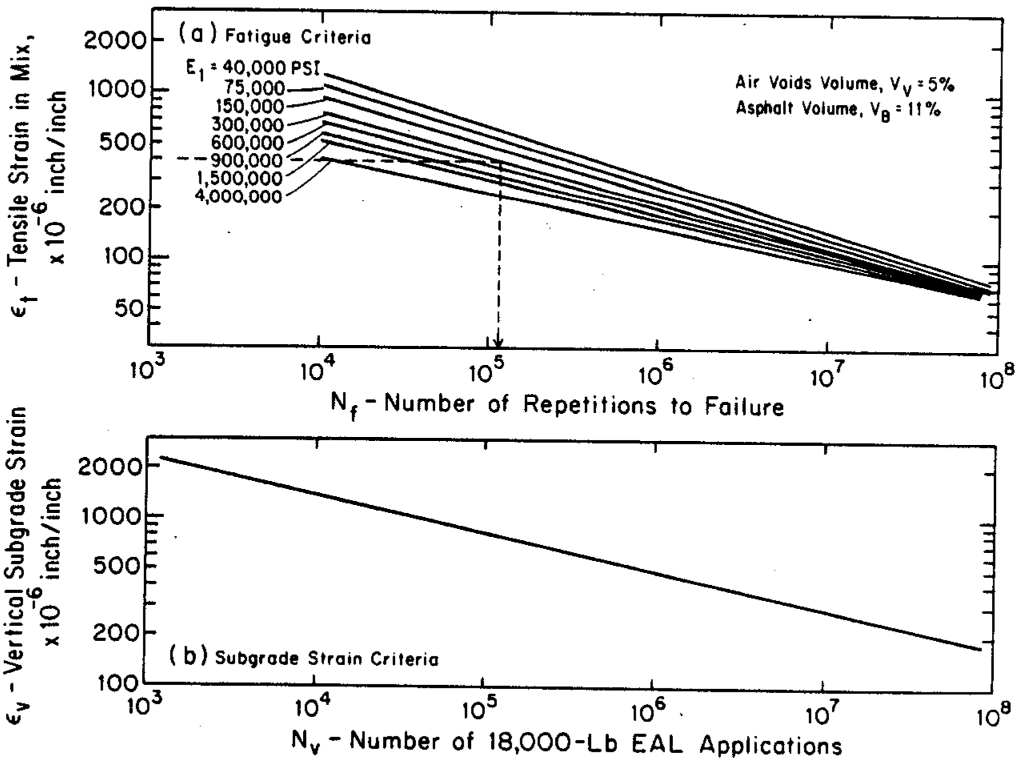

FIGURE 12. Chevron Research Fatigue Design Criteria

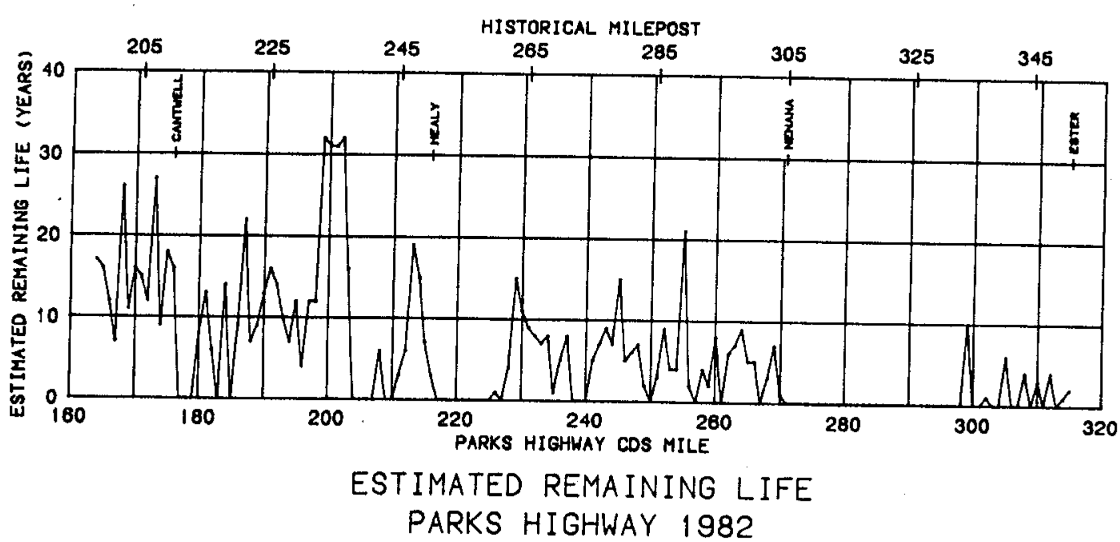

FIGURE 13. Remaining Pavement Life Based on Falling Weight Deflectometer Data and Woodward-Clyde Model

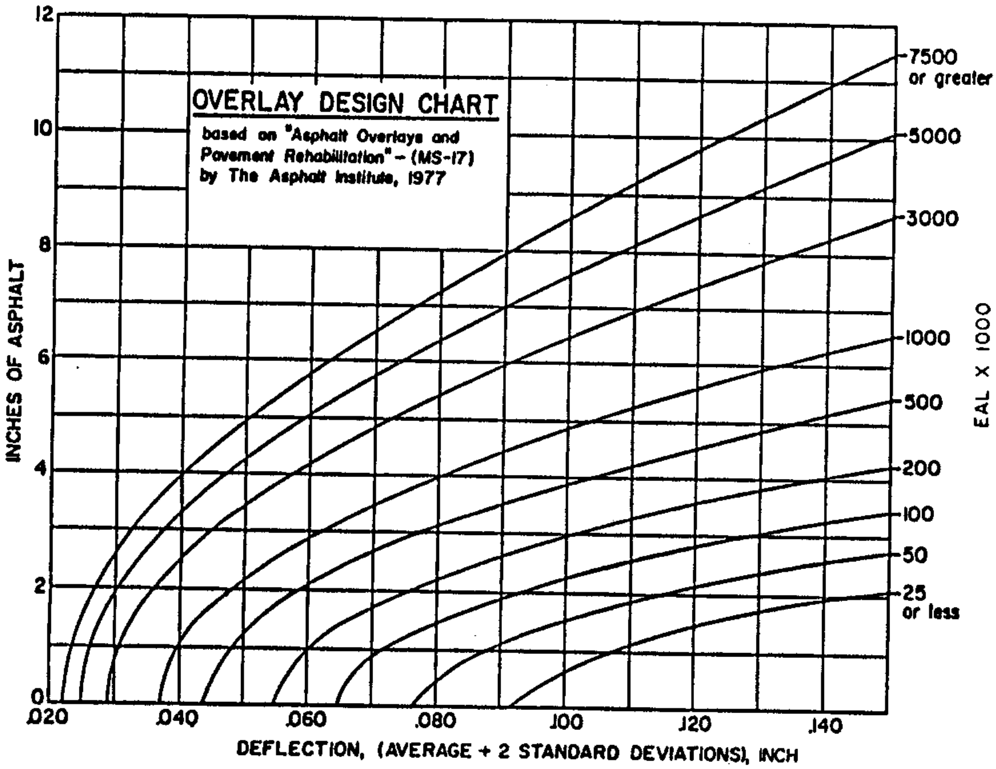

FIGURE 14. Overlay Design Chart Used in Alaska

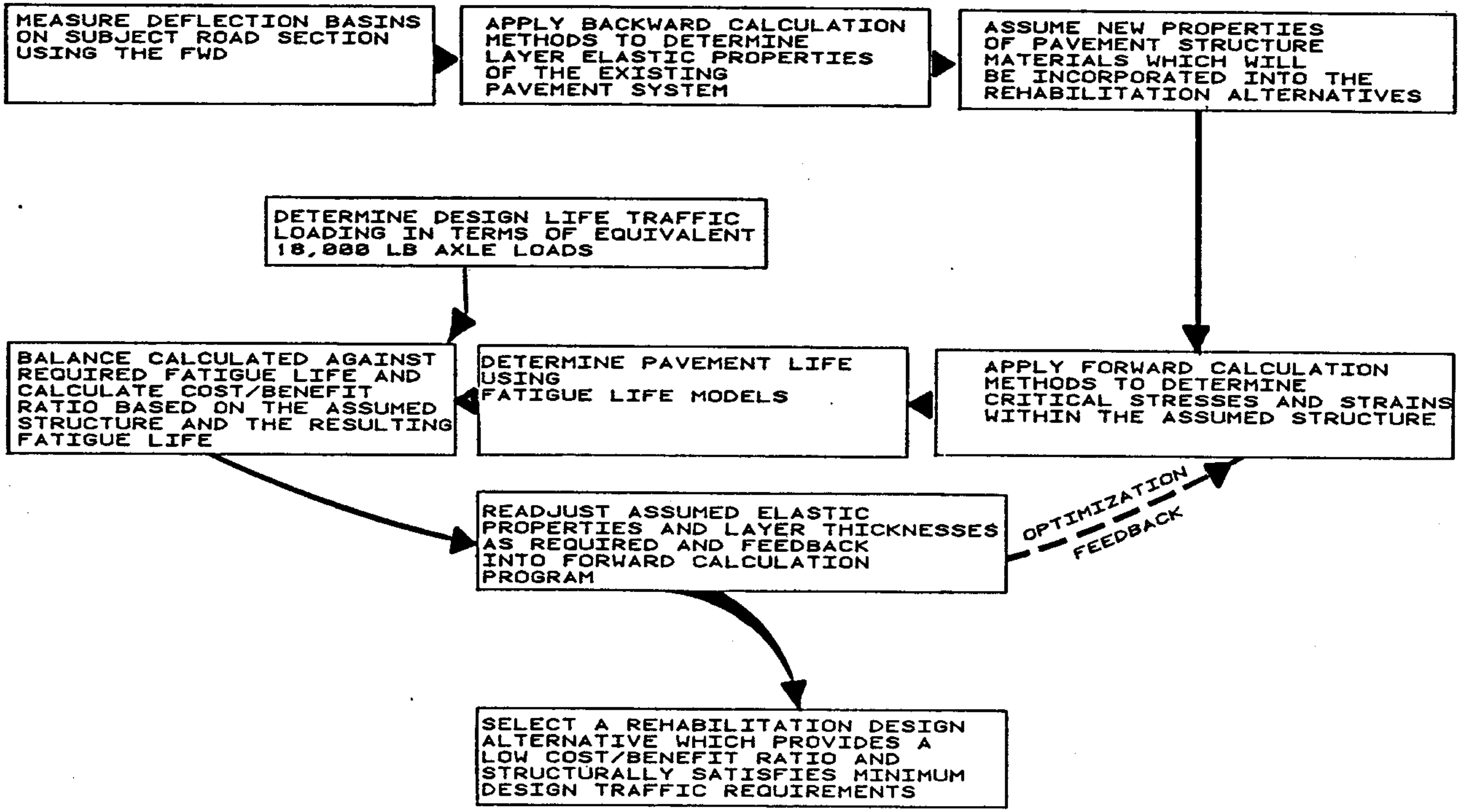

FIGURE 15. Outline of a Mechanistic Rehabilitation Design Procedure Used in Alaska

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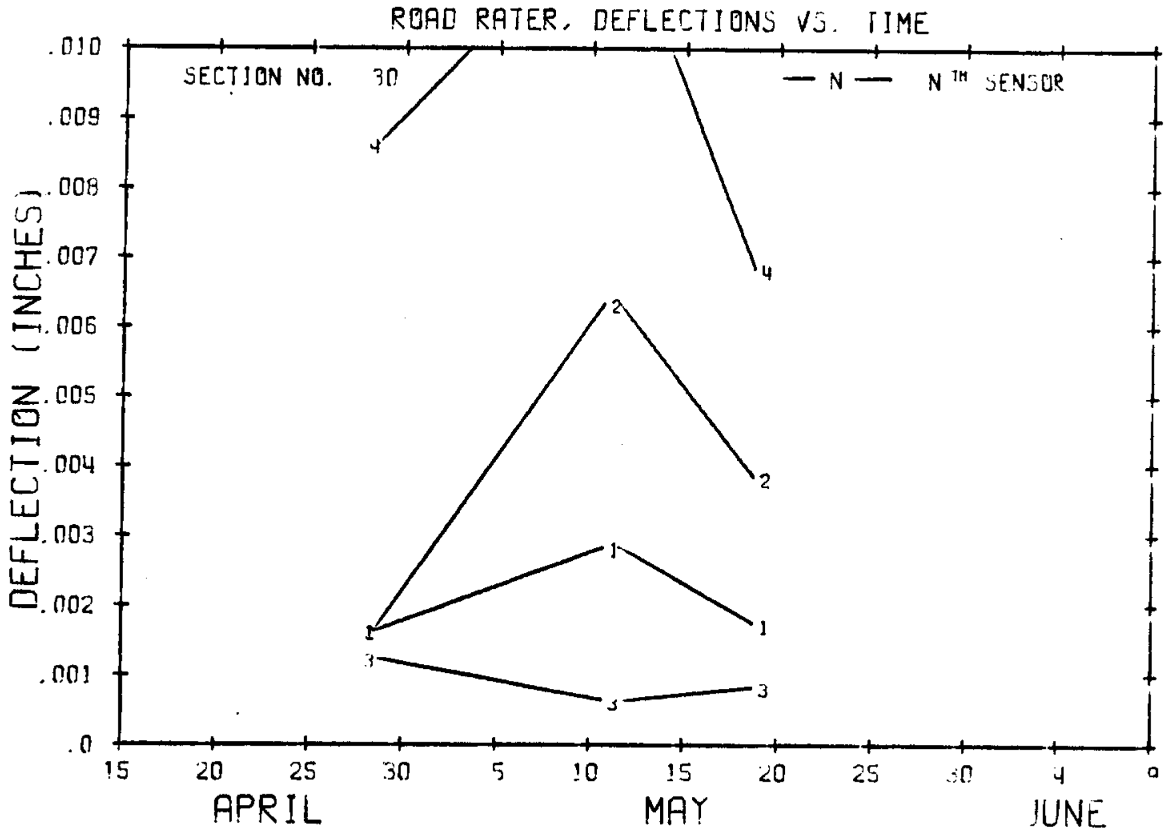
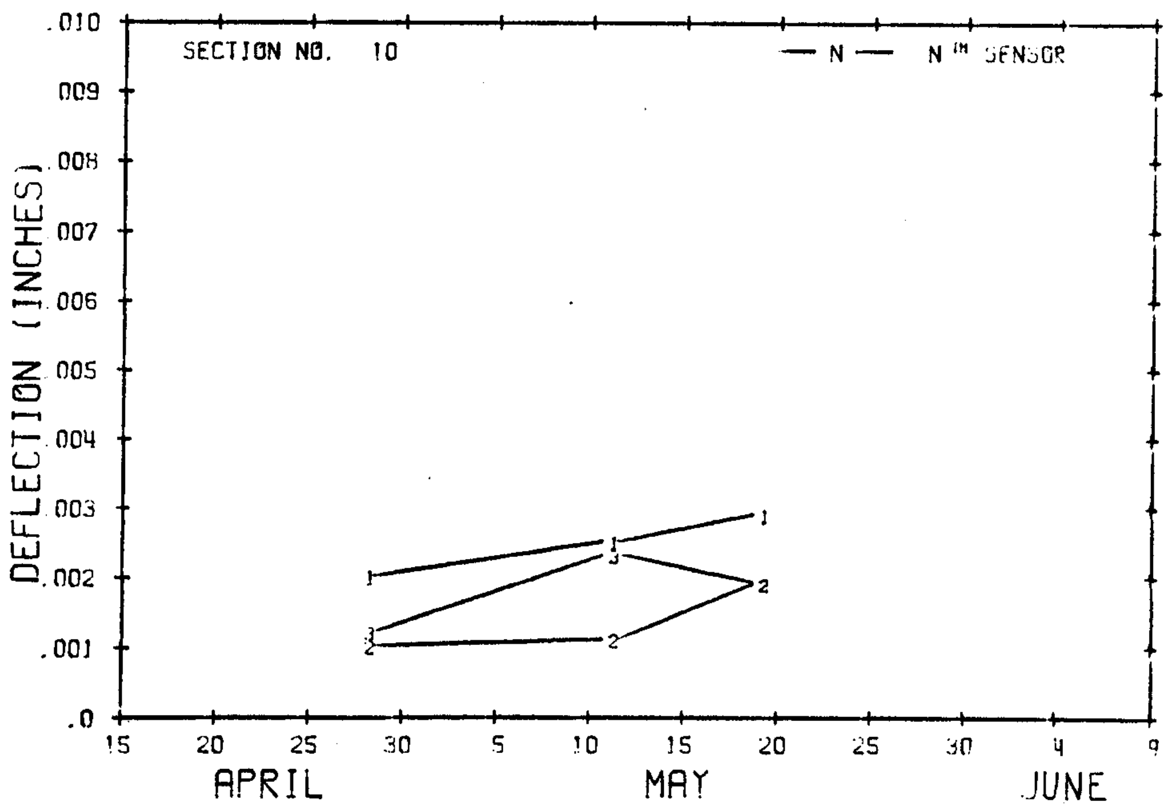
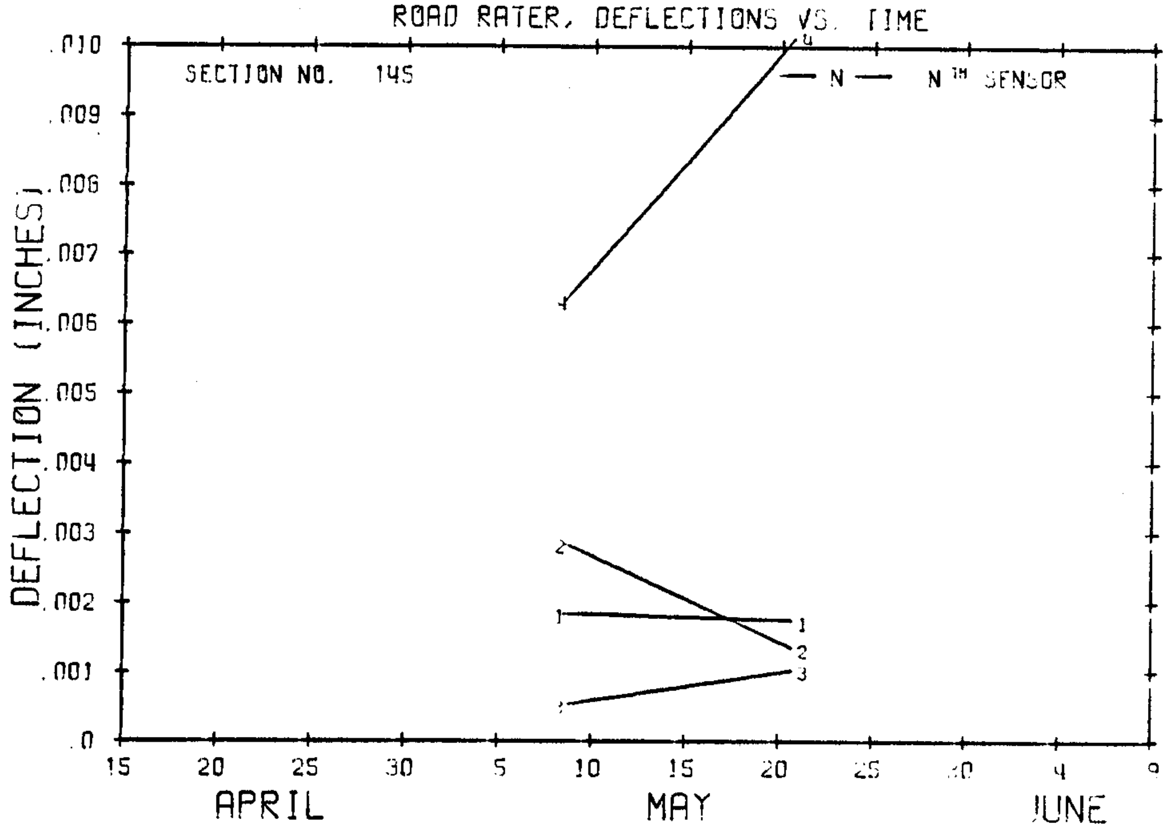
APPENDIX A

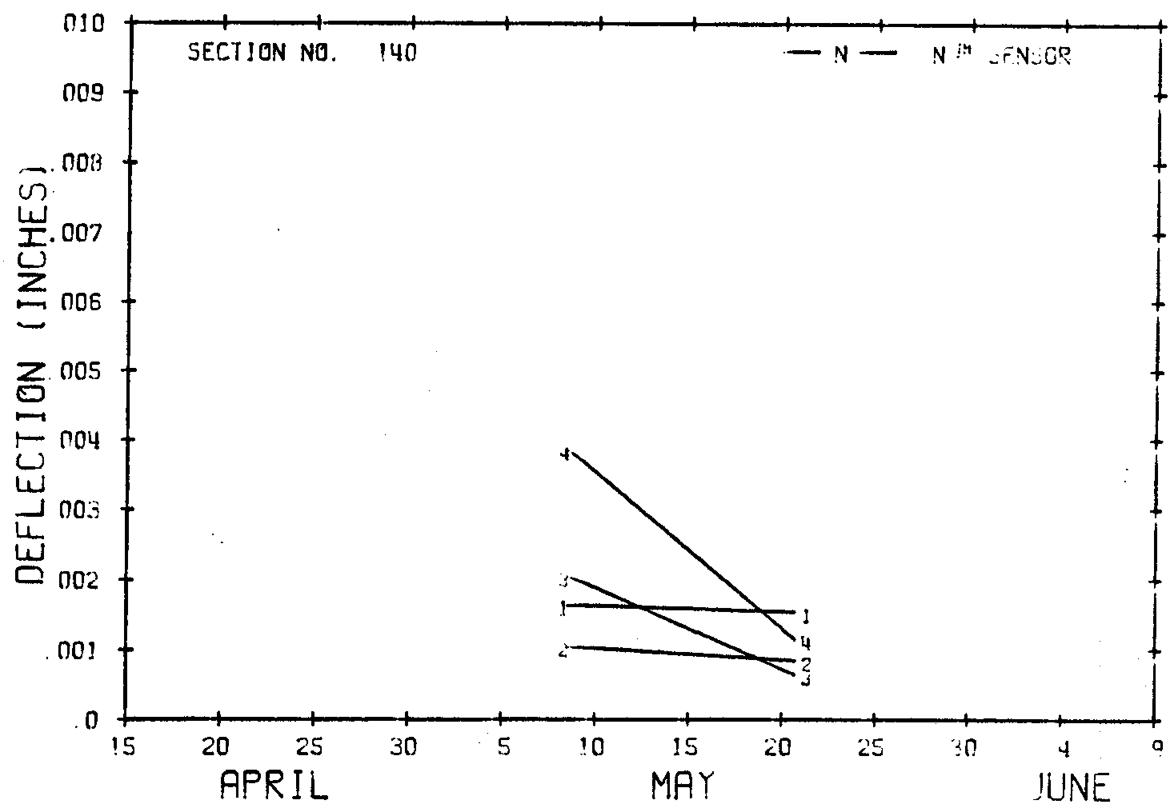
Deflection and Spreadability Versus
Time Plots from Road Rater and
Falling Weight Deflectometer Data
1981


ROAD RATER, DEFLECTIONS VS. TIME
SECTION NO. 30
— N — N TH SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE


SECTION NO. 10
— N — N TH SENSOR
DEFLECTION (INCHES)
.010
009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

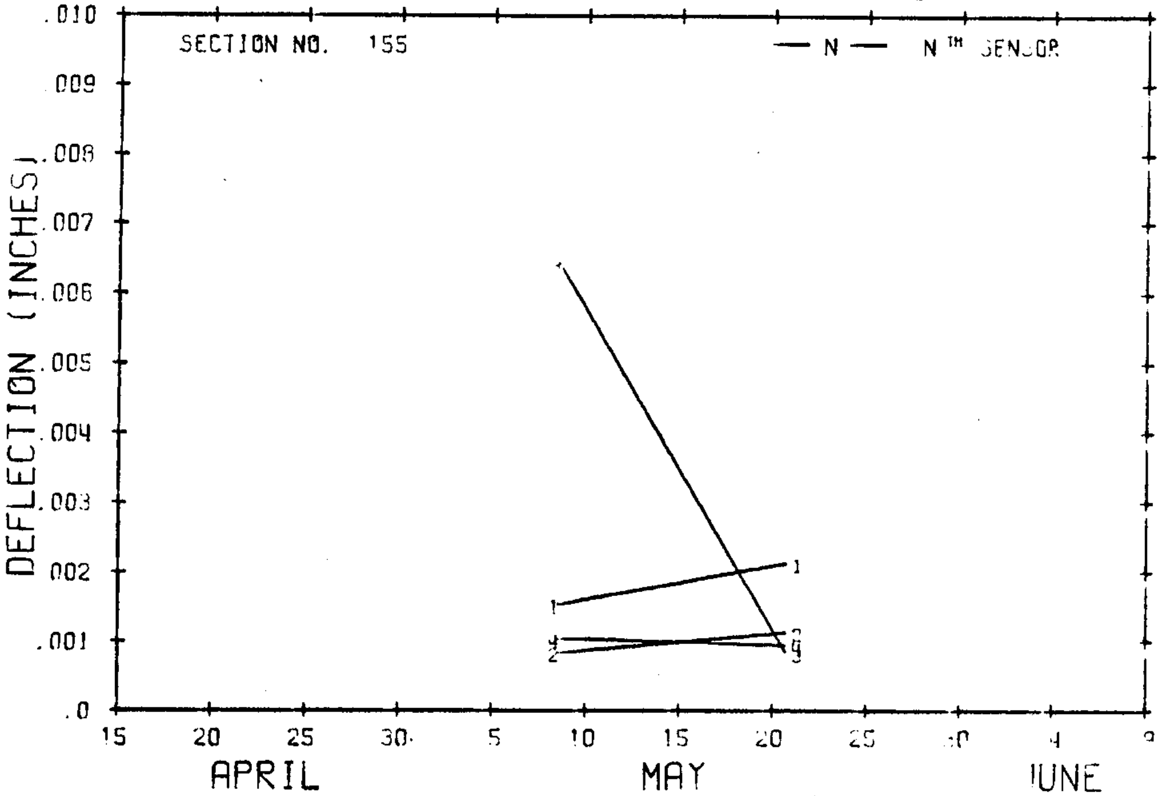


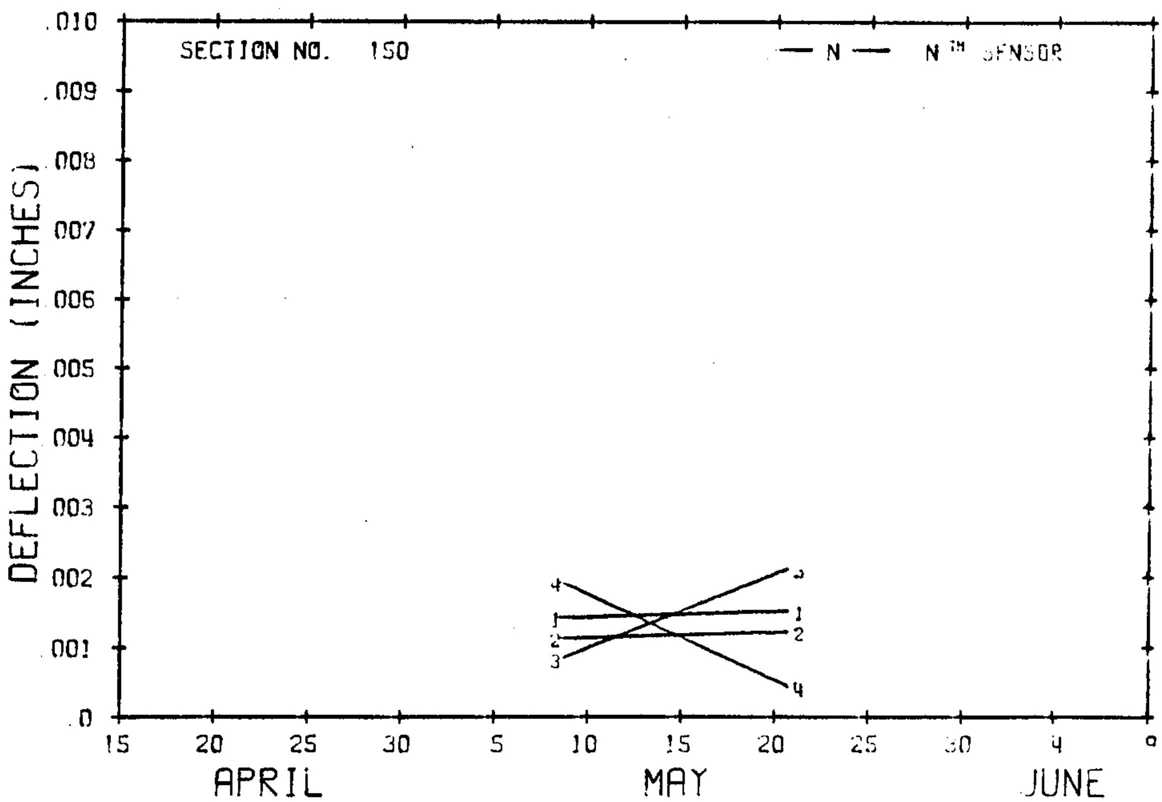
ROAD RATER, DEFLECTIONS VS. TIME
SECTION NO. 145
— N — N TH SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

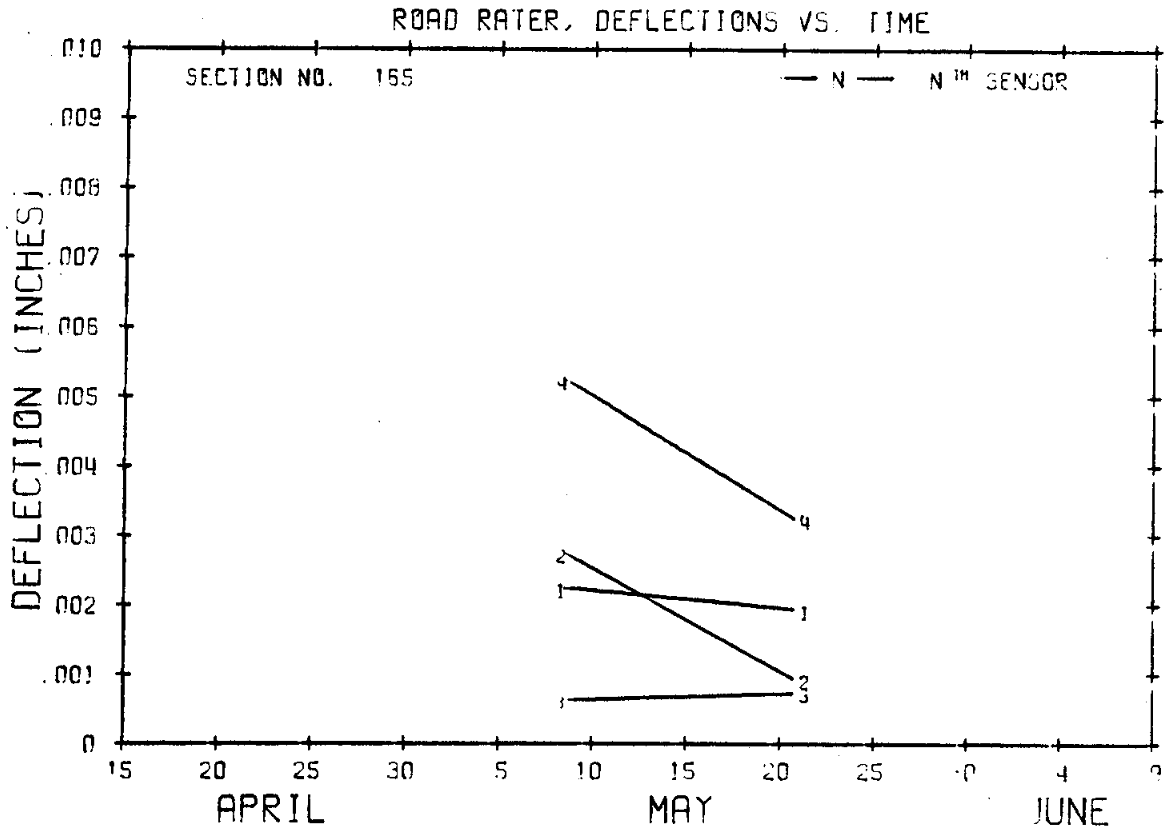


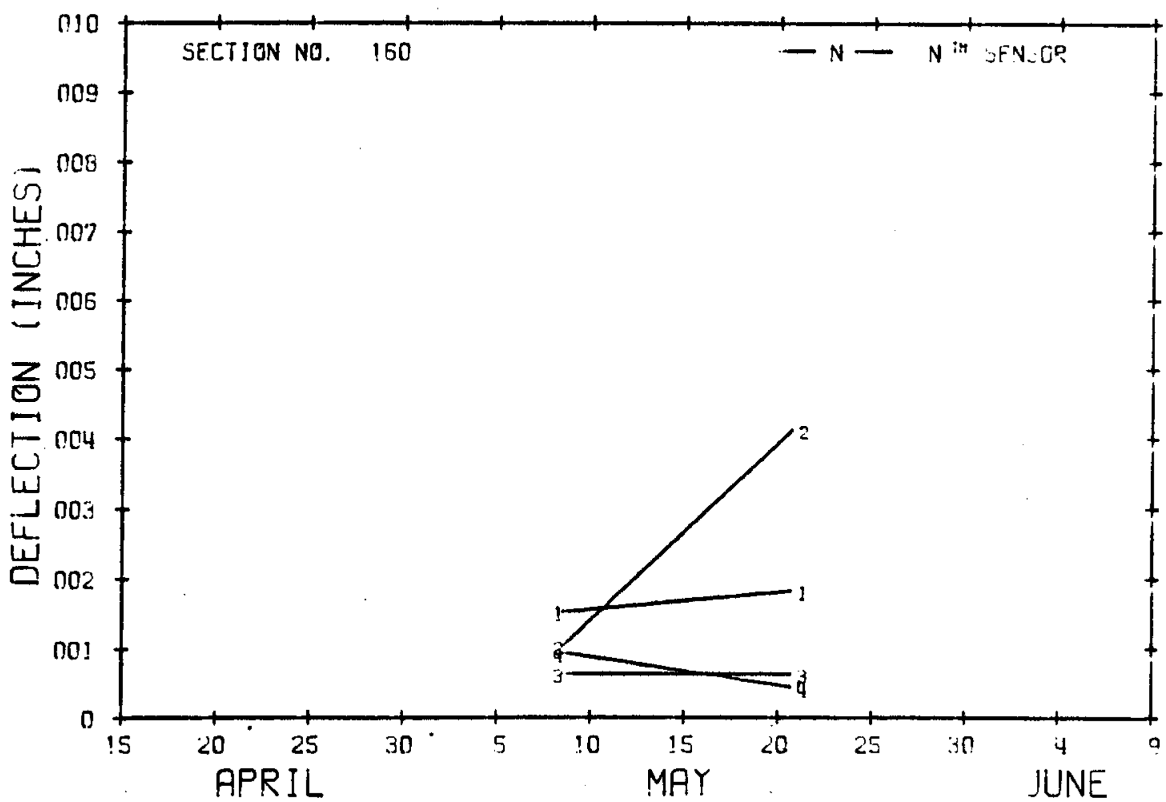
SECTION NO. 140
— N — N TH SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

ROAD RATER, DEFLECTIONS VS. TIME

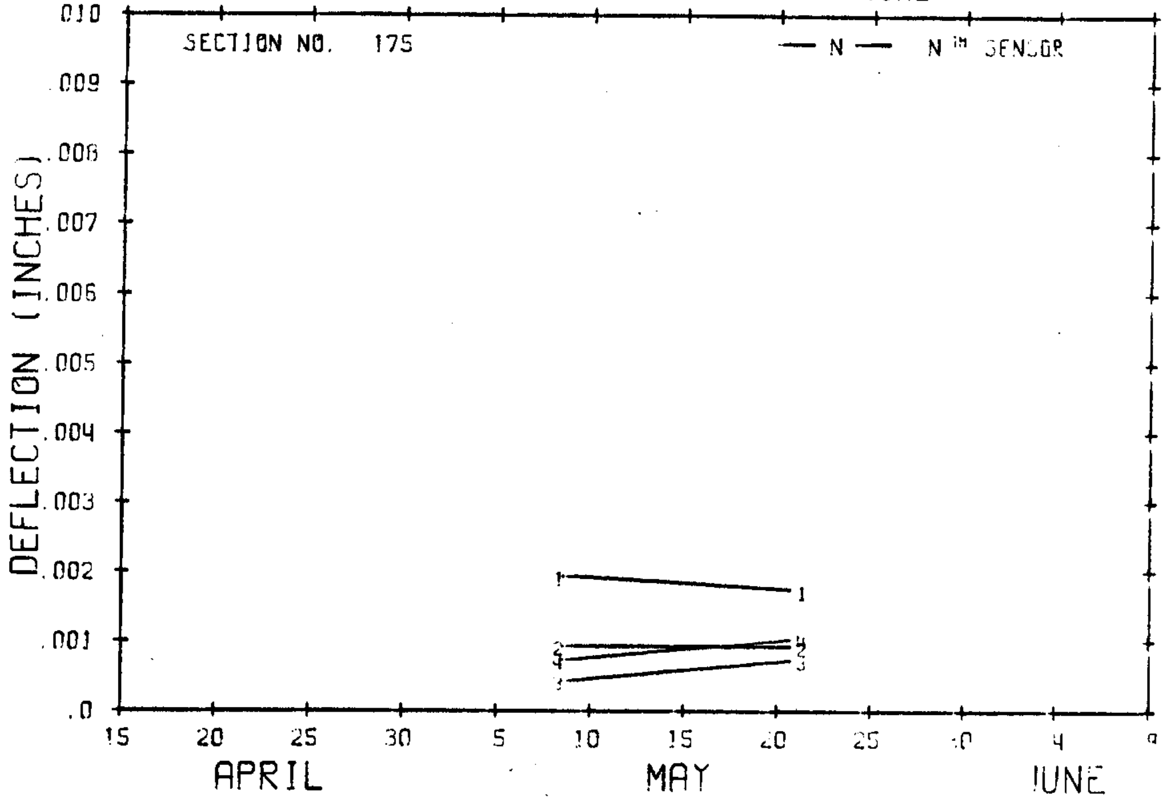


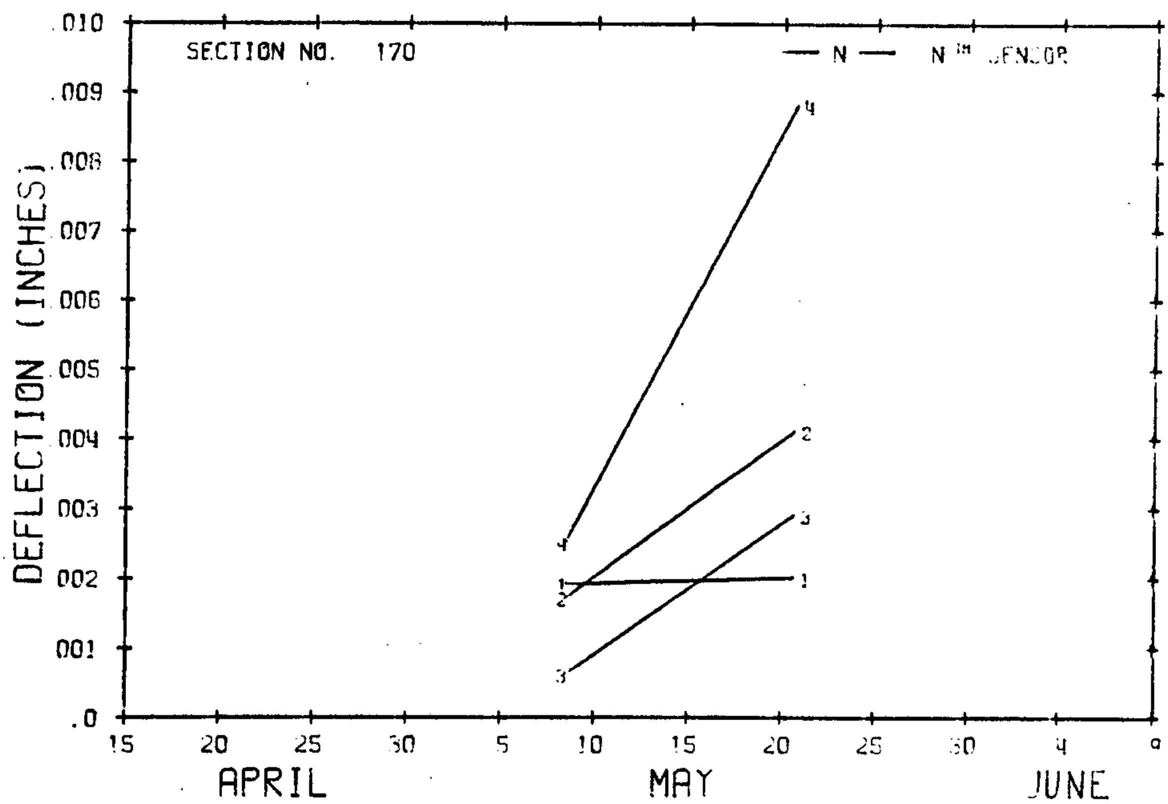



ROAD RATER, DEFLECTIONS VS. TIME
SECTION NO. 165
— N — Nth SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

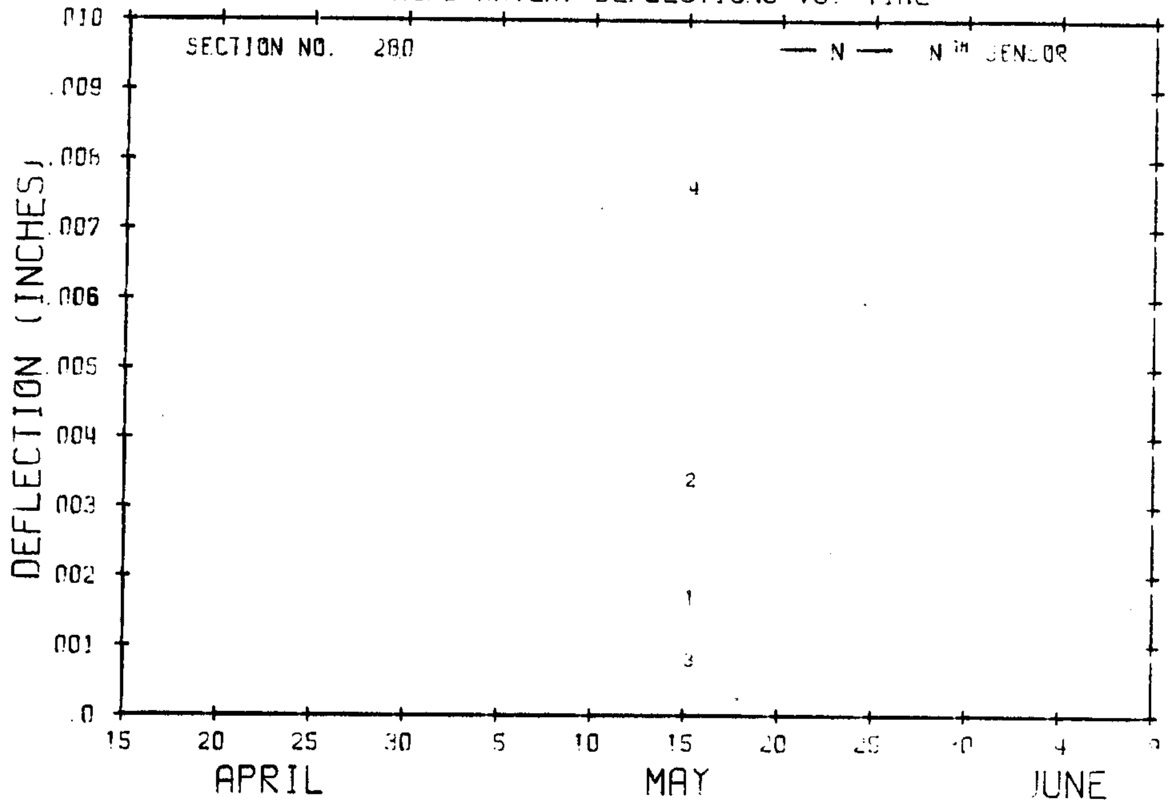

SECTION NO. 160
— N — Nth SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

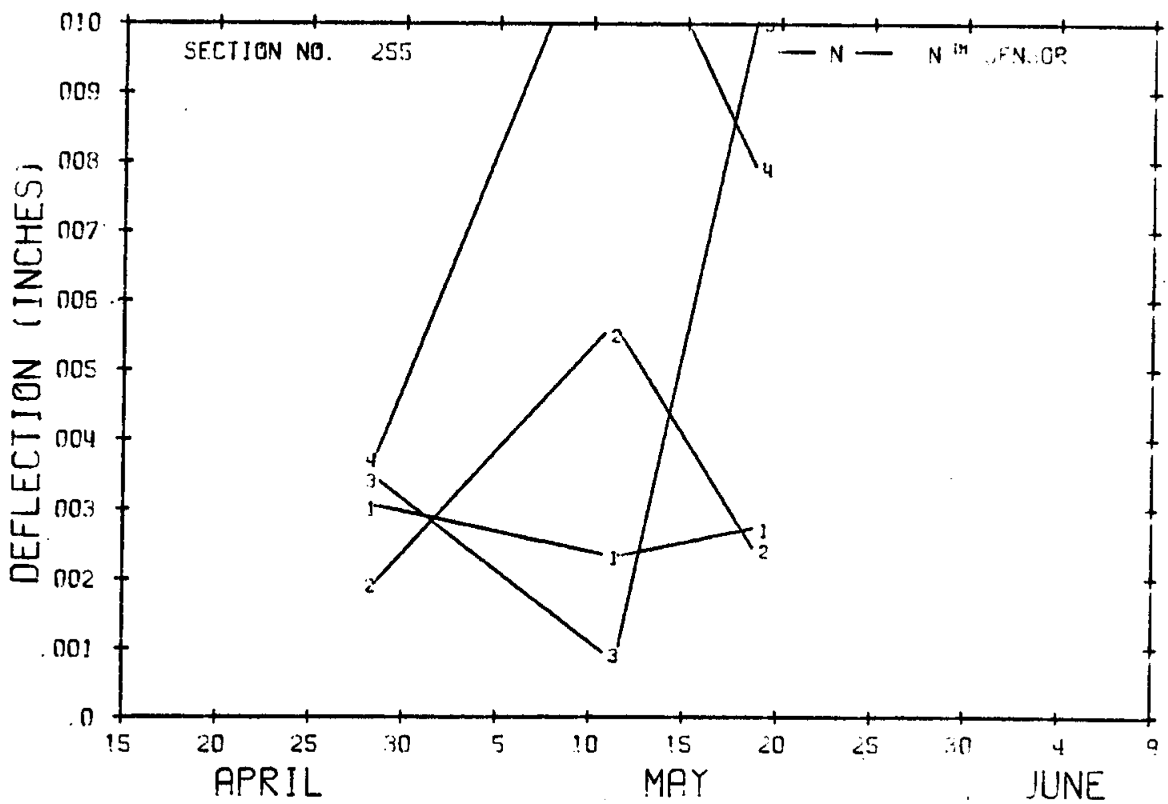
ROAD RATER, DEFLECTIONS VS. TIME



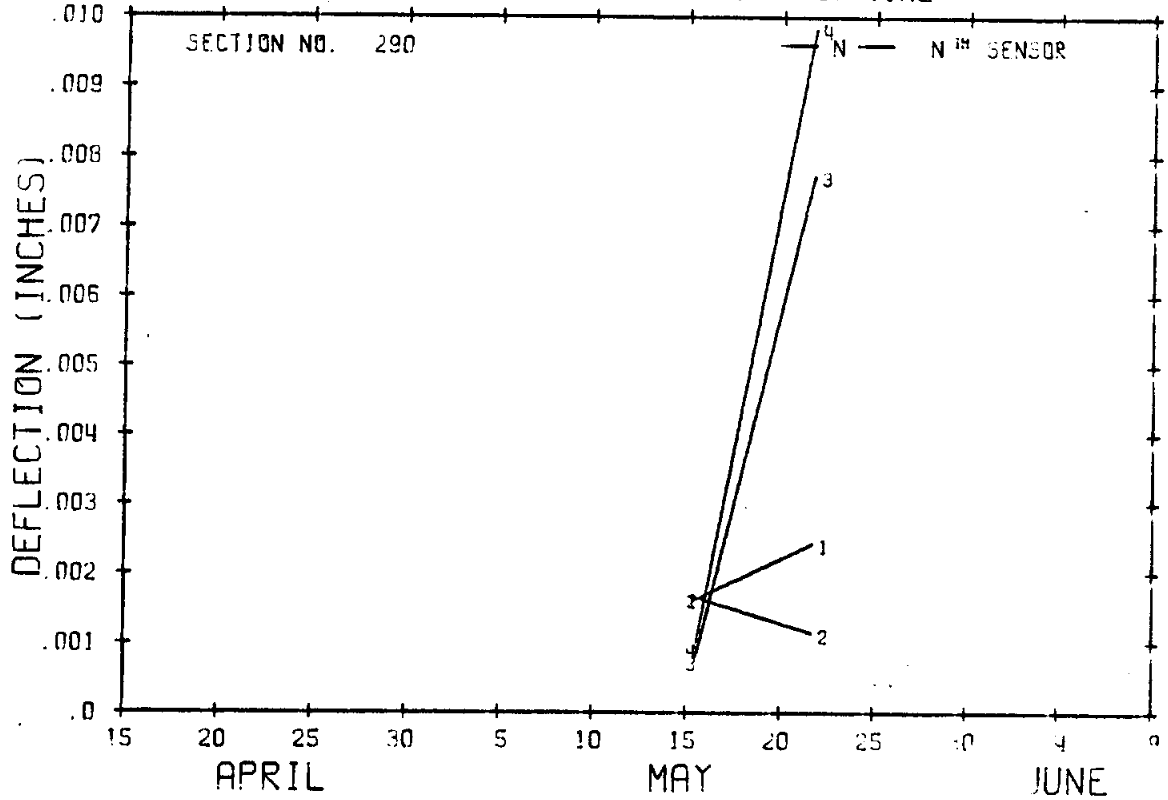


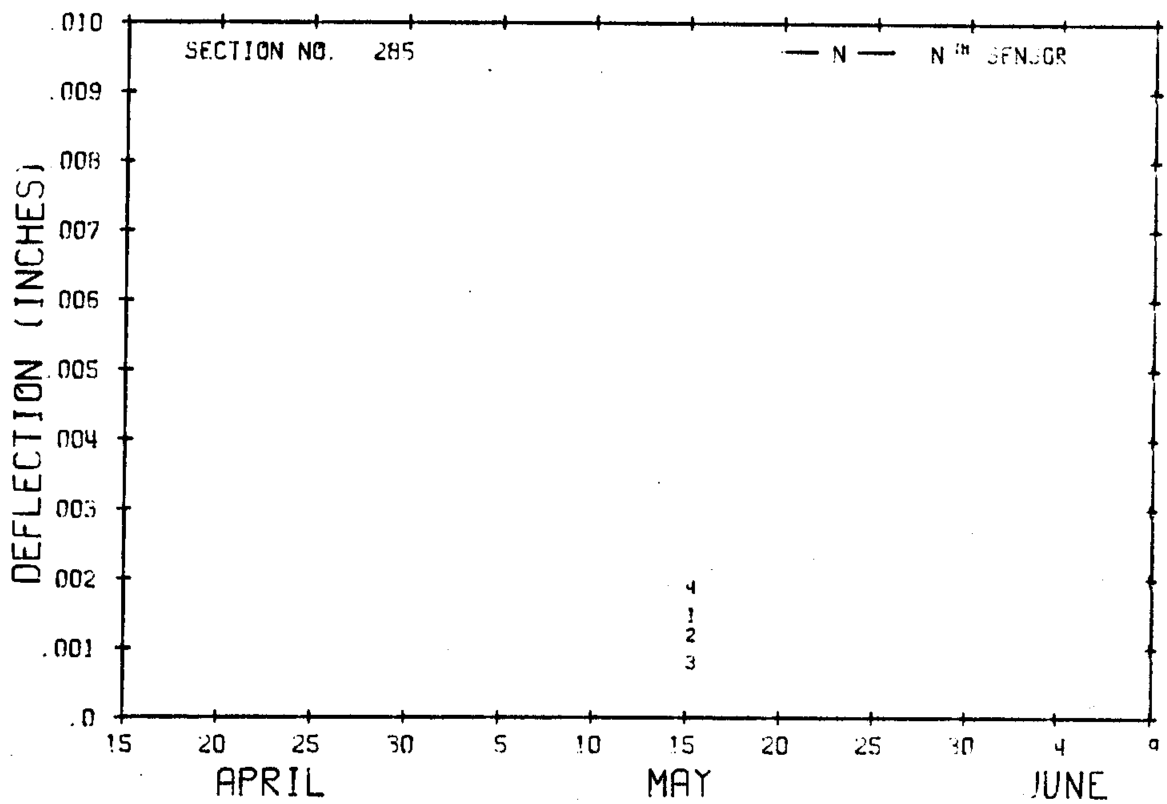
ROAD RATER, DEFLECTIONS VS. TIME



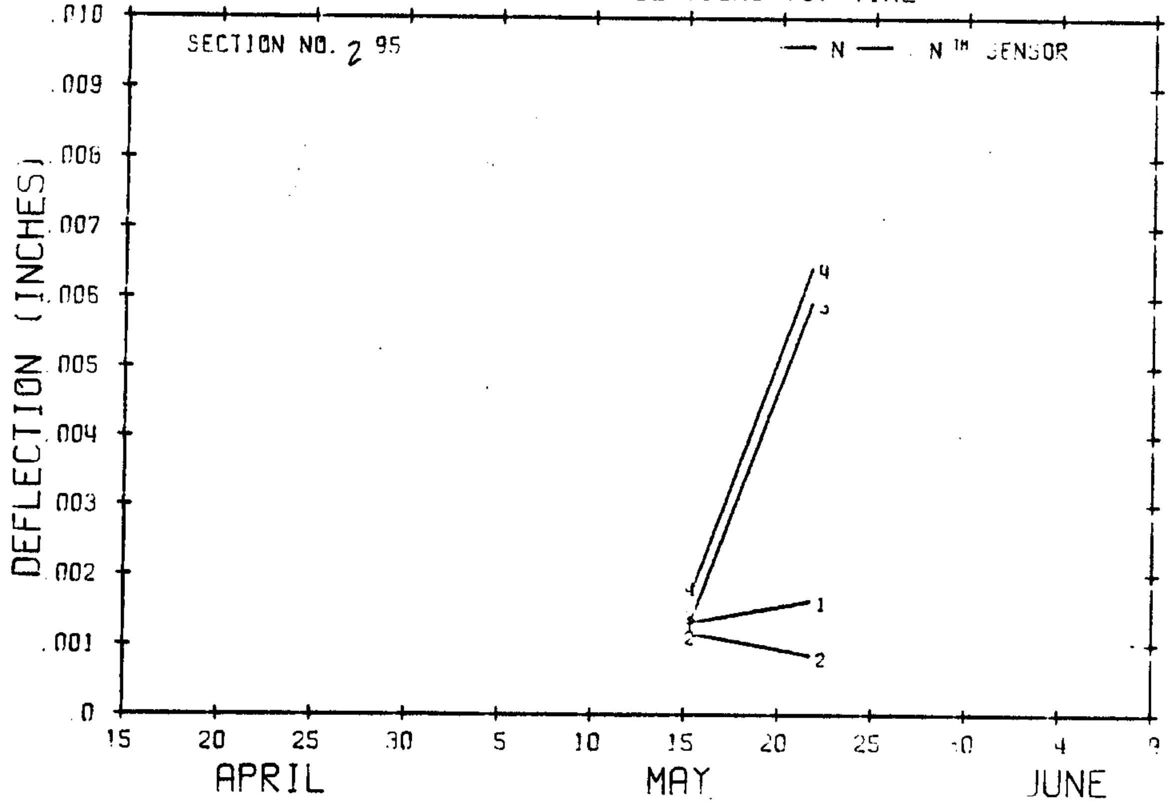


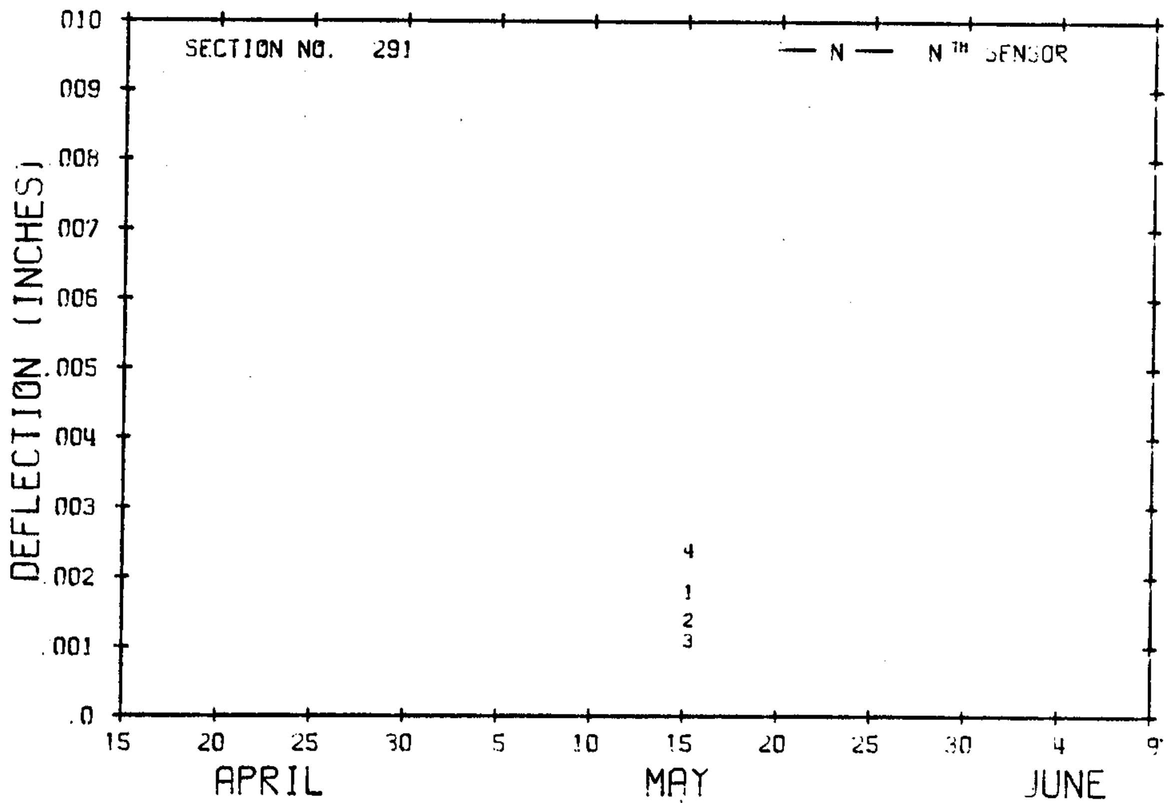
ROAD RATER, DEFLECTIONS VS. TIME



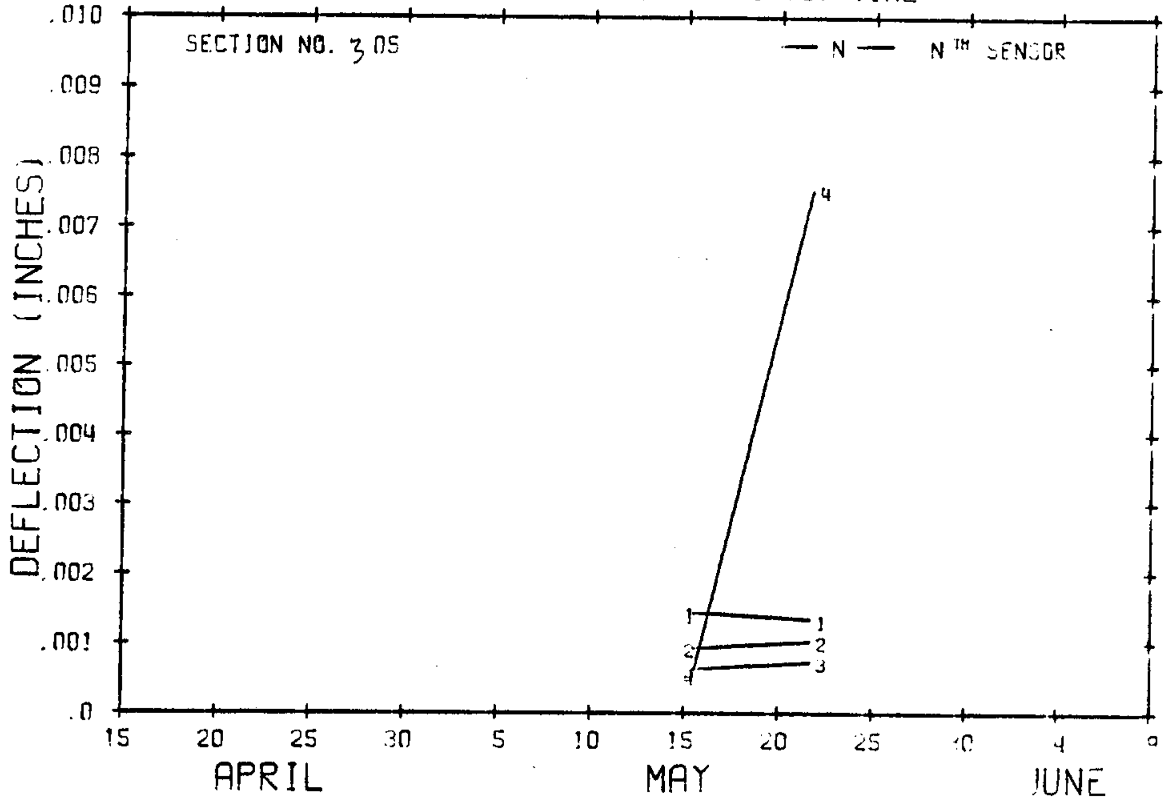


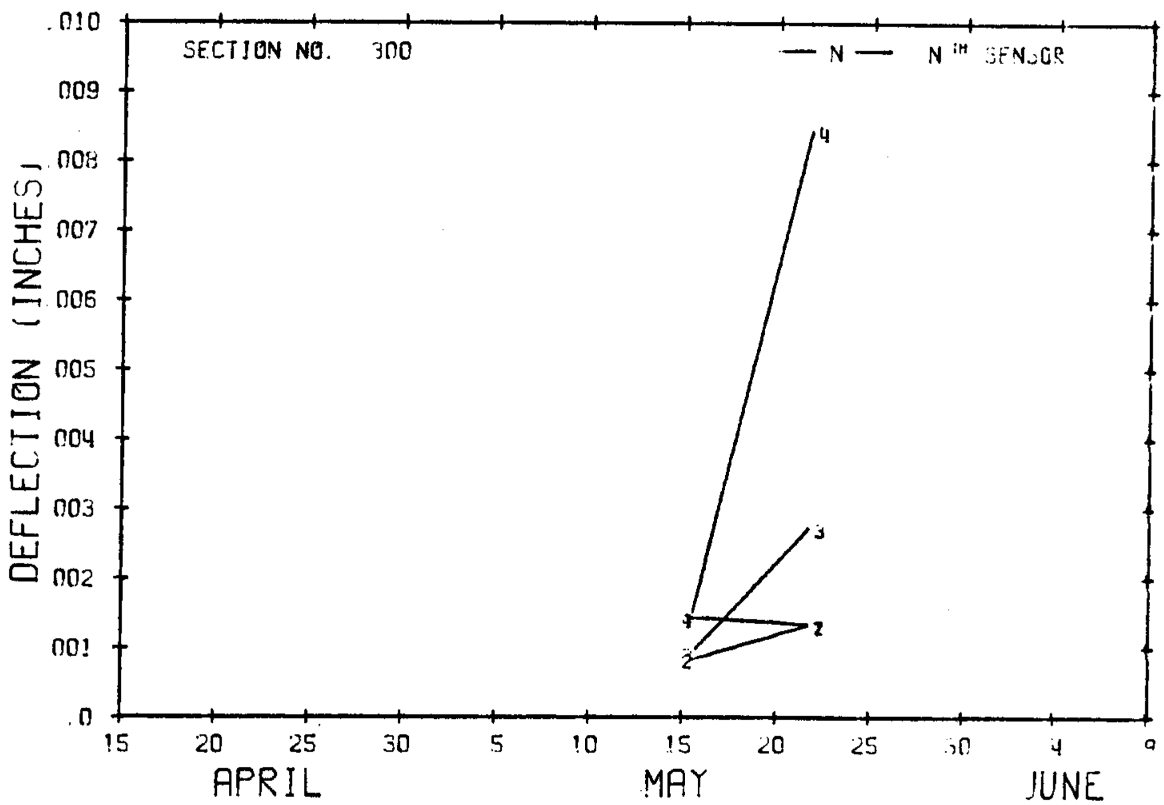
ROAD RATER, DEFLECTIONS VS. TIME



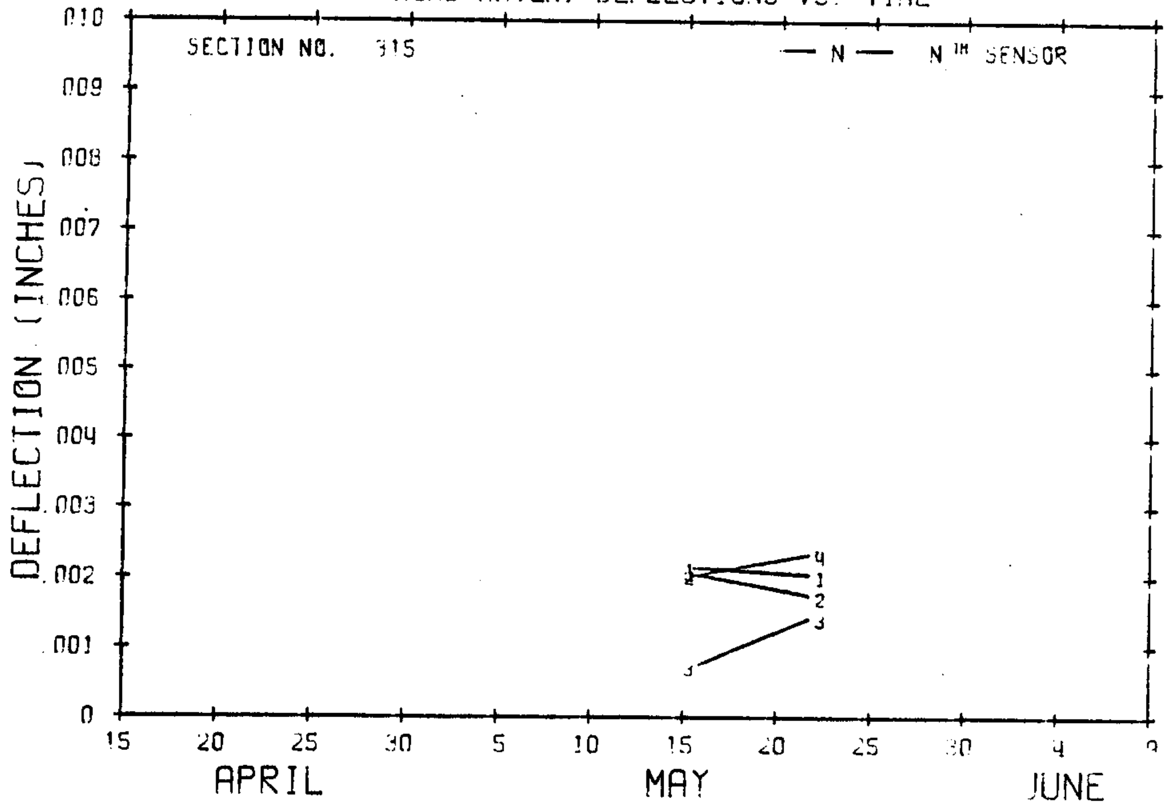


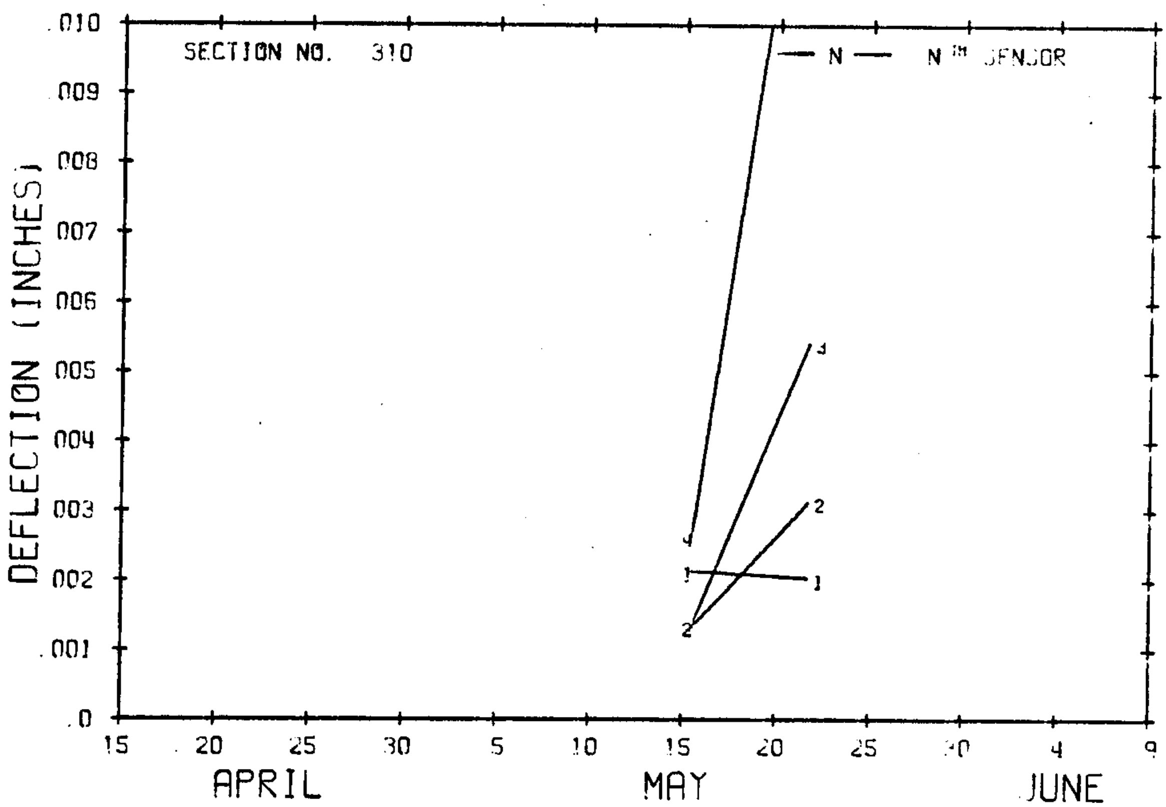
ROAD RATER, DEFLECTIONS VS. TIME

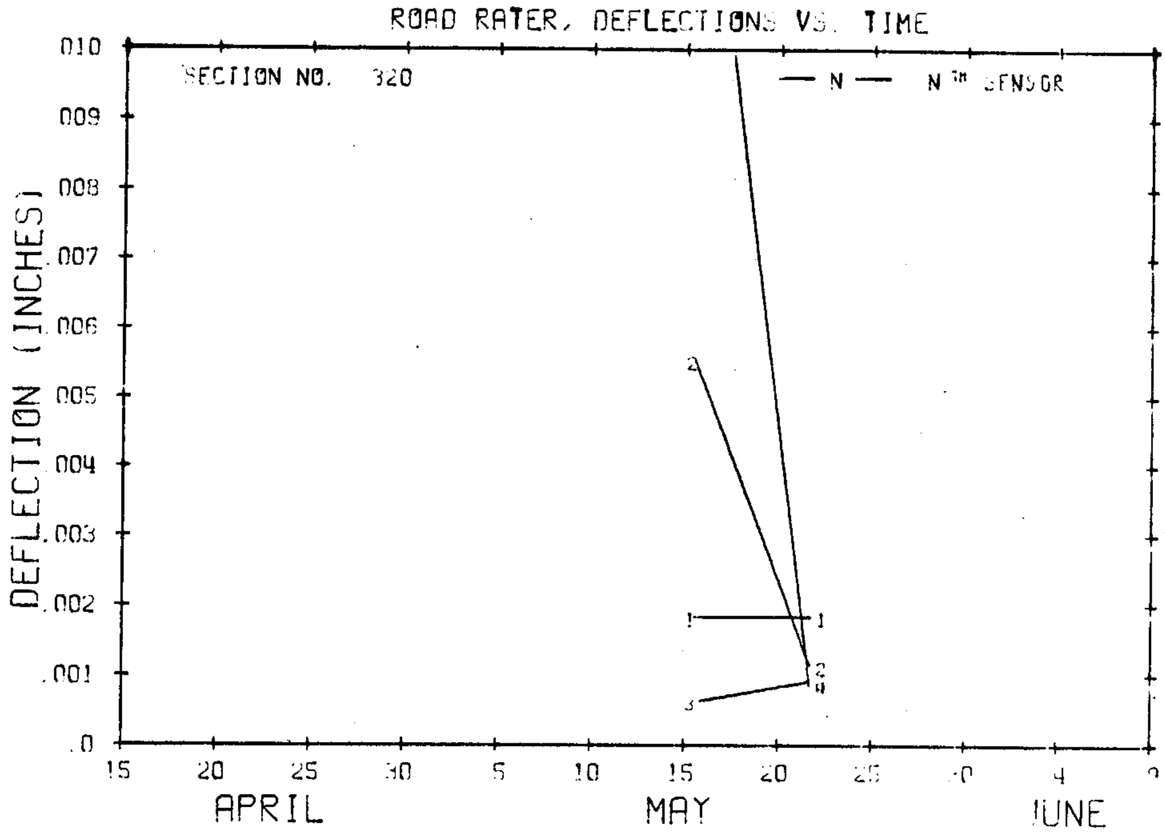


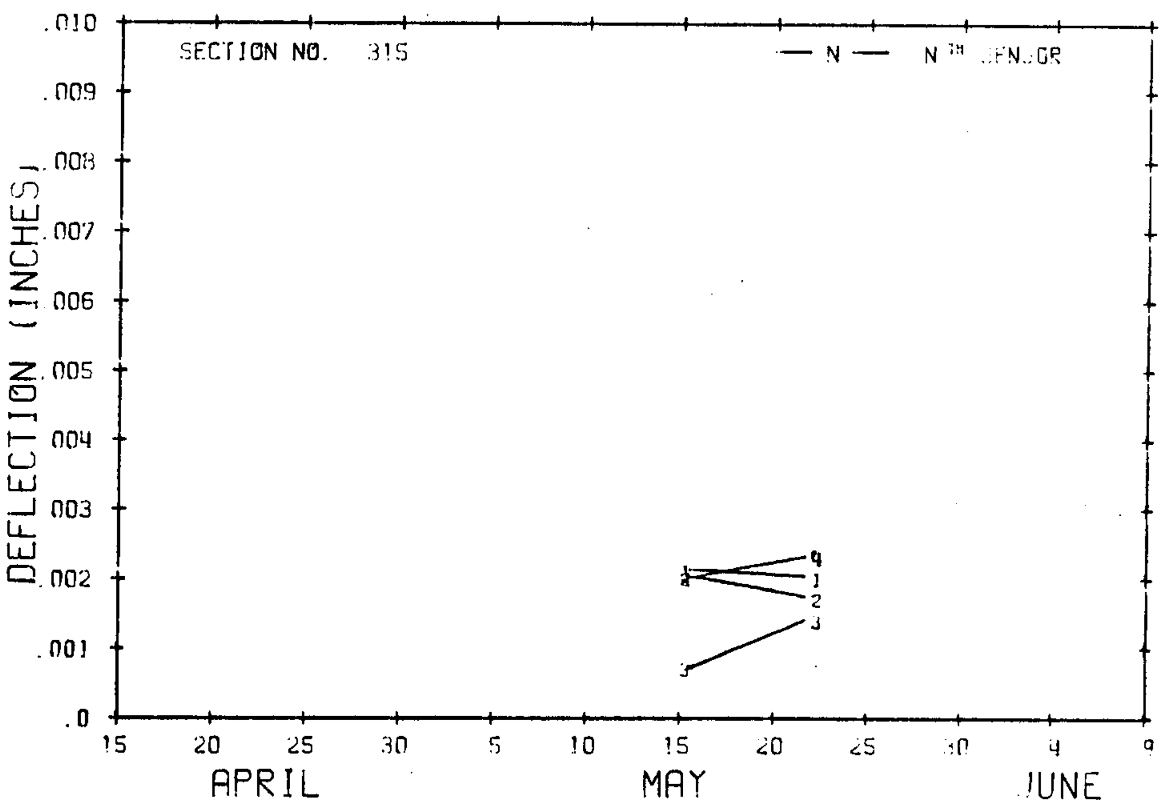


ROAD RATER, DEFLECTIONS VS. TIME

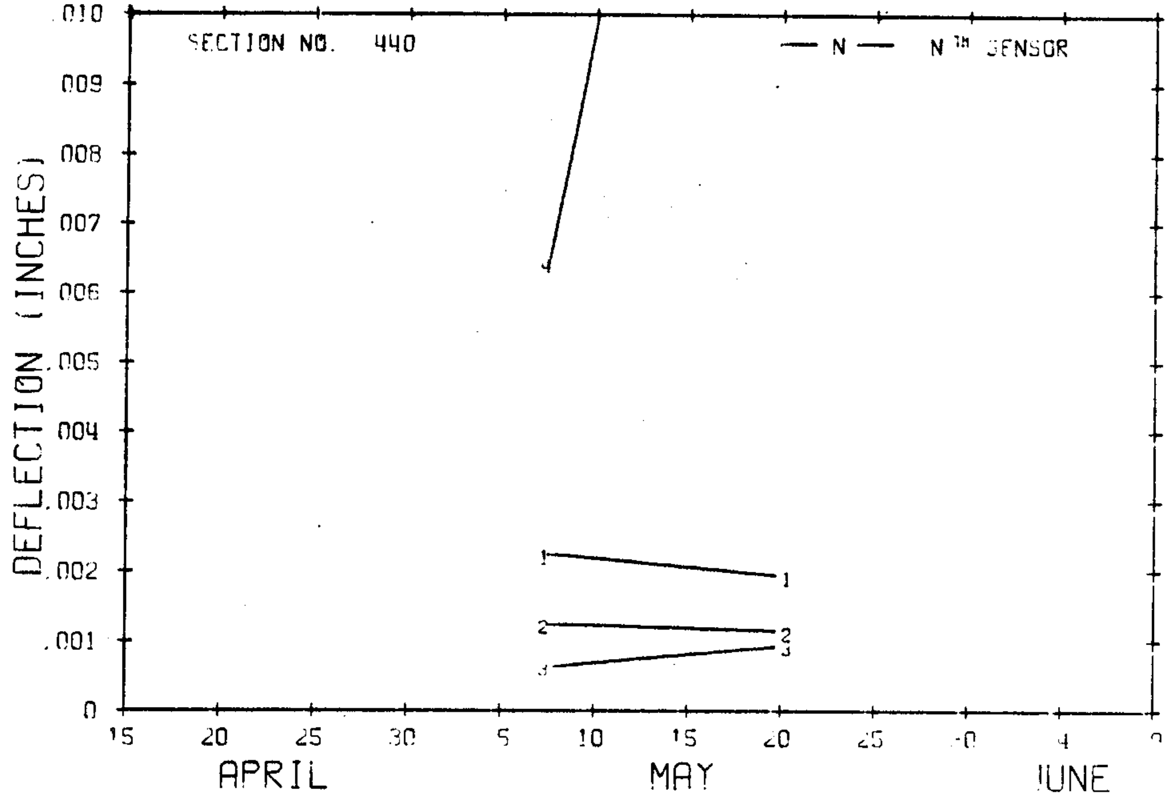


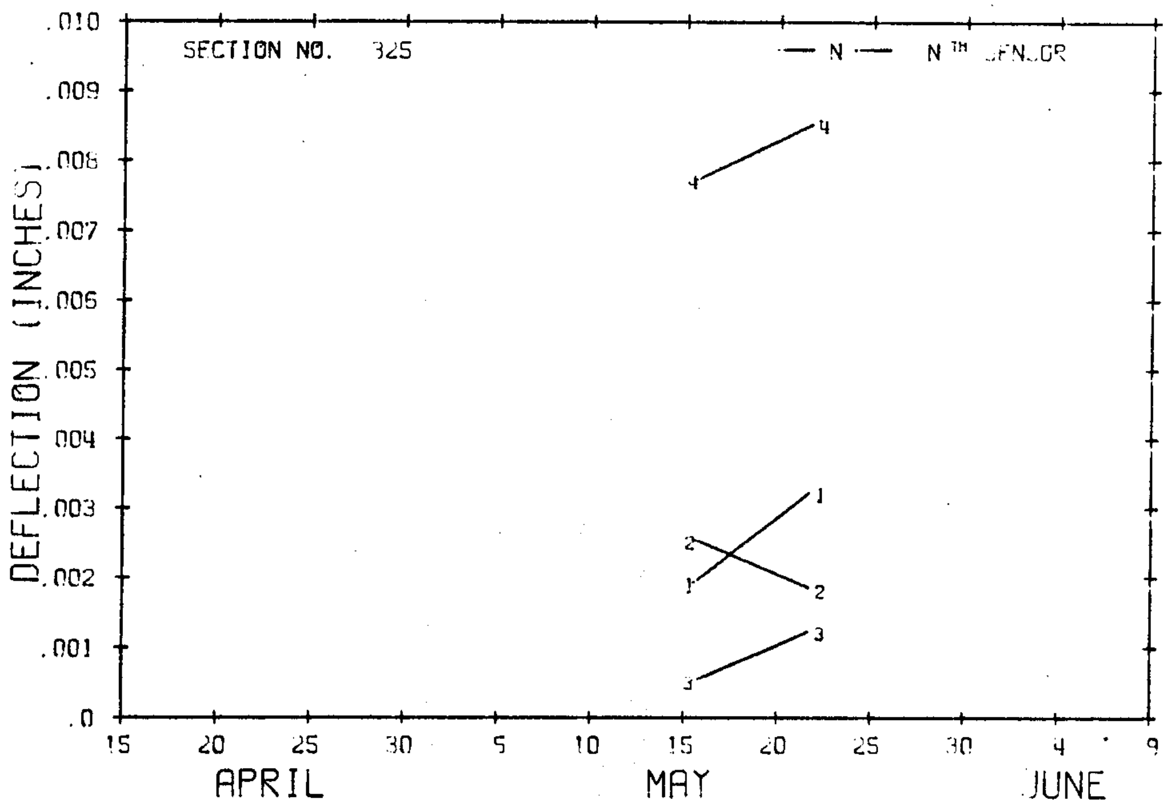



ROAD RATER, DEFLECTIONS VS. TIME
SECTION NO. 320
— N — N TH SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15
20
25
30
5
10
15
20
APRIL
MAY
JUNE

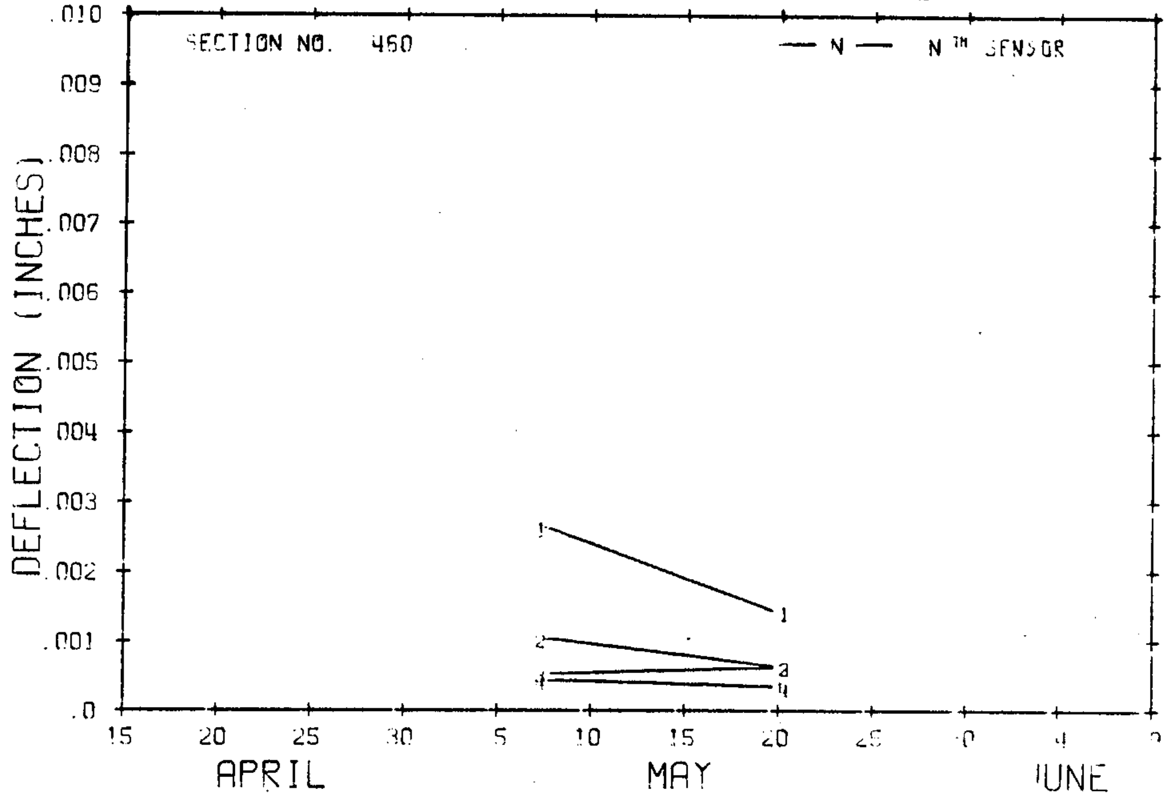

SECTION NO. 315
— N — N TH SENSOR
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15
20
25
30
5
10
15
20
25
4
9
APRIL
MAY
JUNE

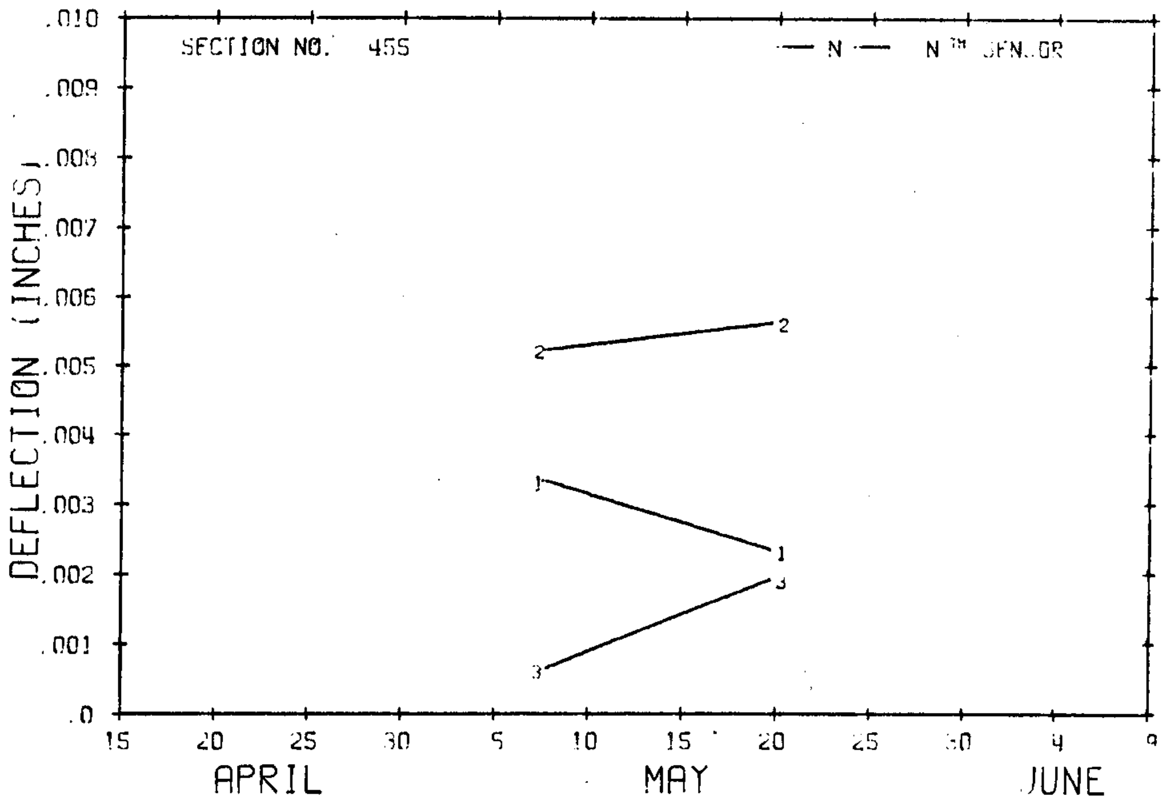
ROAD RATER, DEFLECTIONS VS. TIME



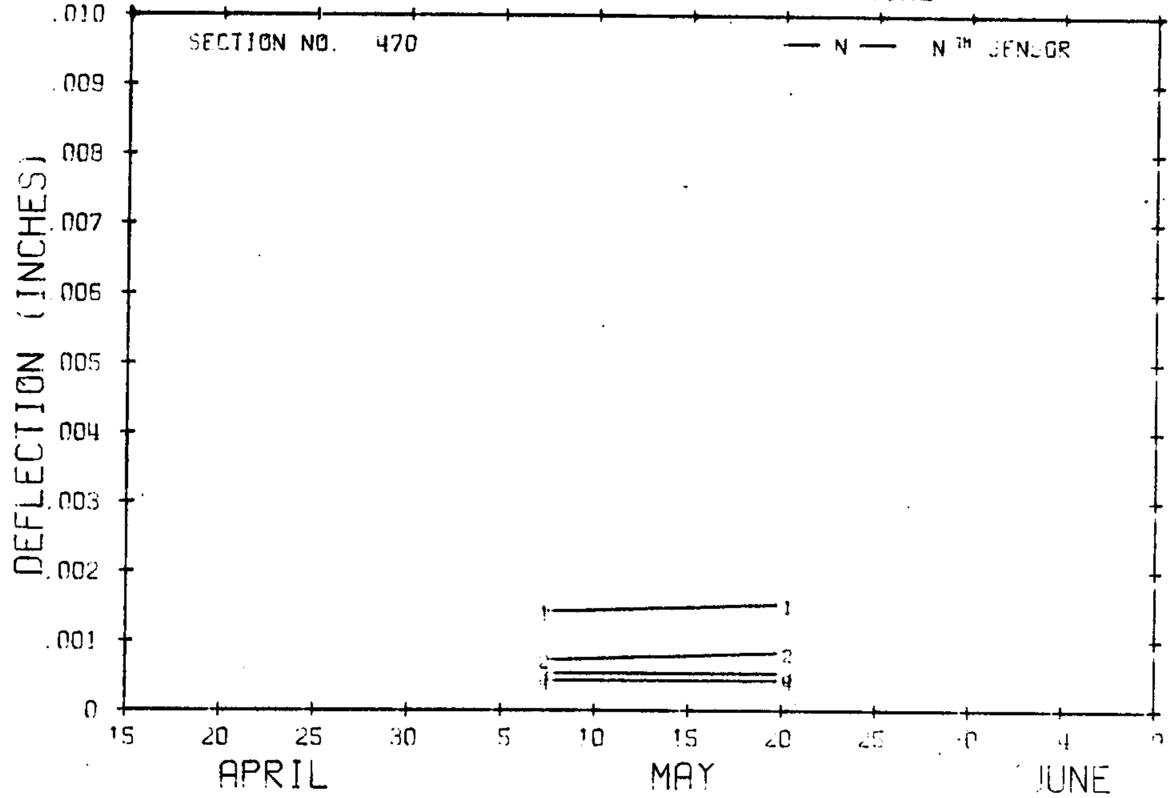


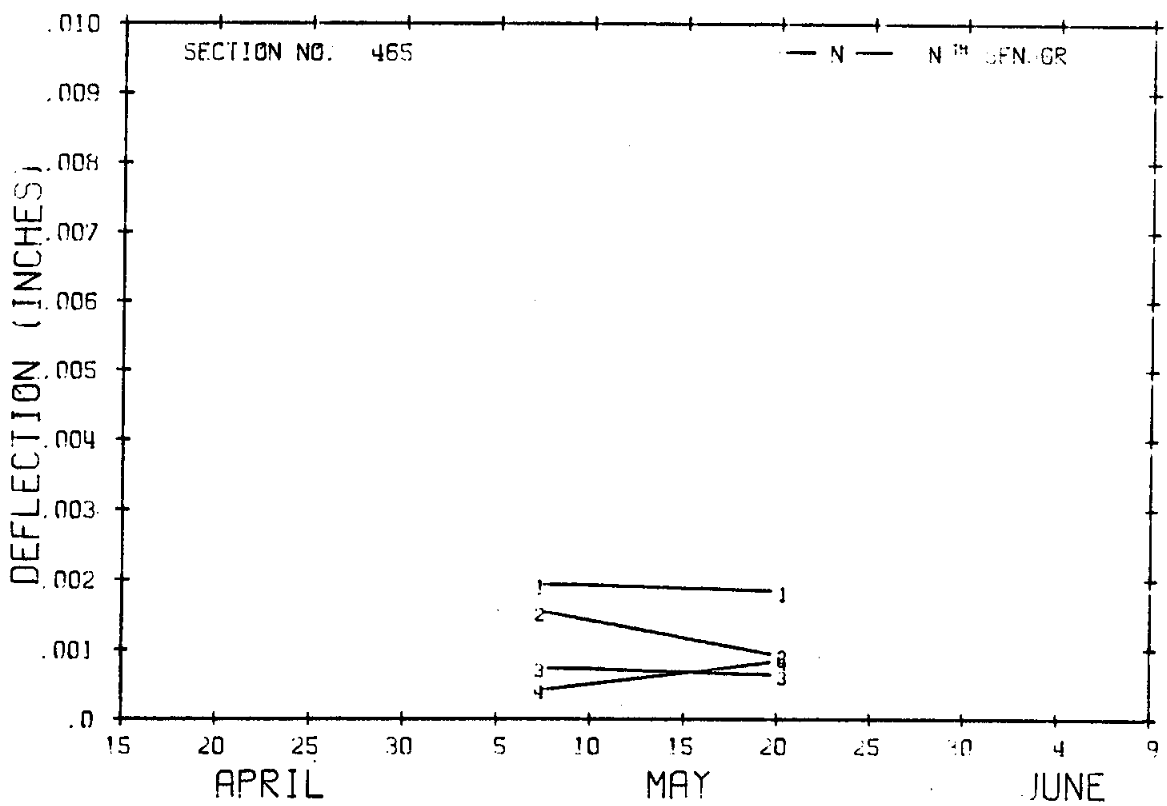
ROAD RATER, DEFLECTIONS VS. TIME



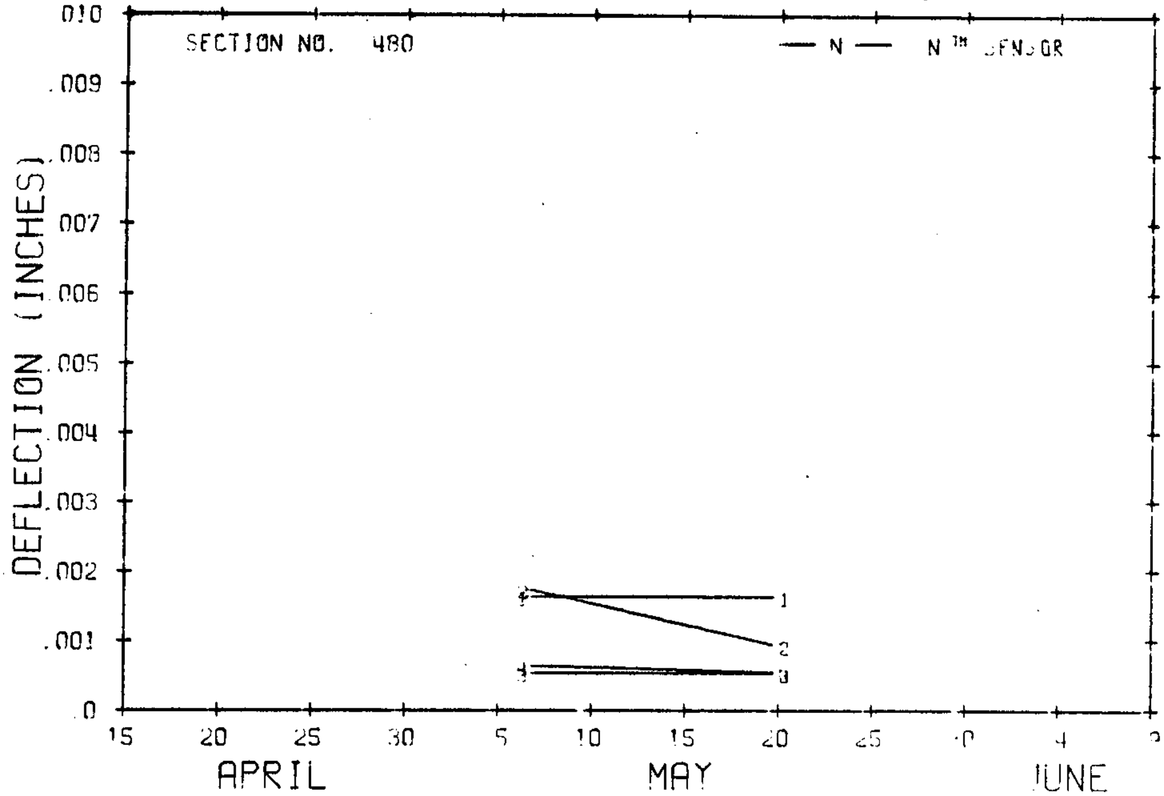


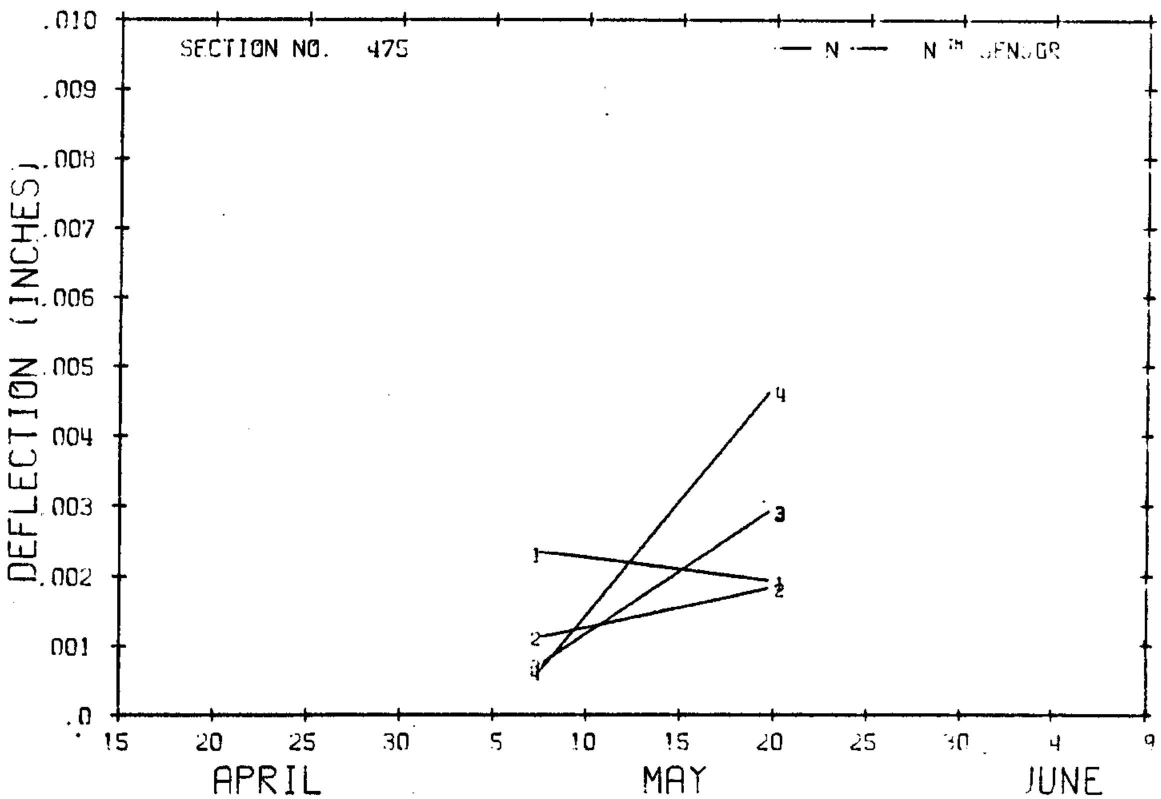
ROAD RATER, DEFLECTIONS VS. TIME



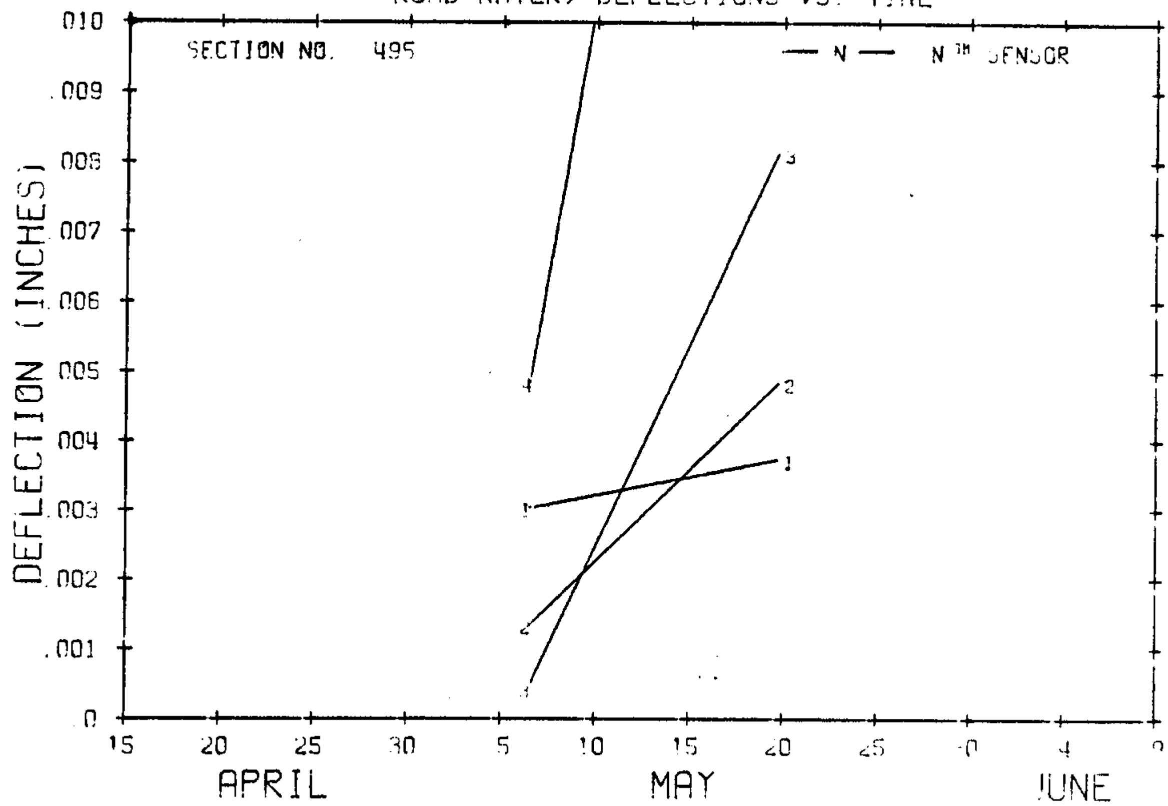


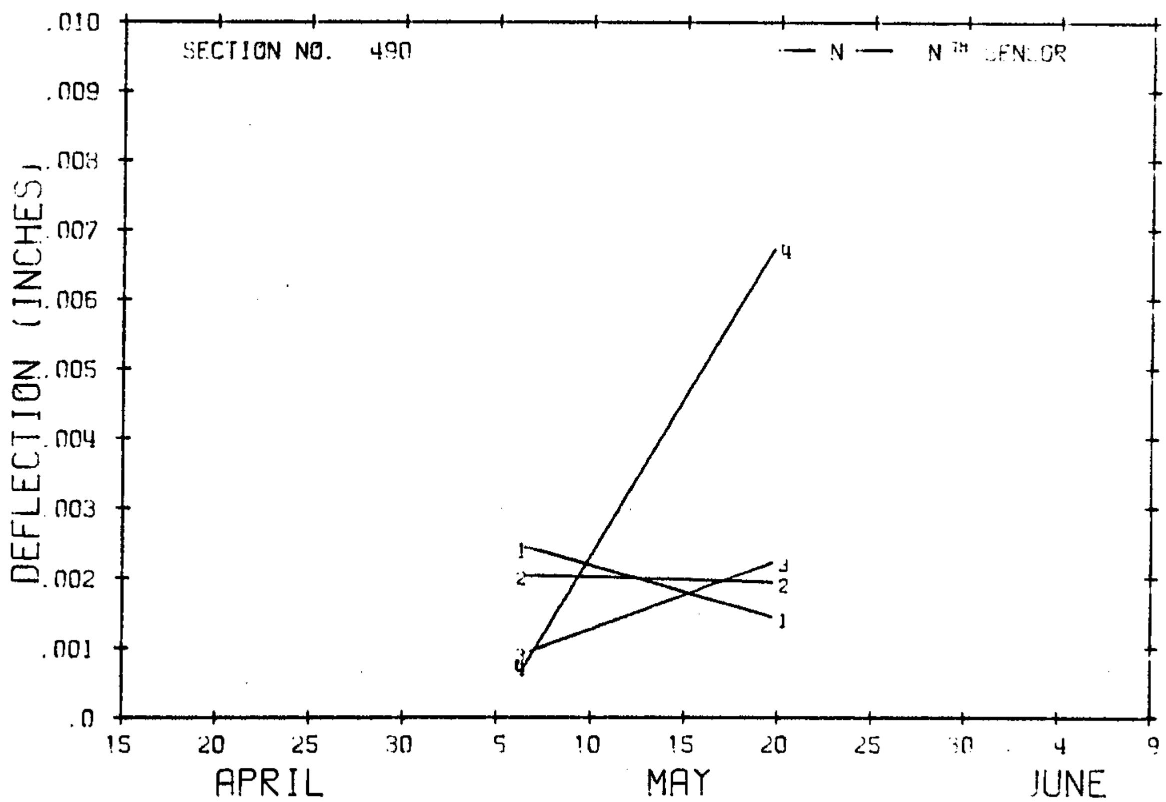
ROAD RATER, DEFLECTIONS VS. TIME



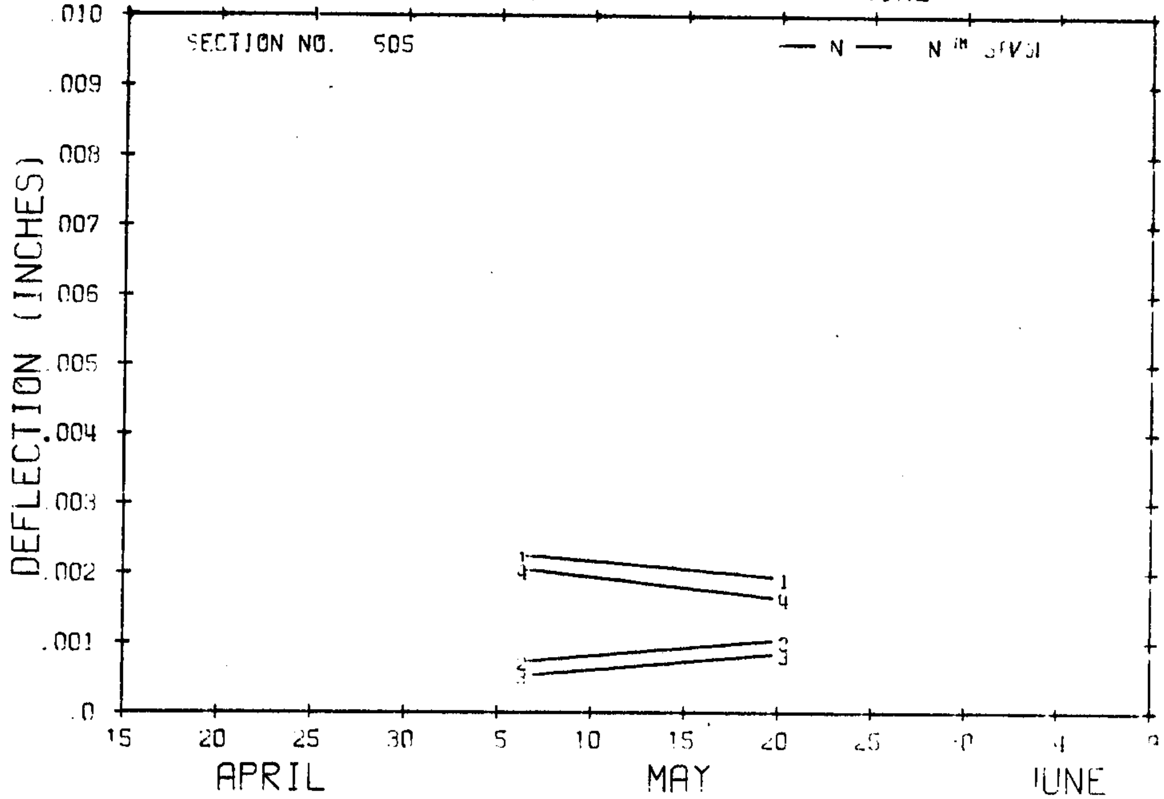


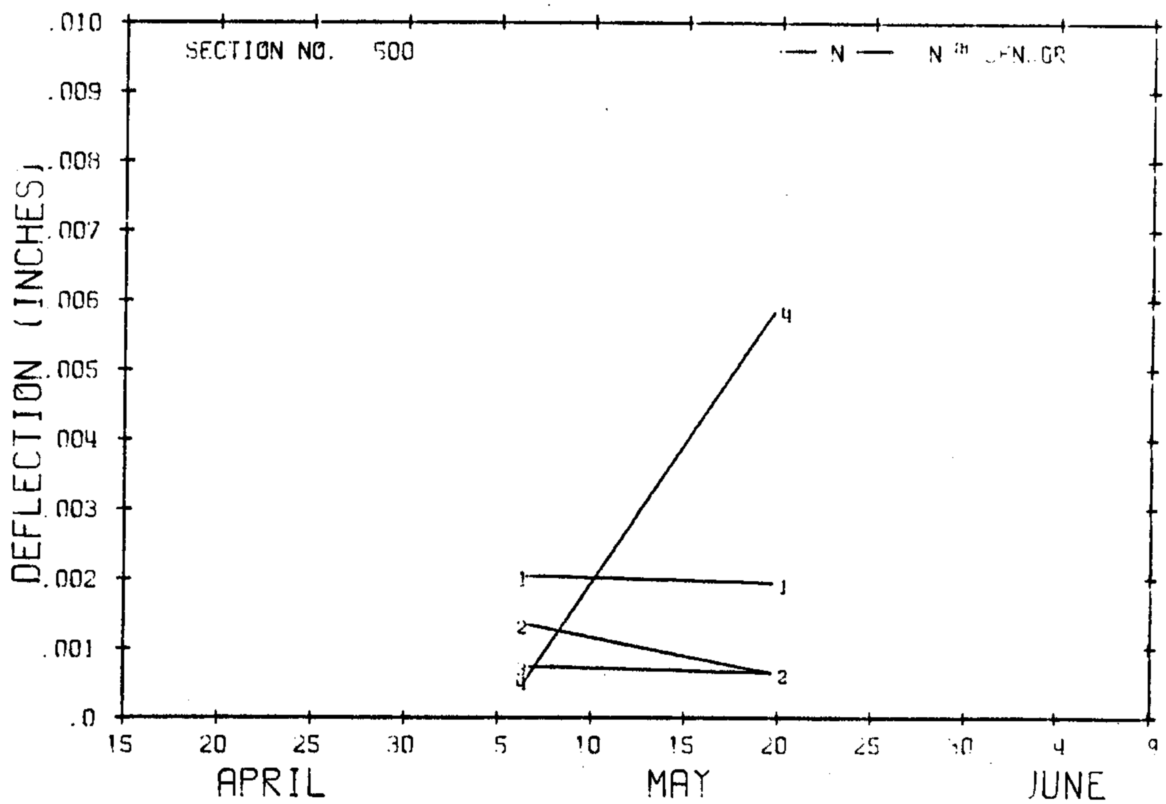
ROAD RATER, DEFLECTIONS VS. TIME



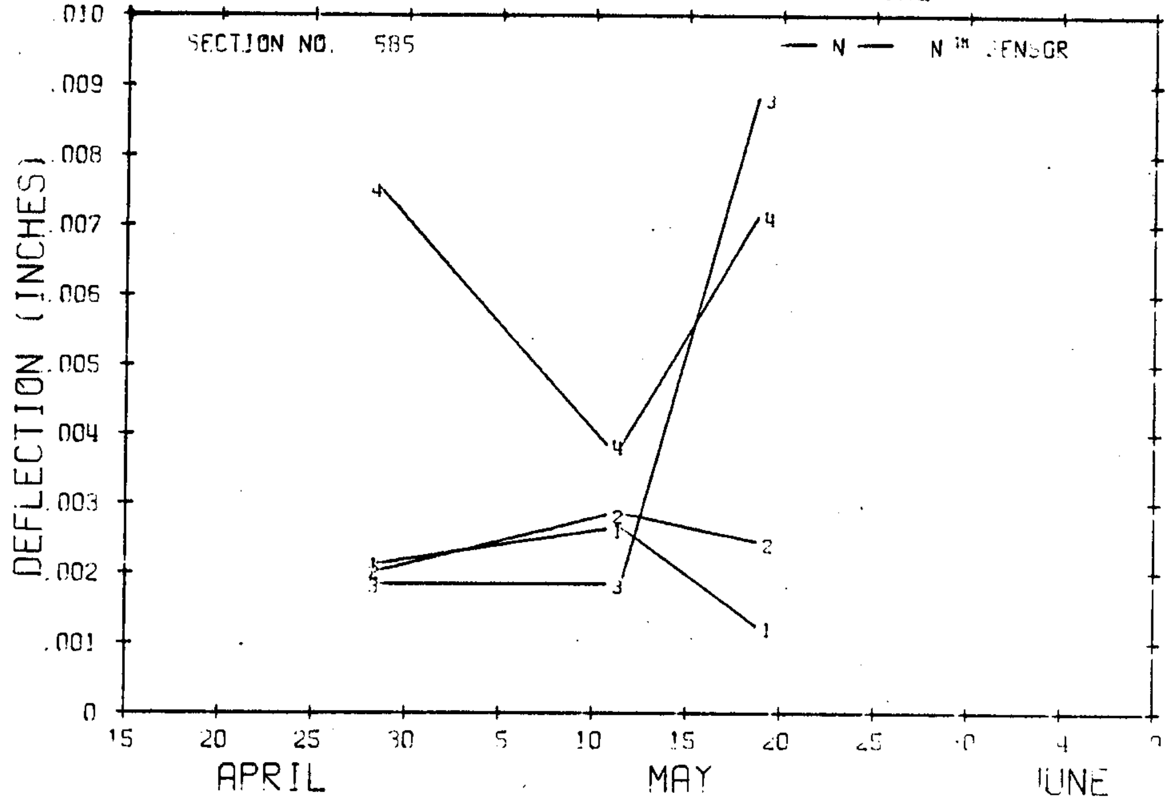


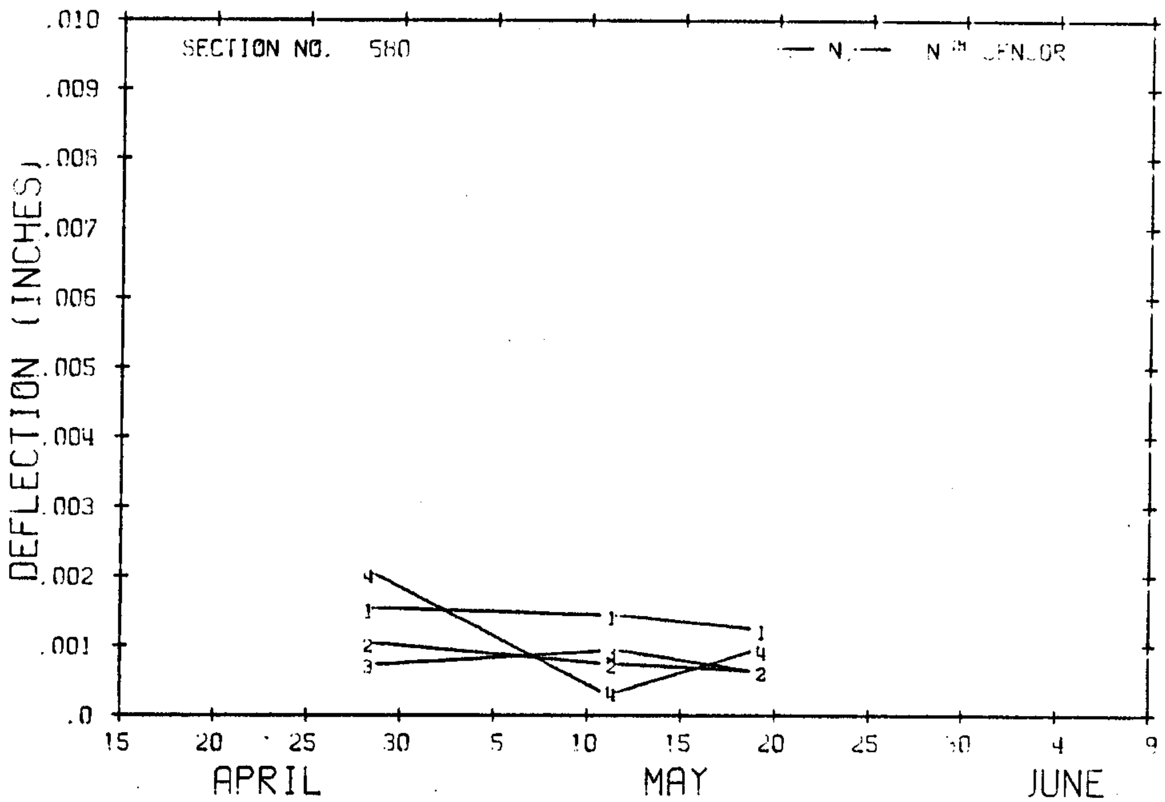
ROAD RATER, DEFLECTIONS VS. TIME



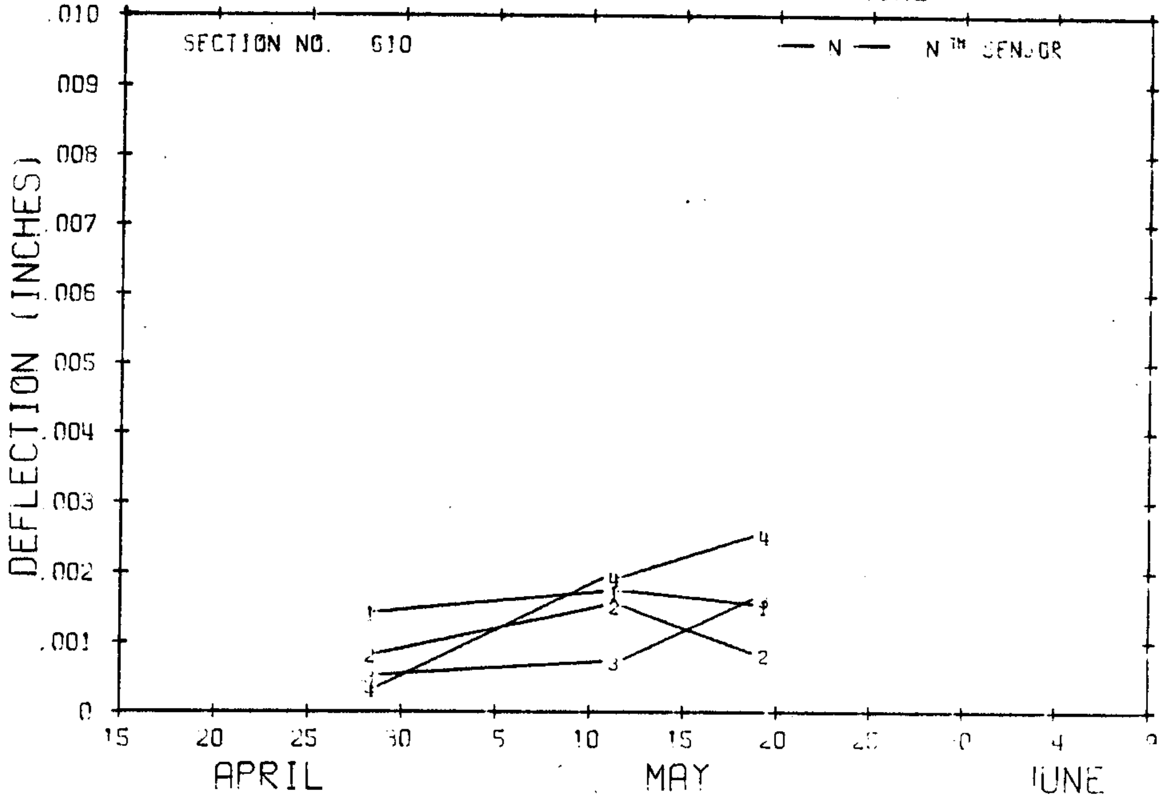


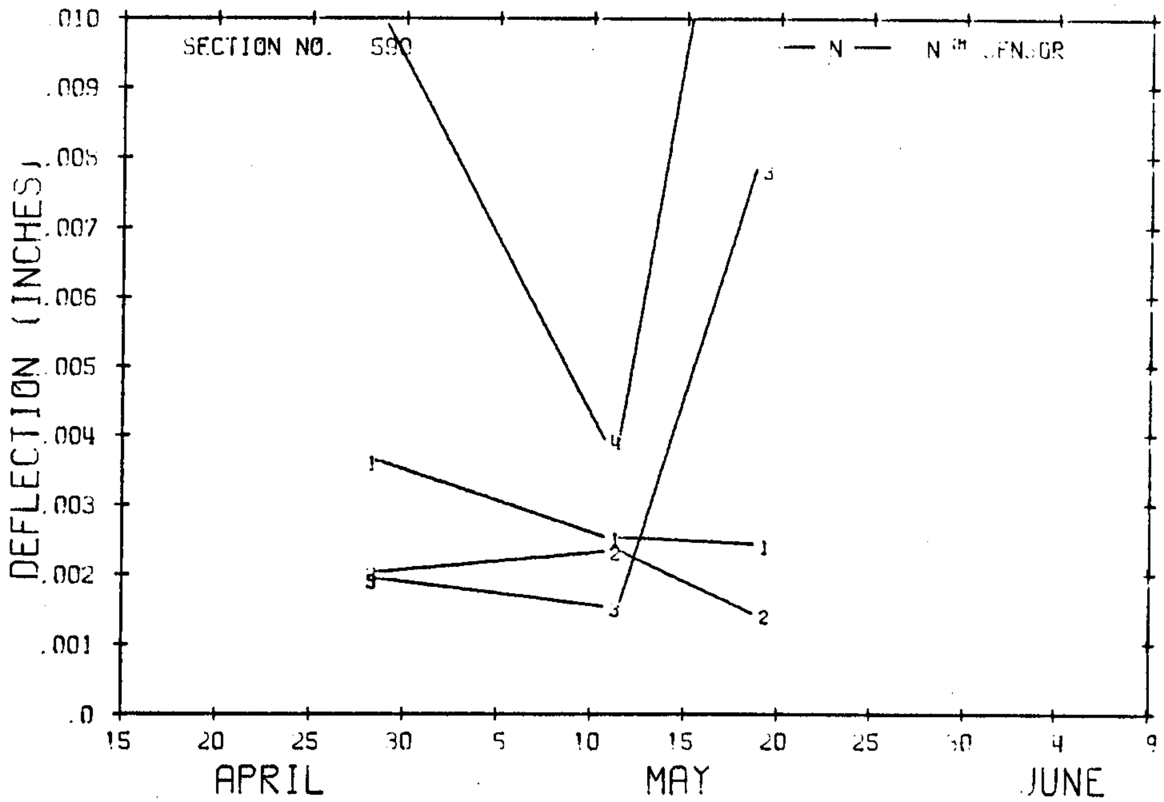
ROAD RATER, DEFLECTIONS VS. TIME

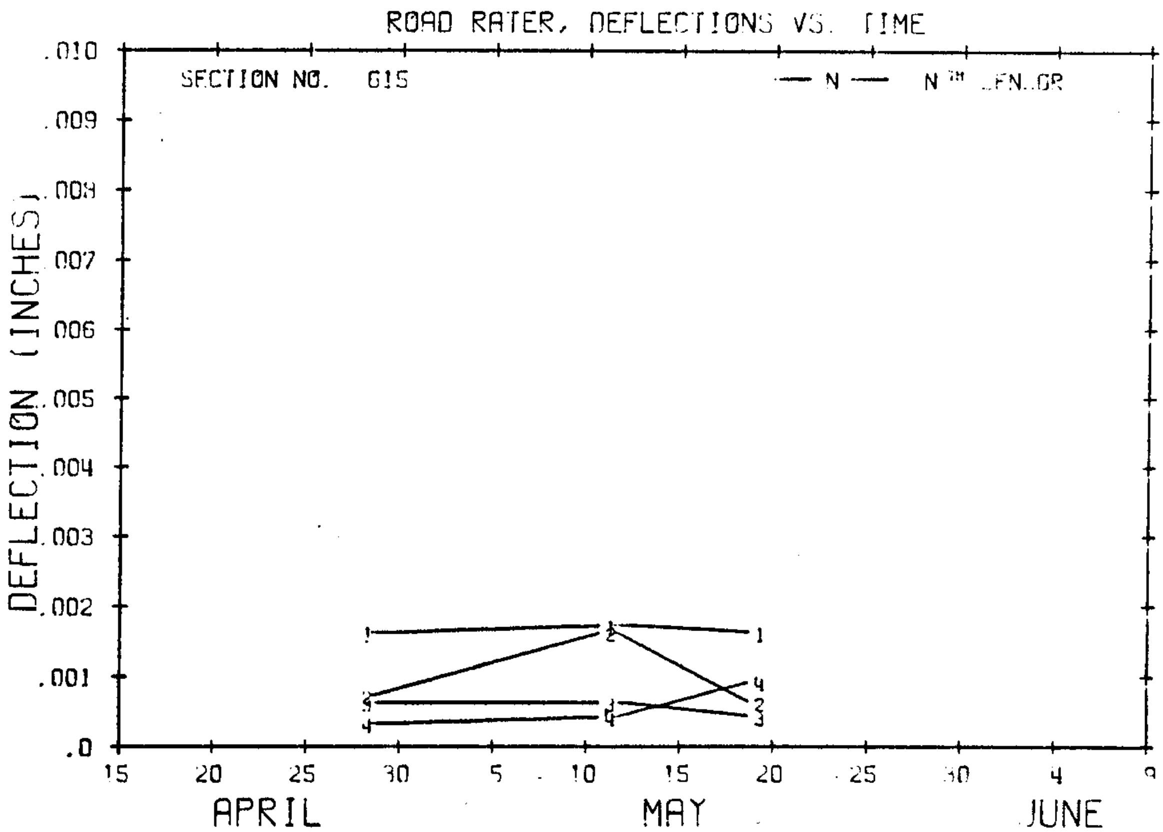




ROAD RATER, DEFLECTIONS VS. TIME

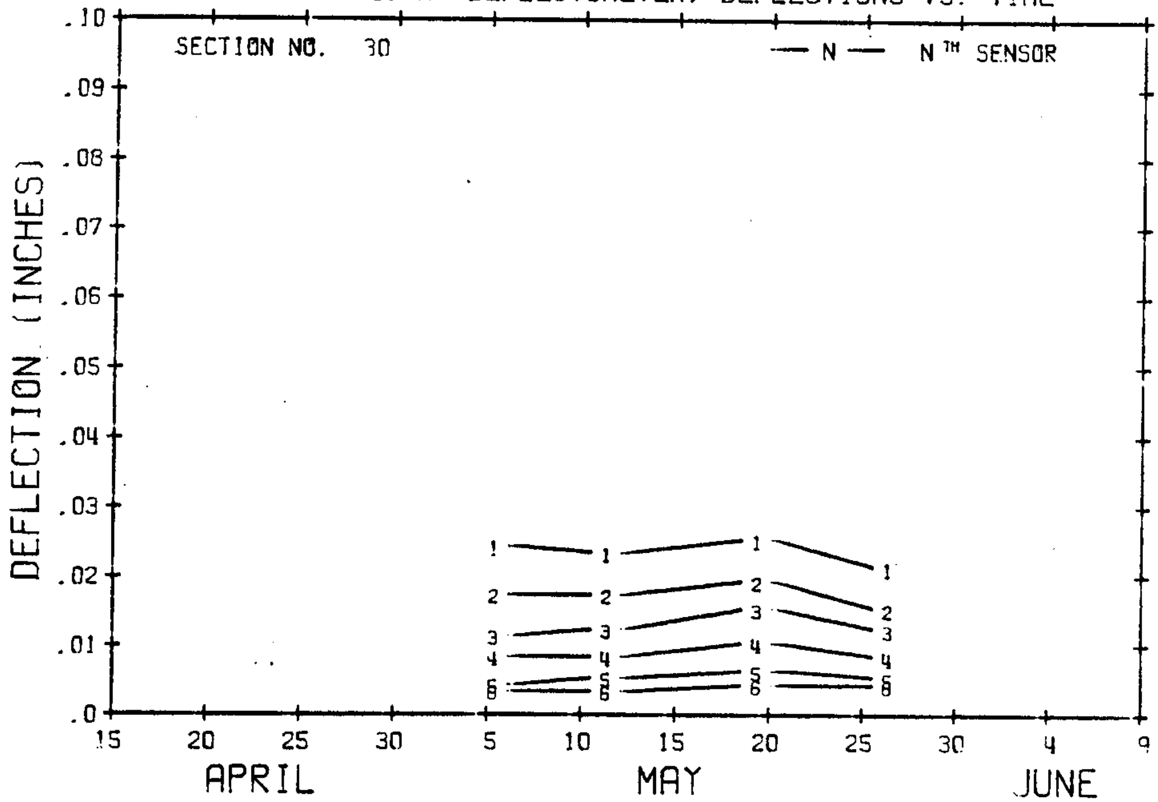


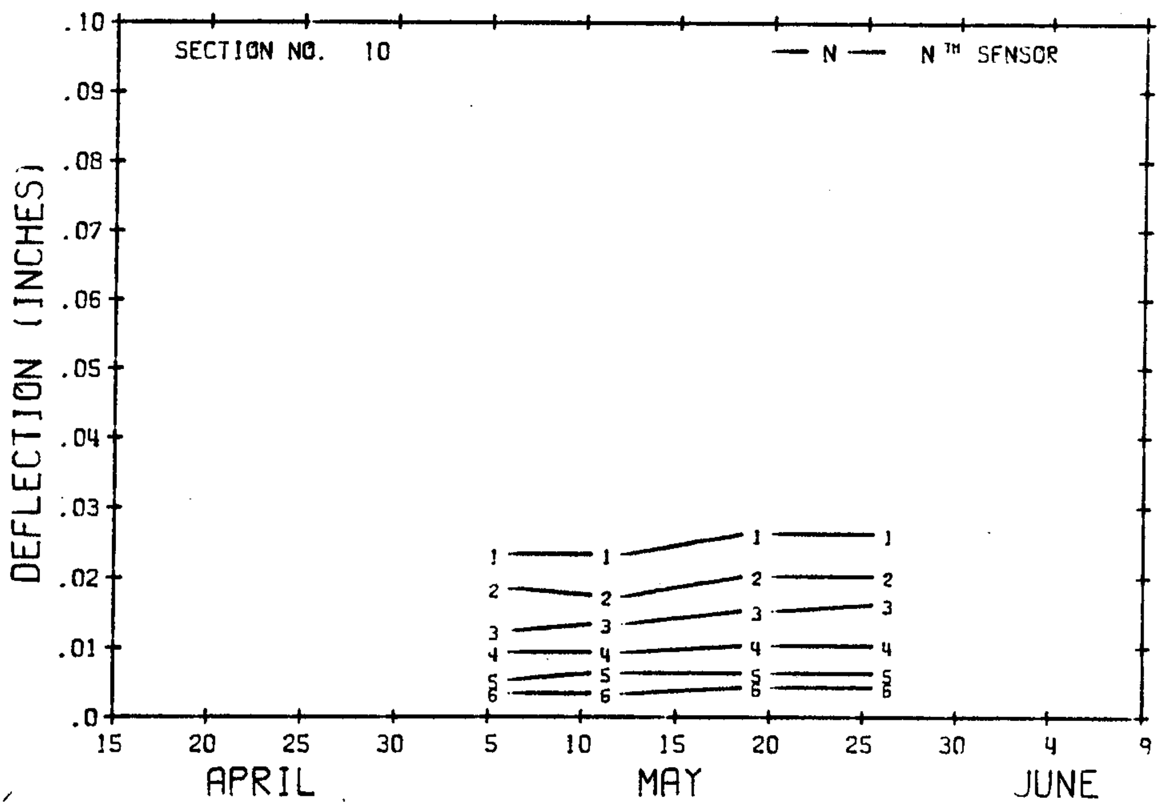




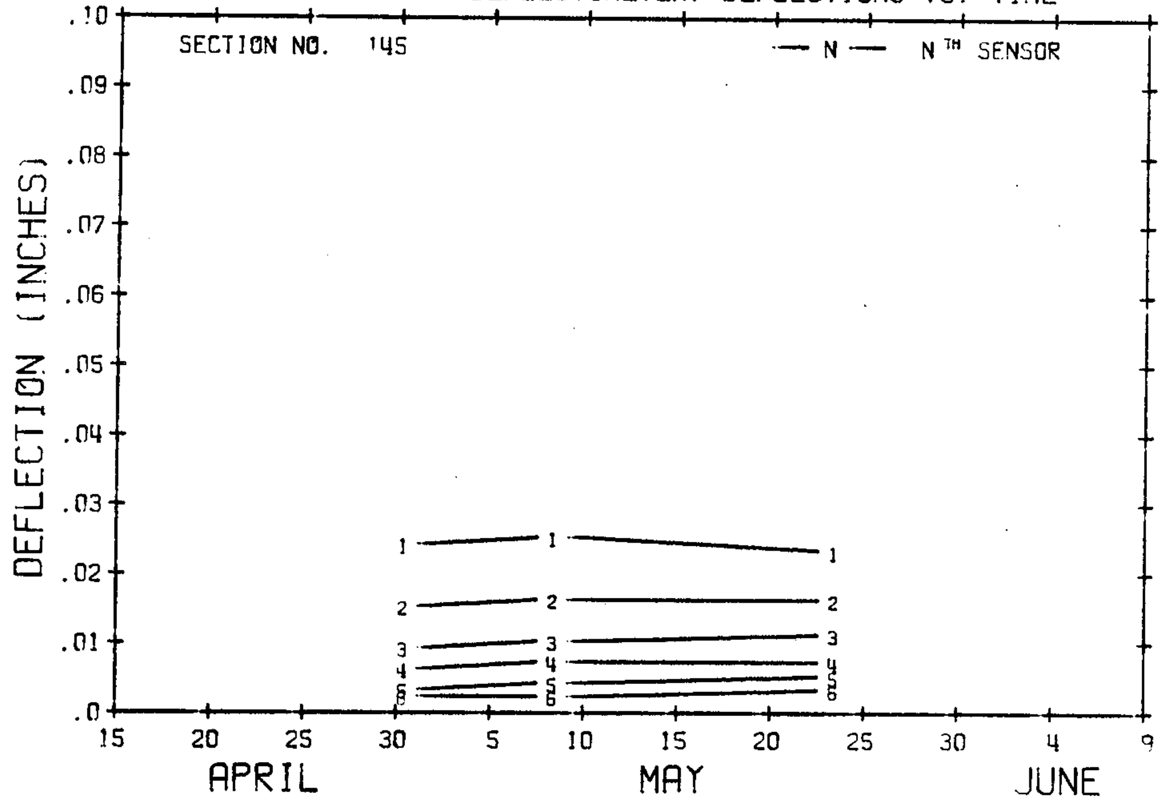
ROAD RATER, DEFLECTIONS VS. TIME
SECTION NO. 615
DEFLECTION (INCHES)
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

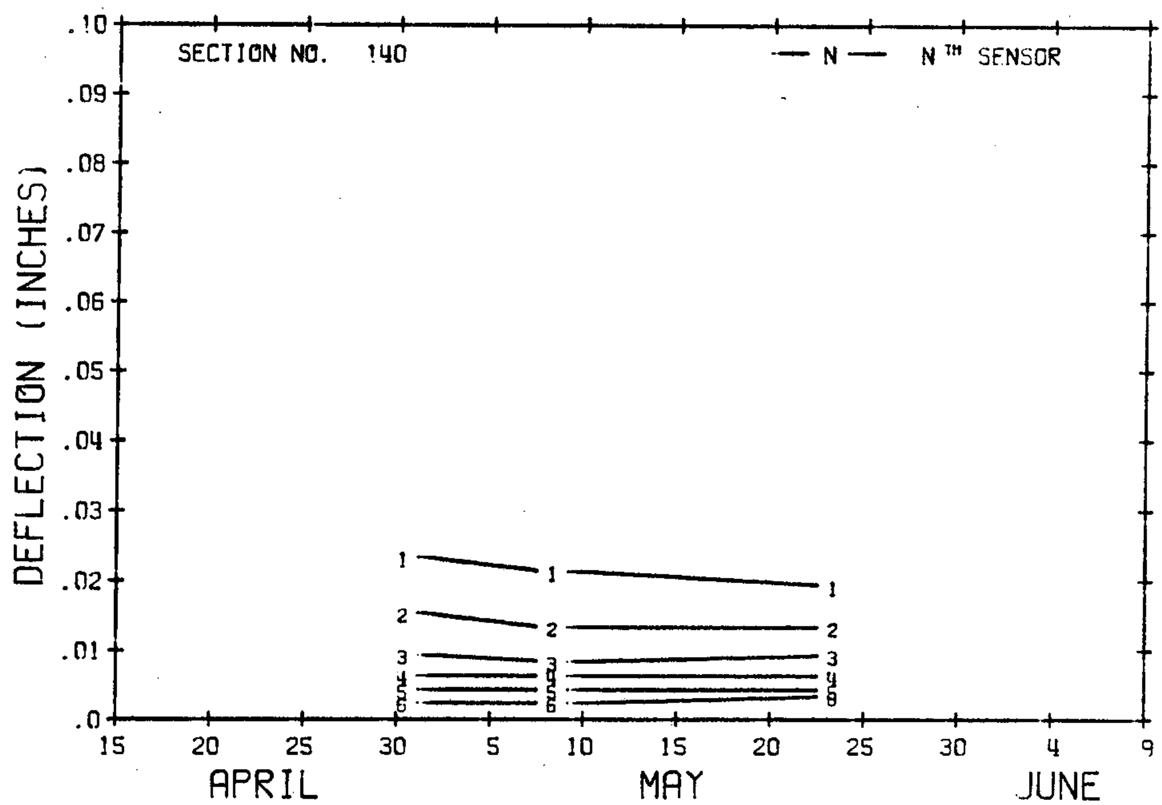
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME



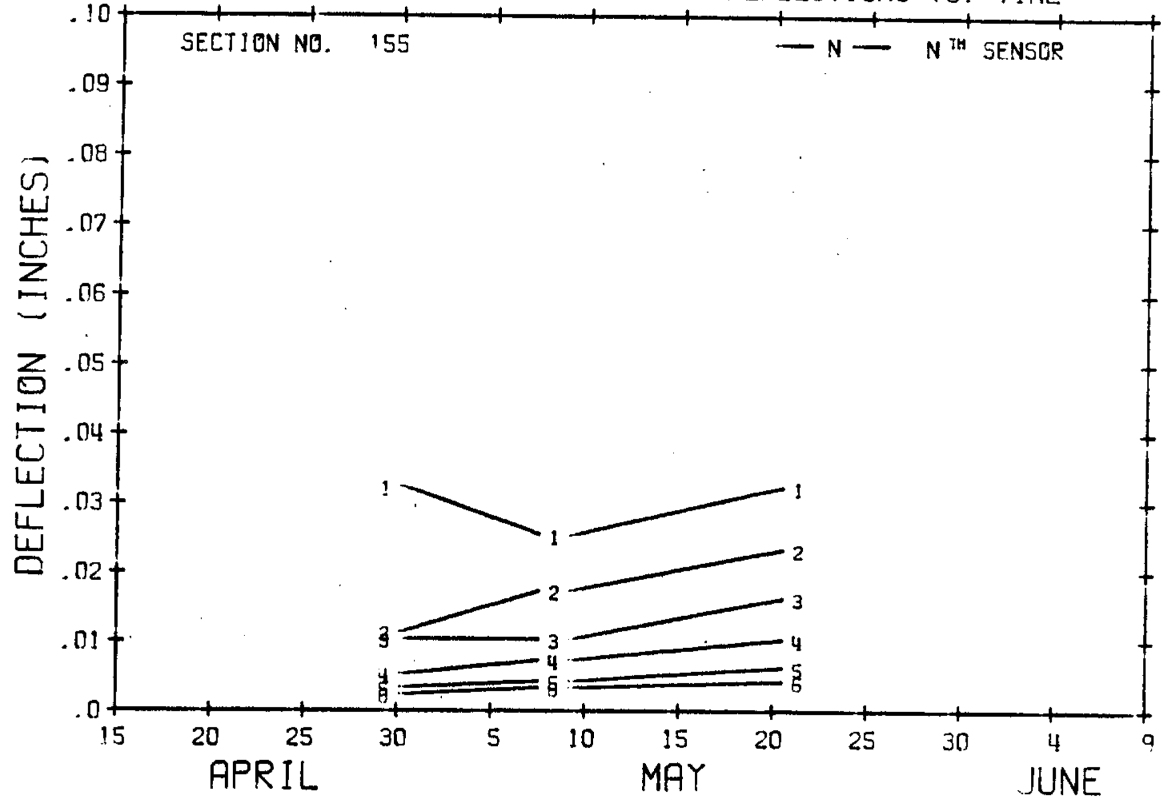


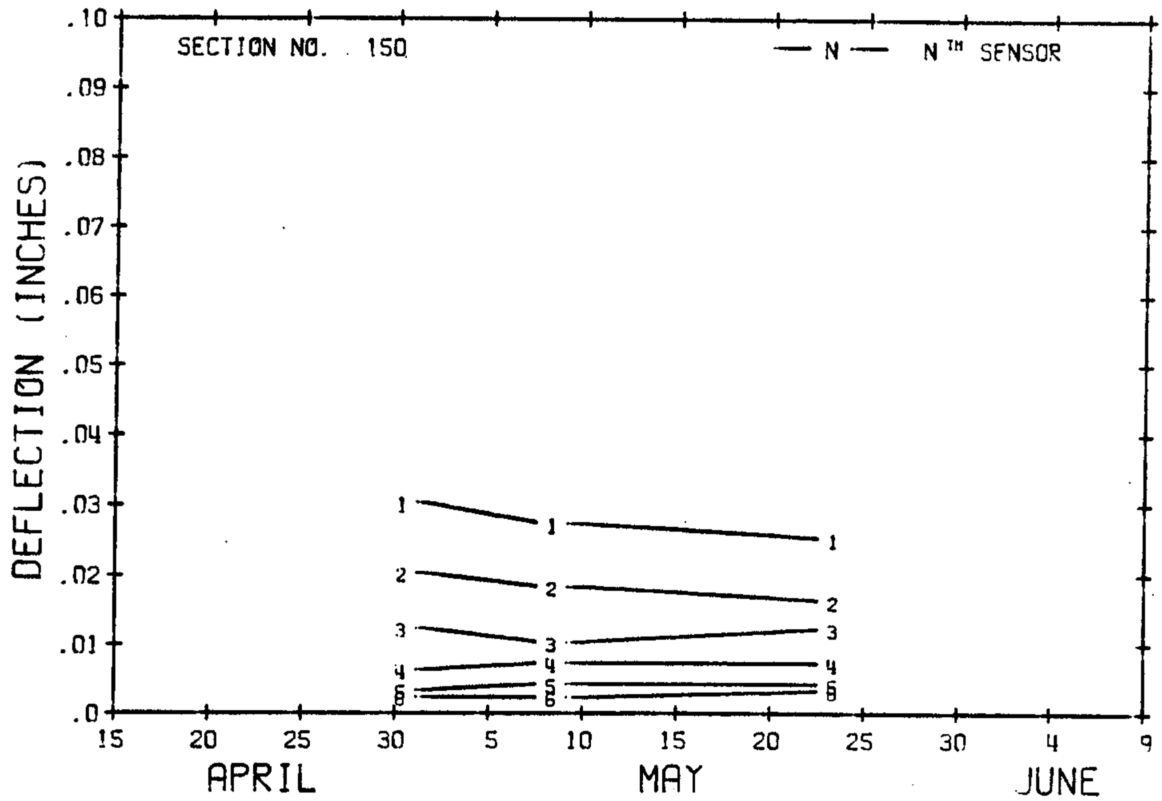
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME



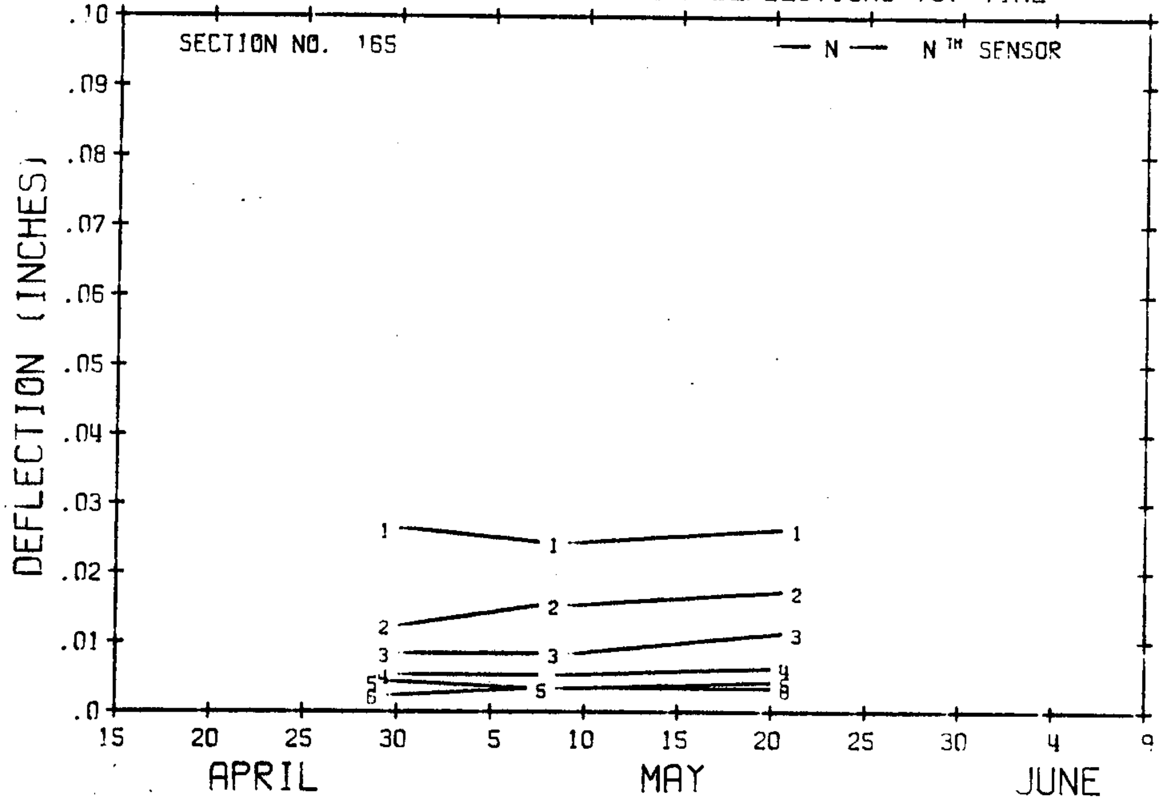


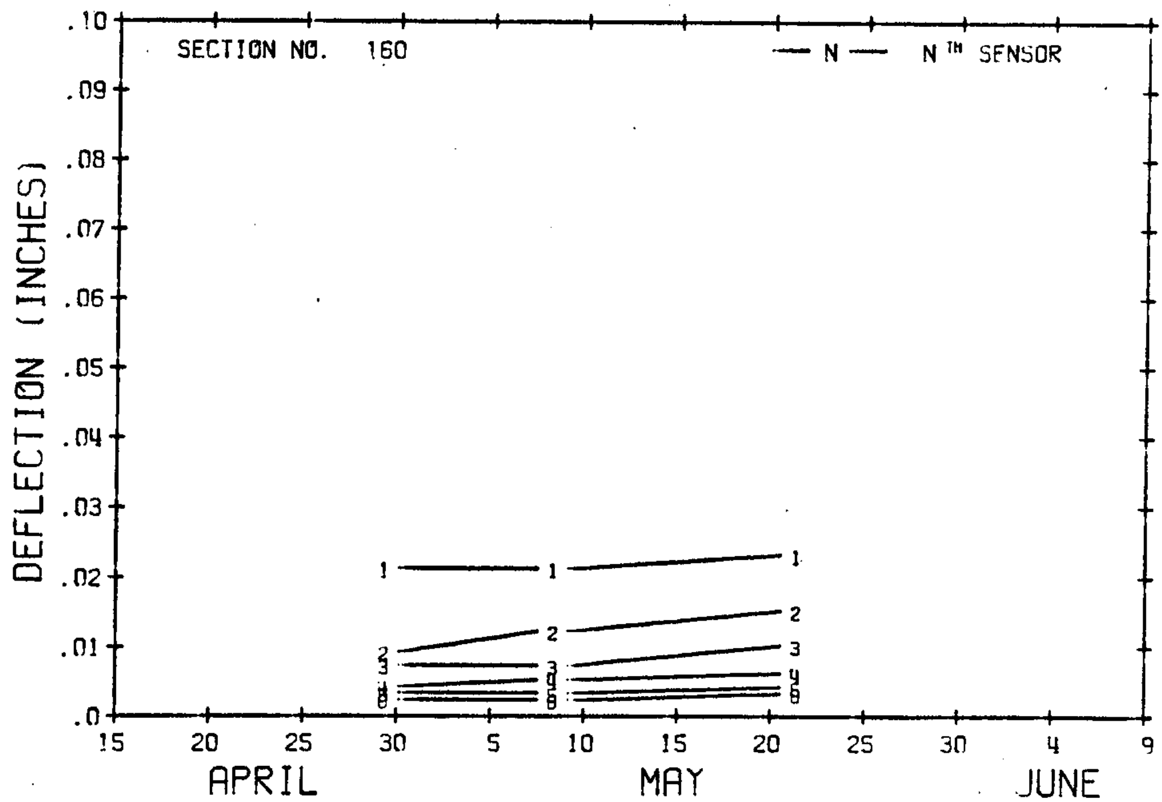
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

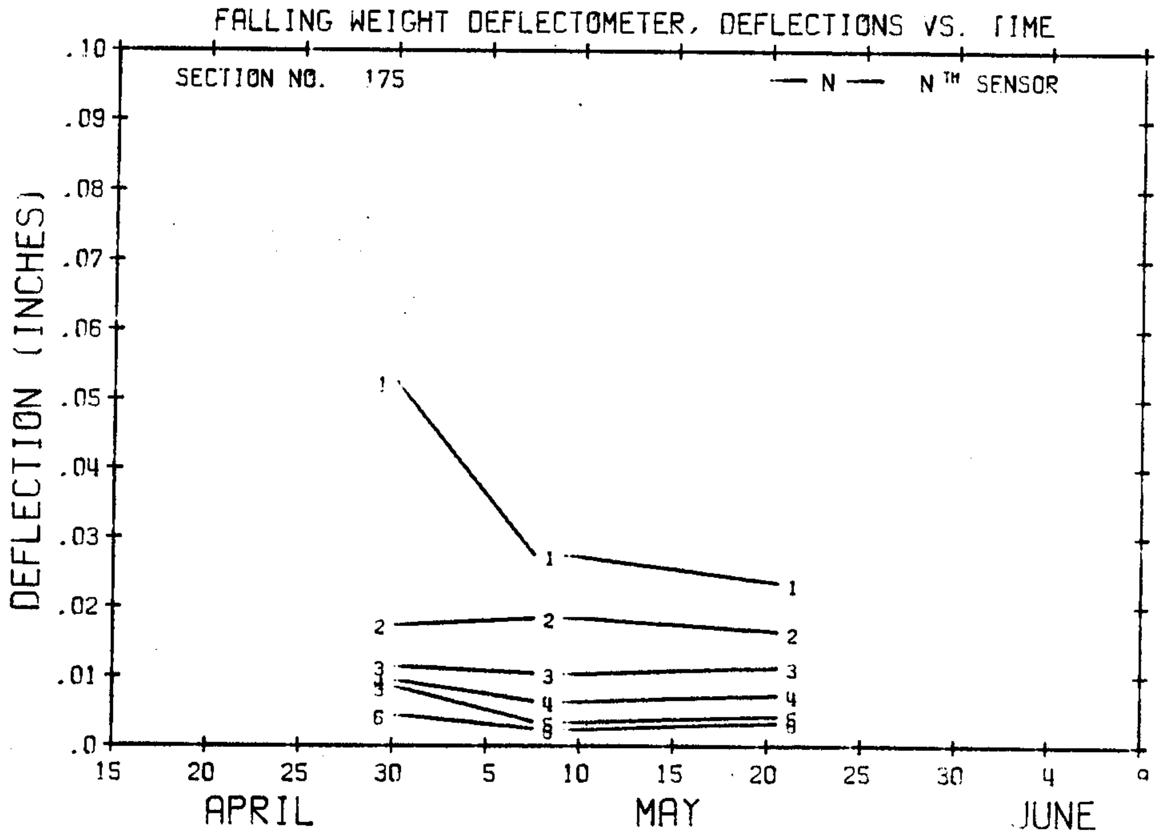


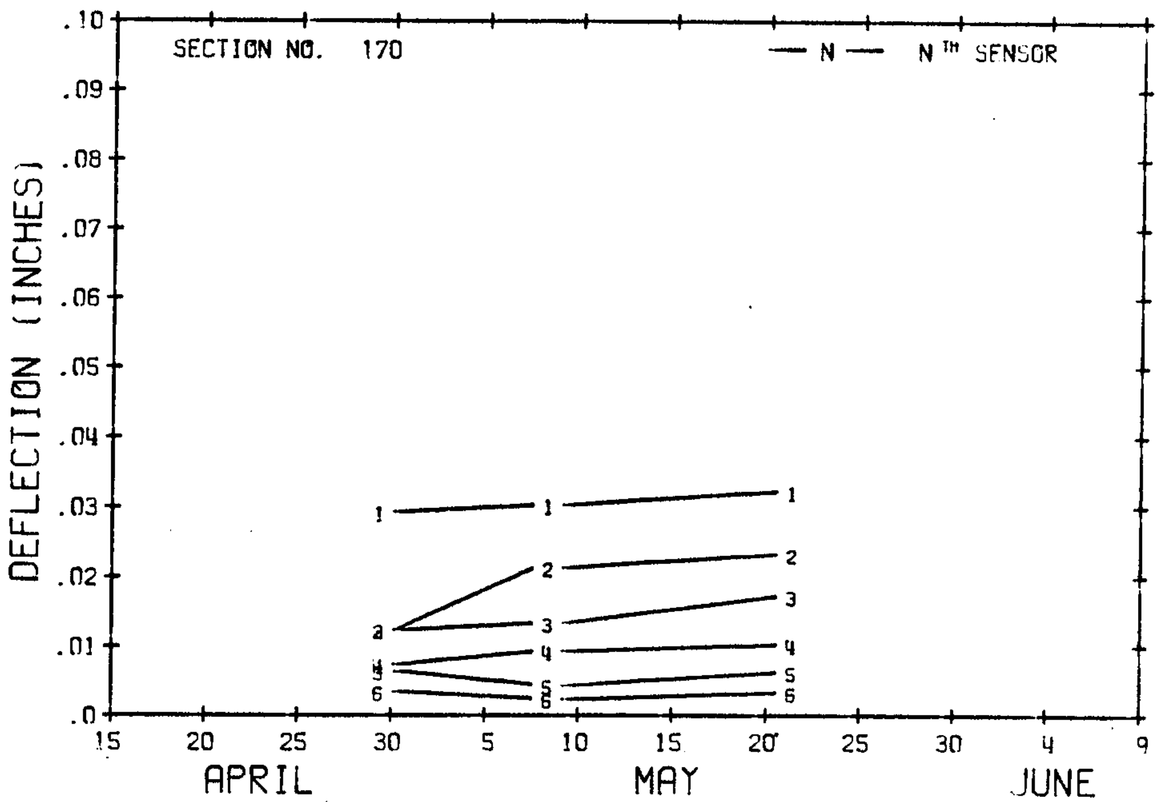


FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

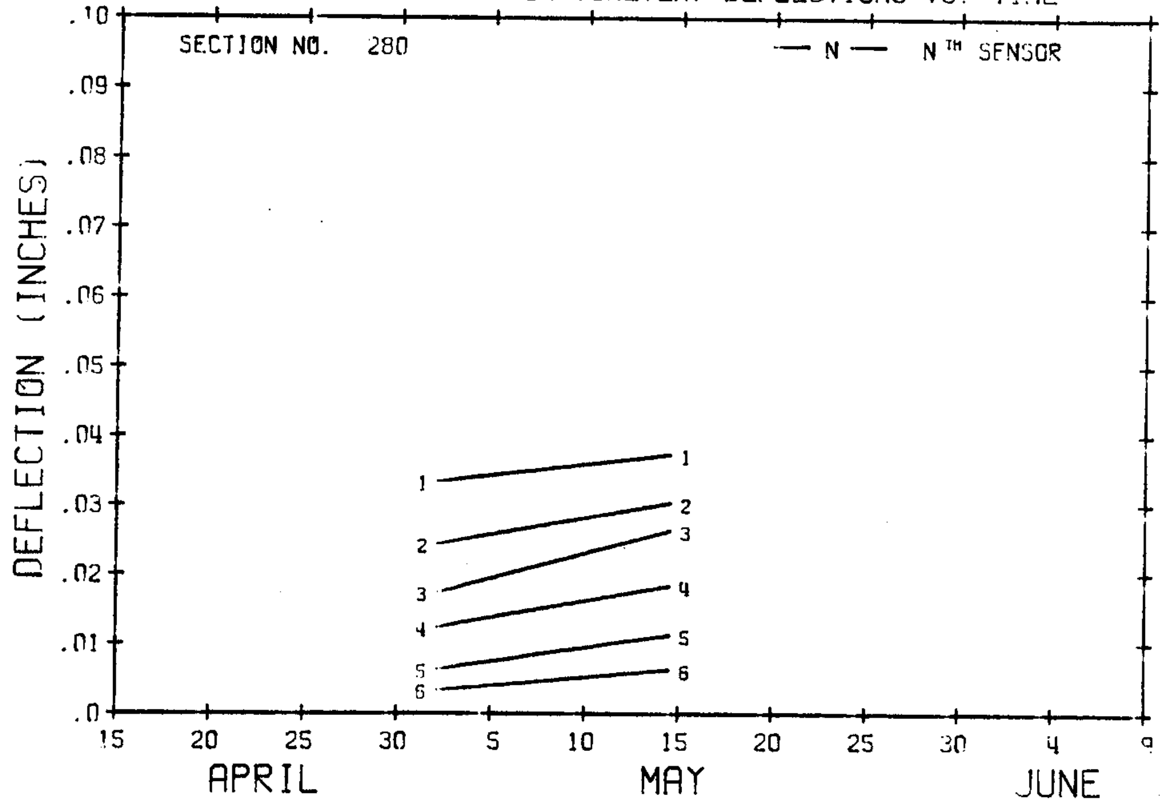


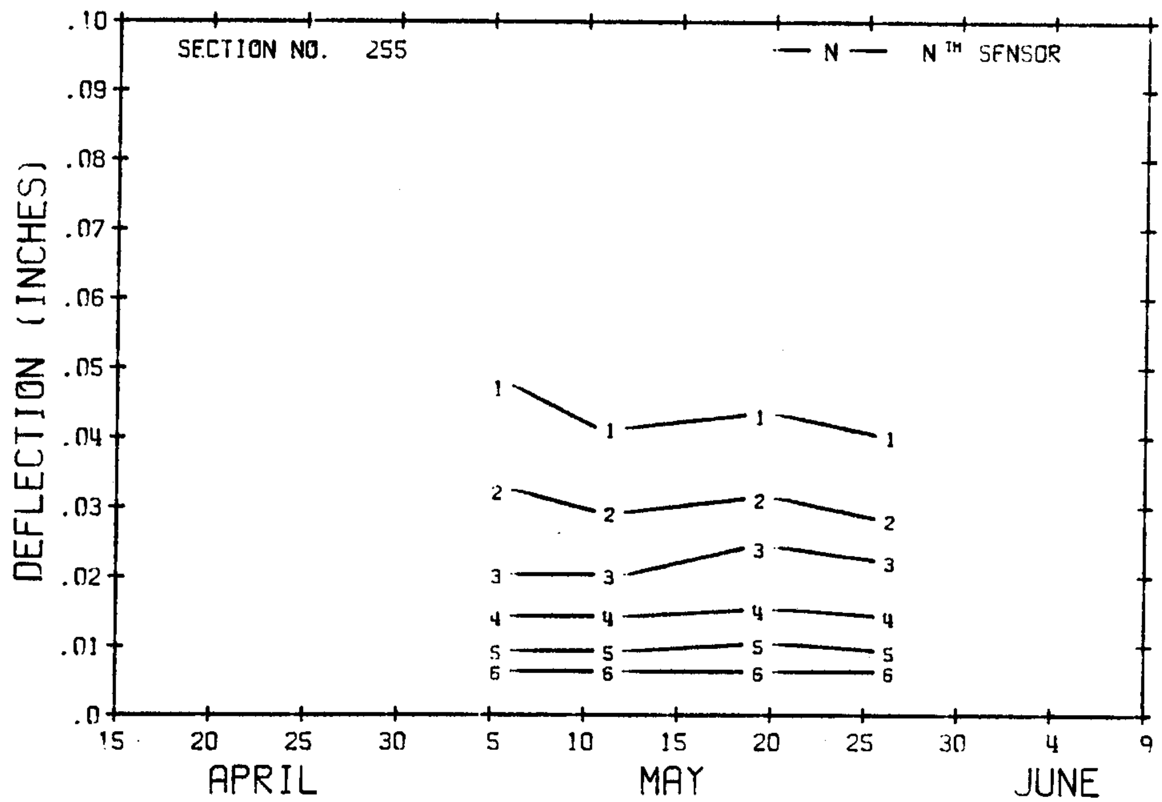


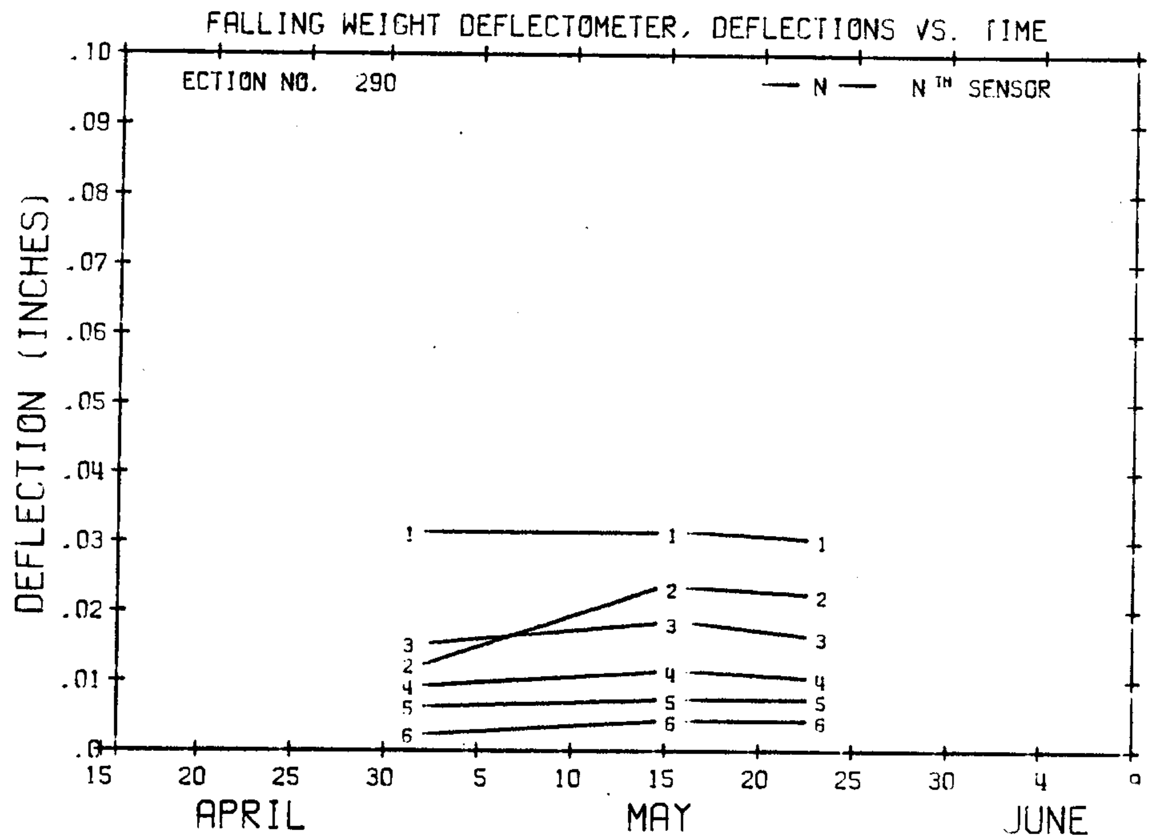

FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME
SECTION NO. 175
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

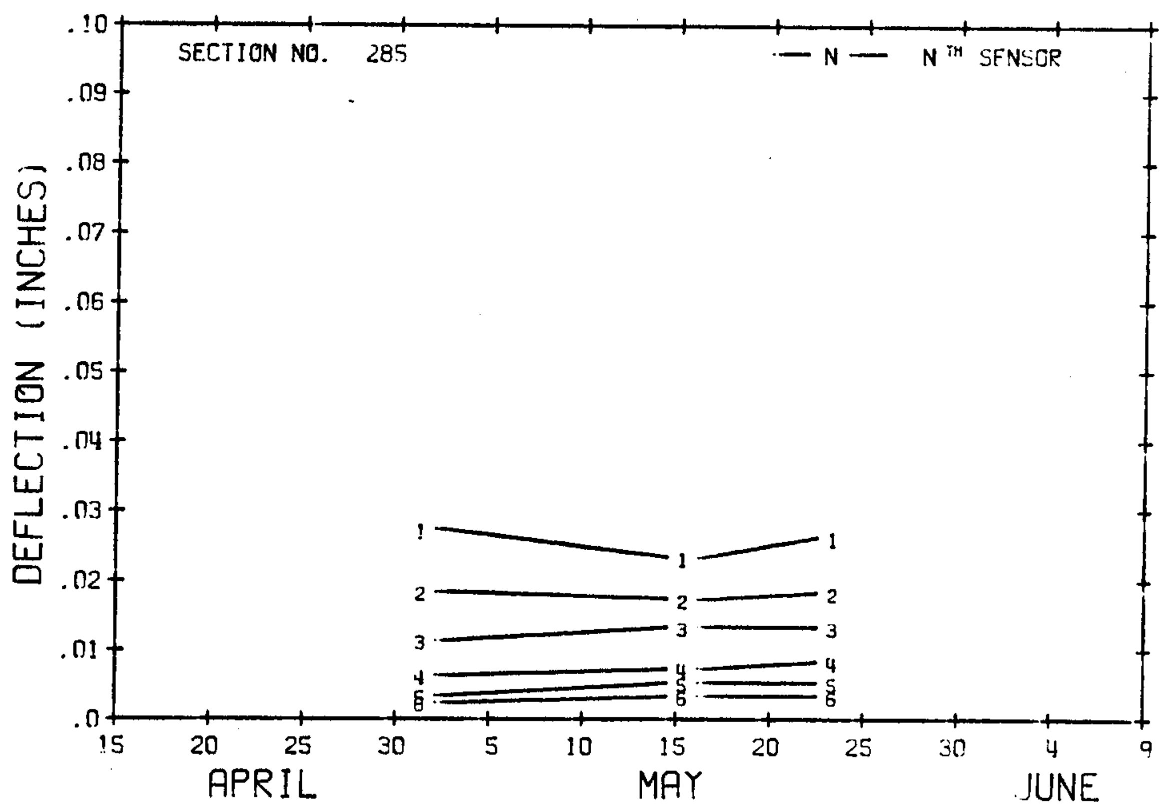

SECTION NO. 170
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

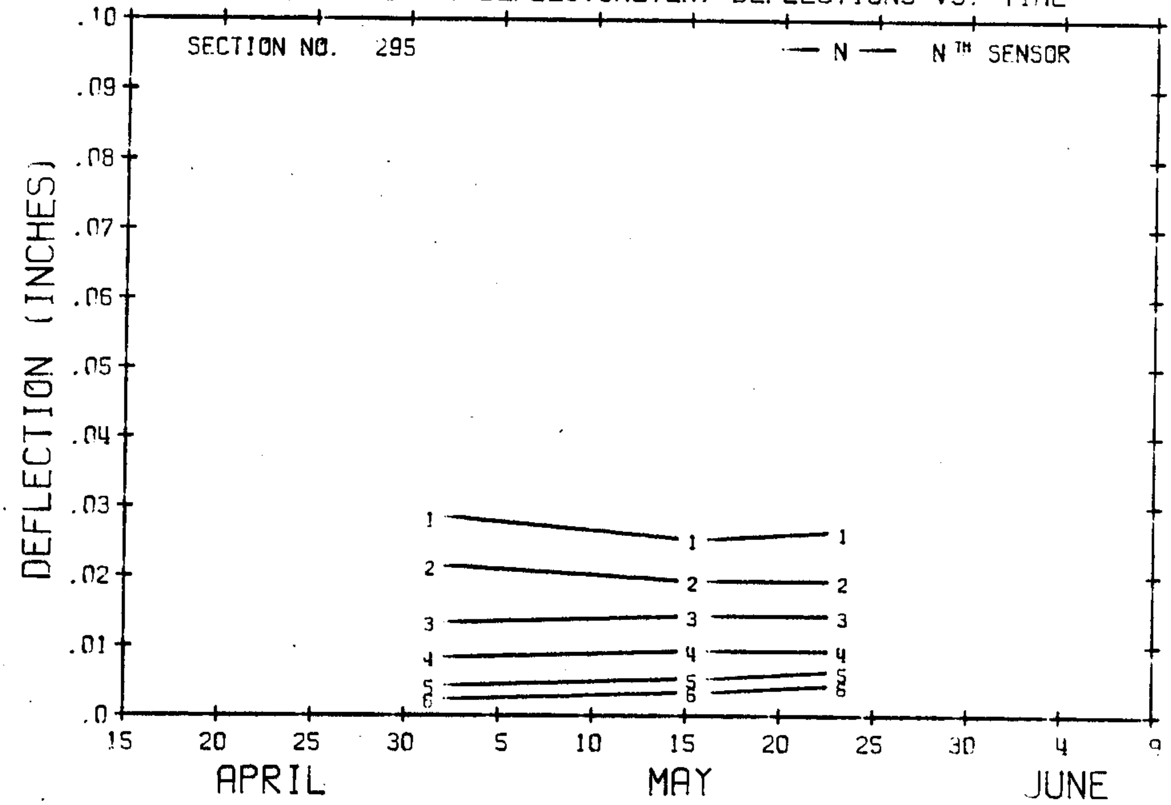


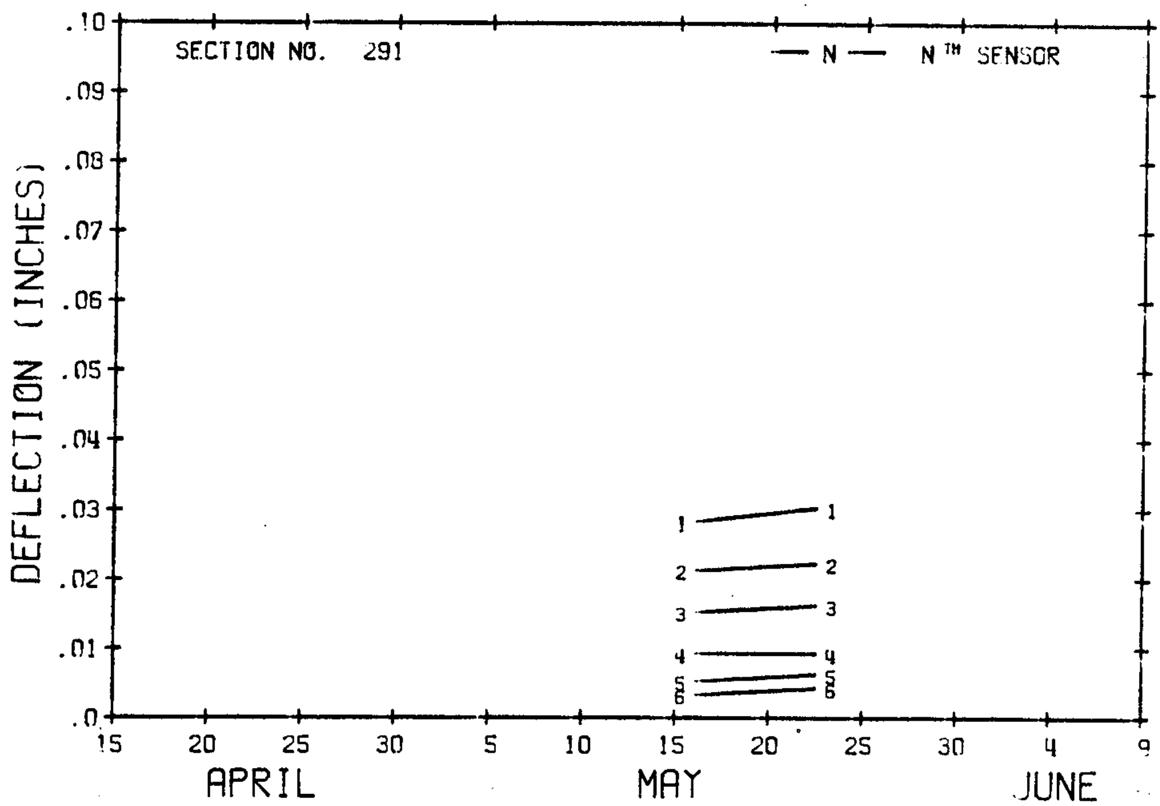



FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME
ECTION NO. 290
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

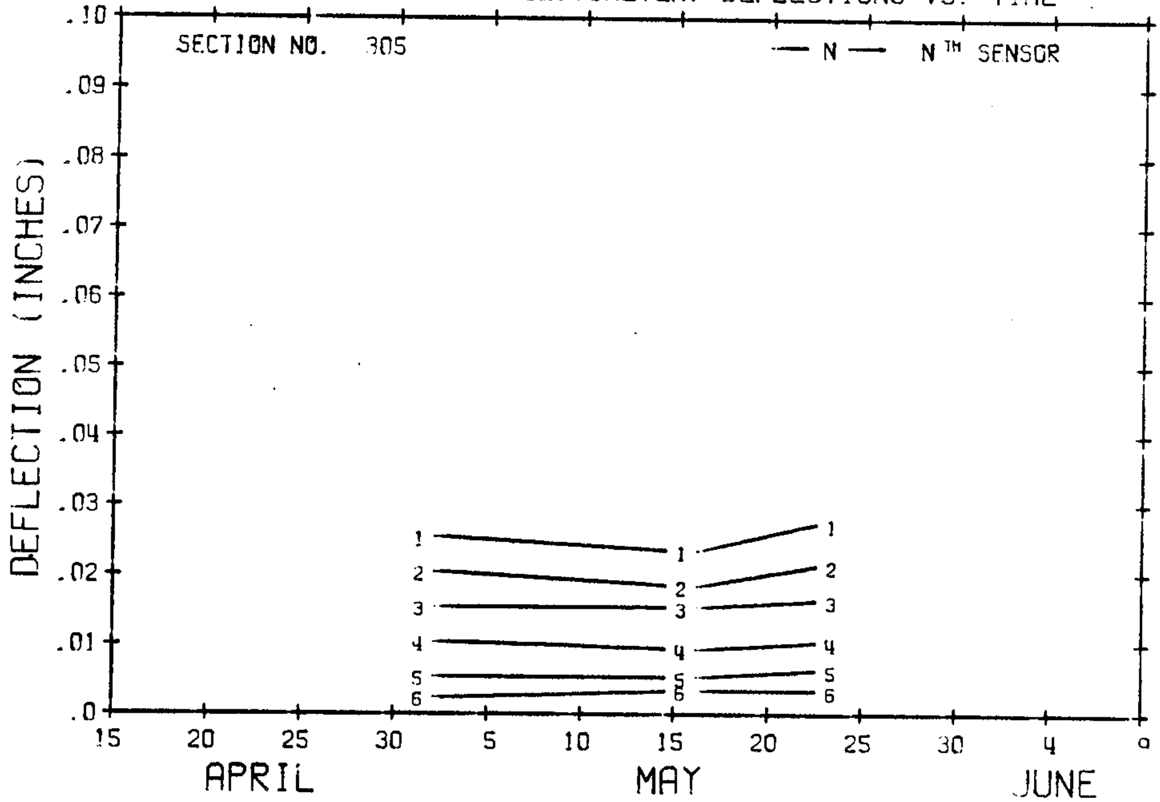

SECTION NO. 285
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

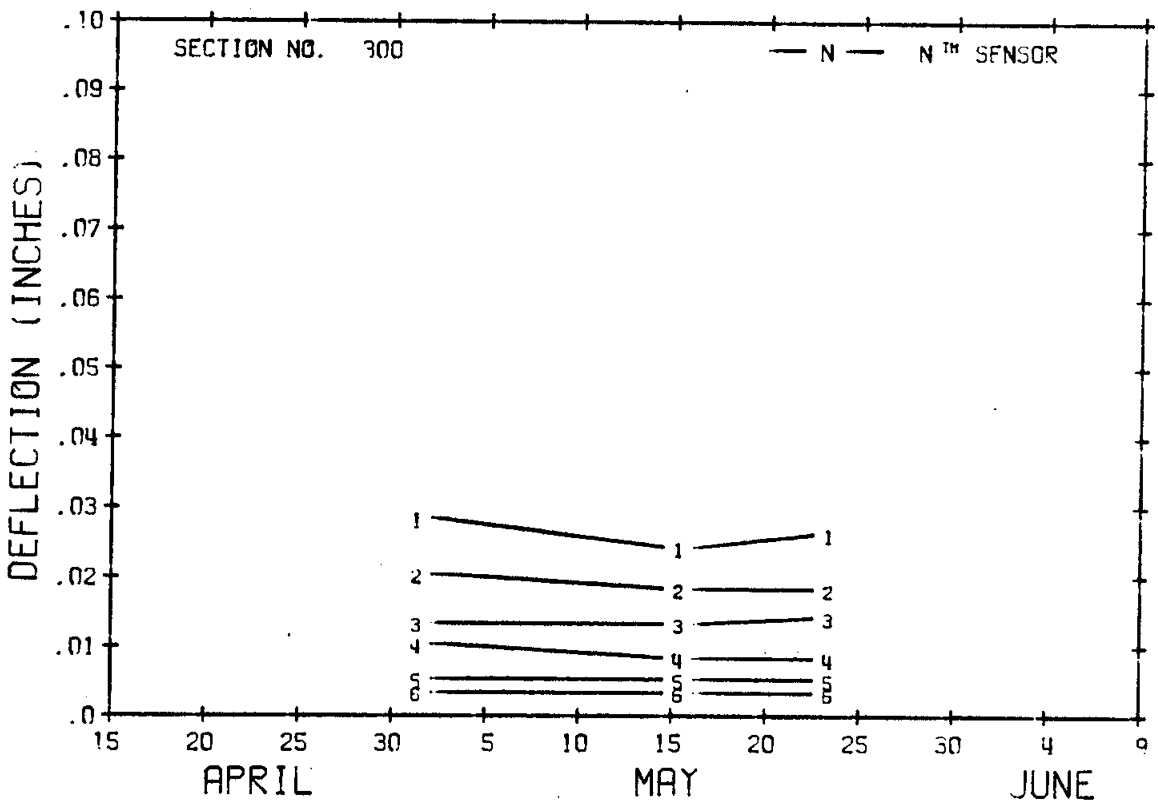
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME



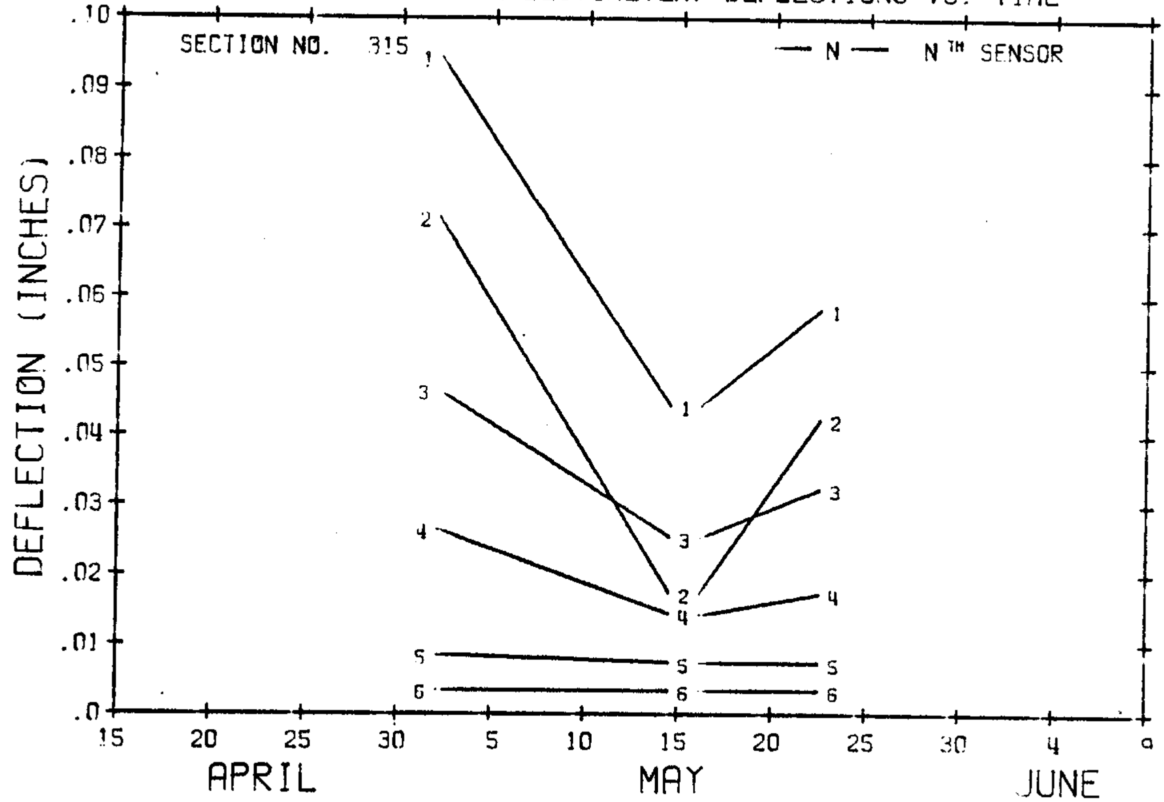


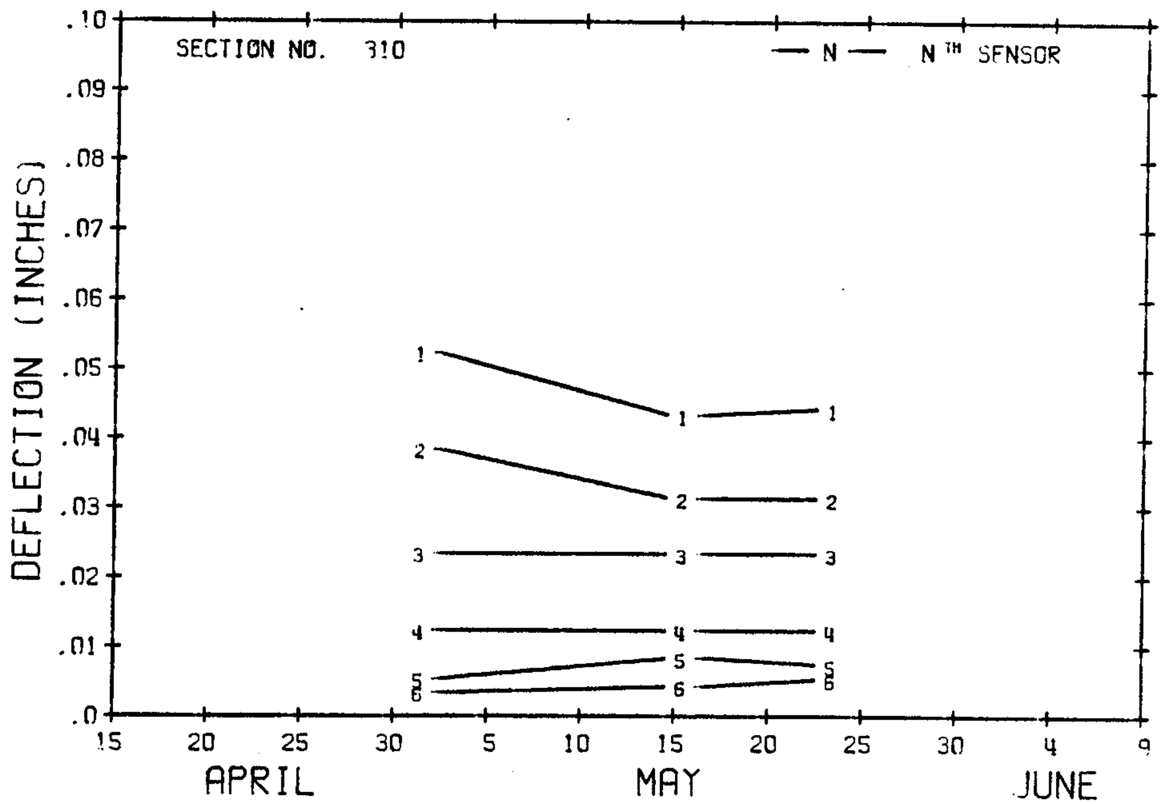
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME



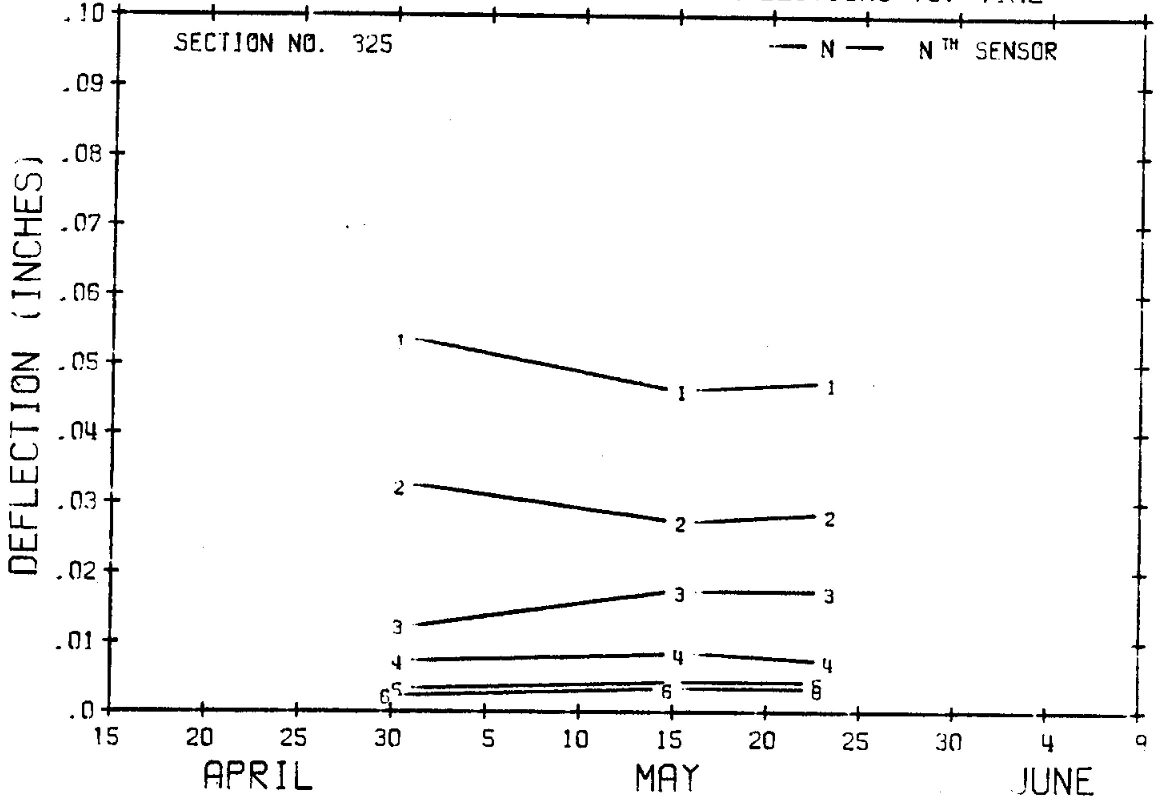


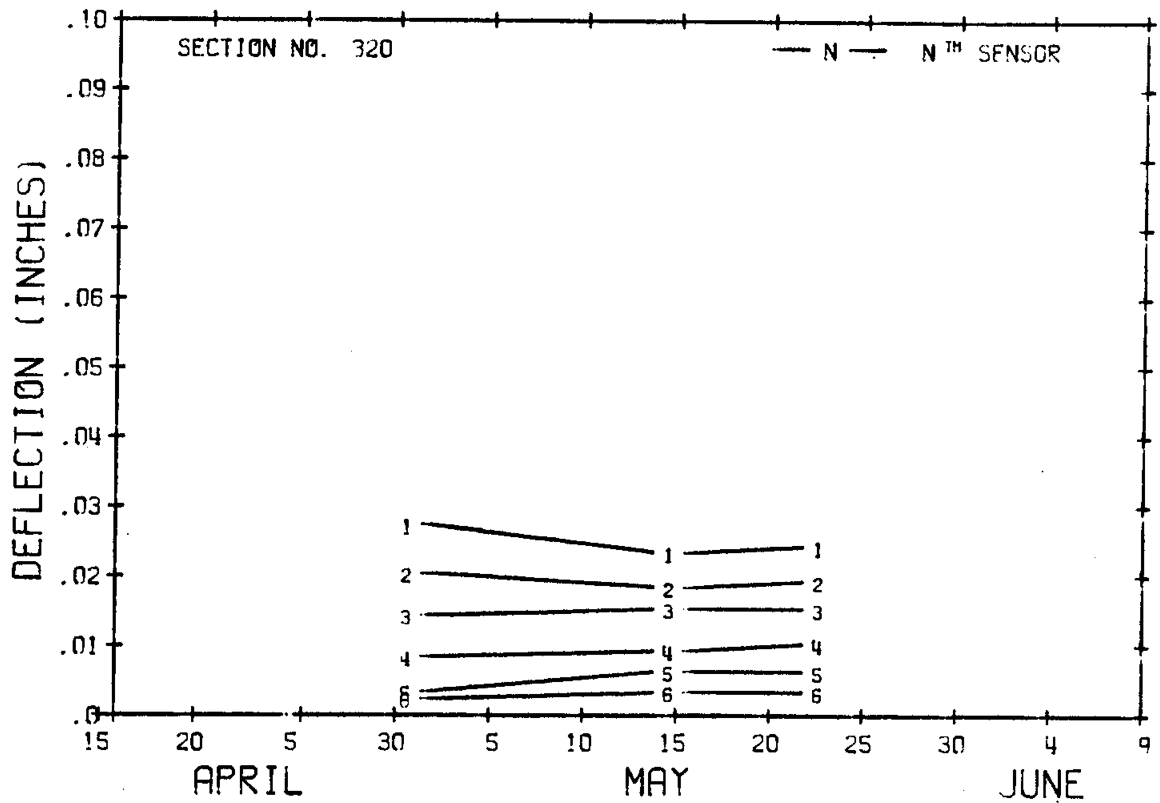
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

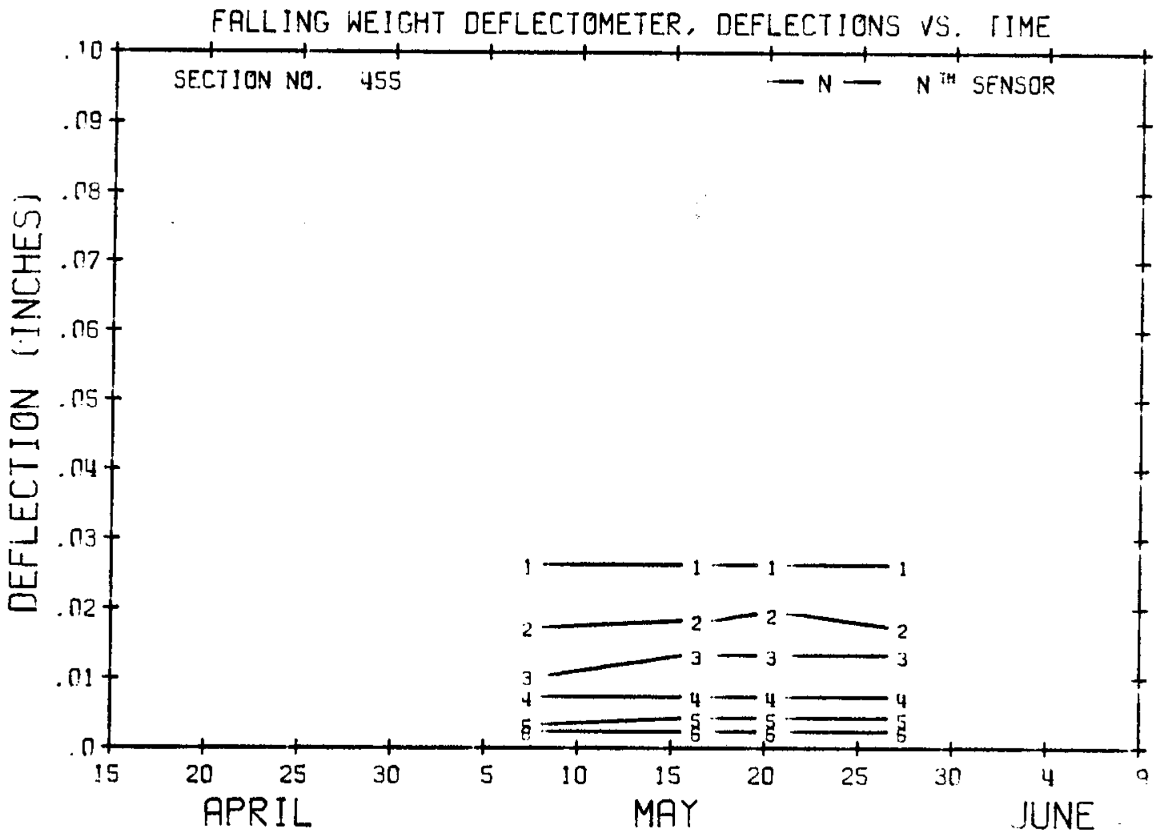


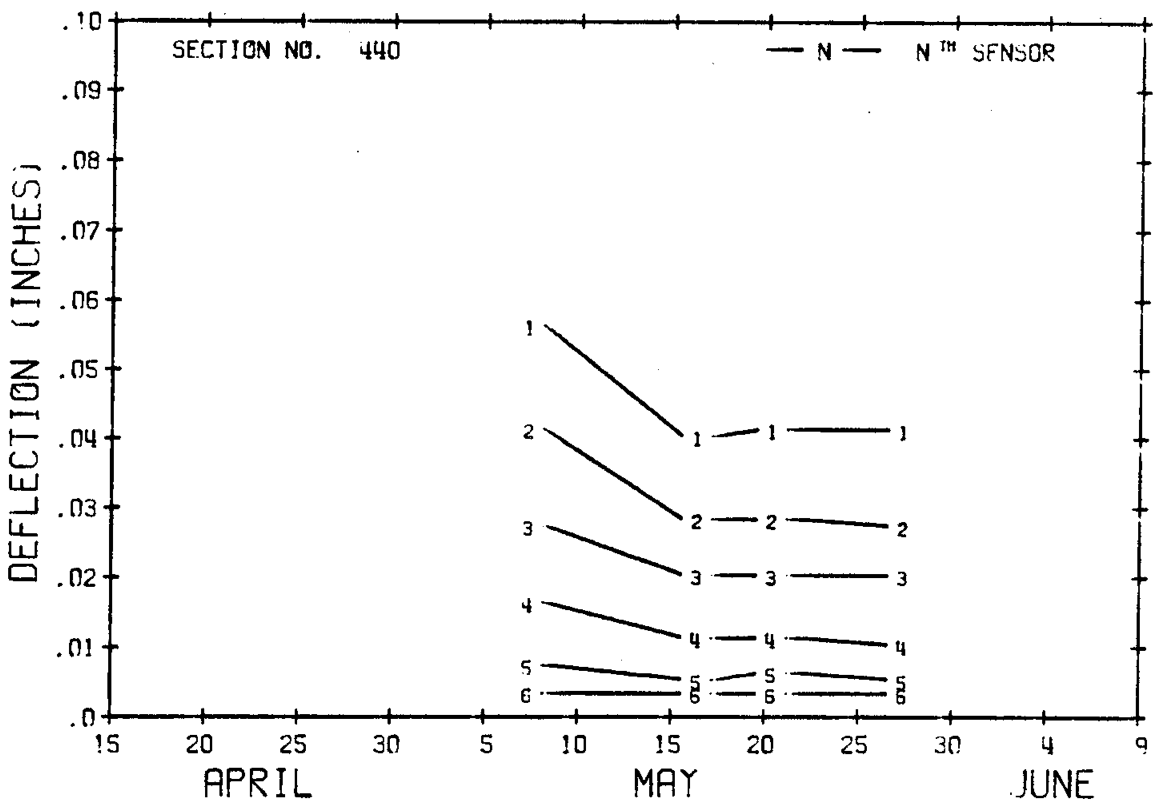


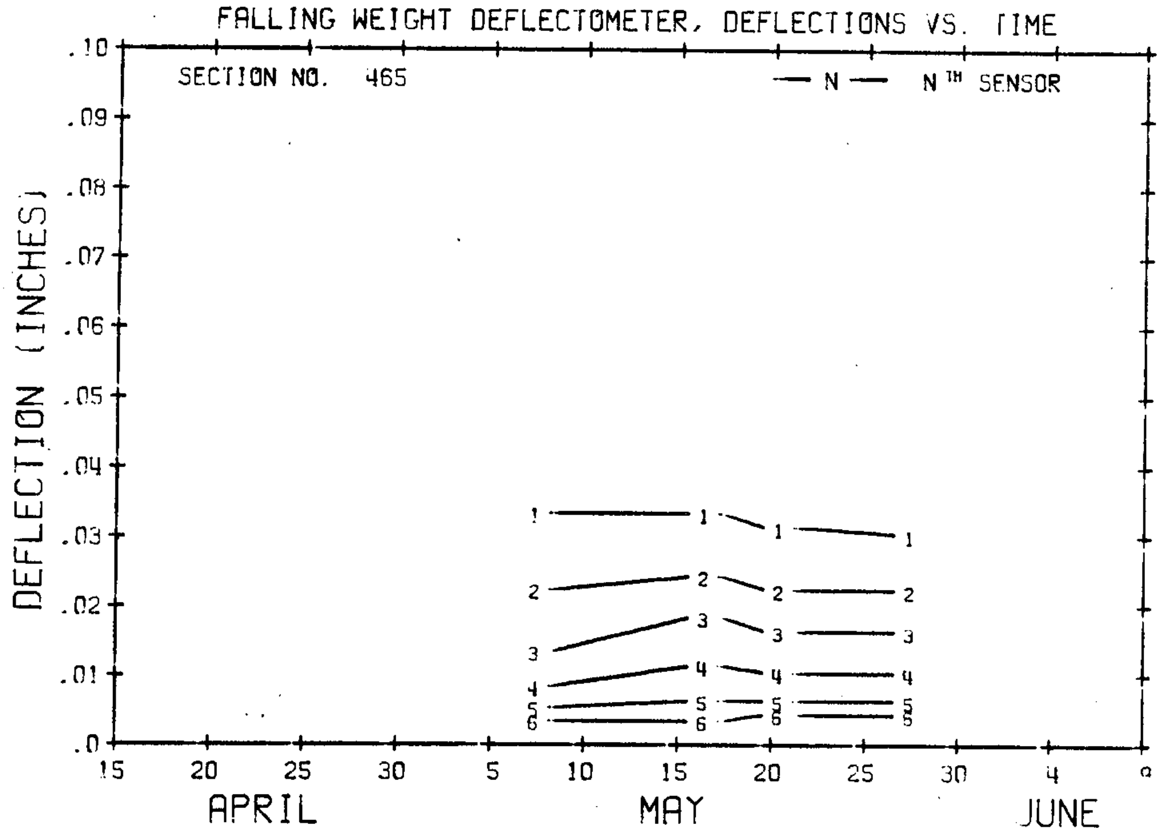
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

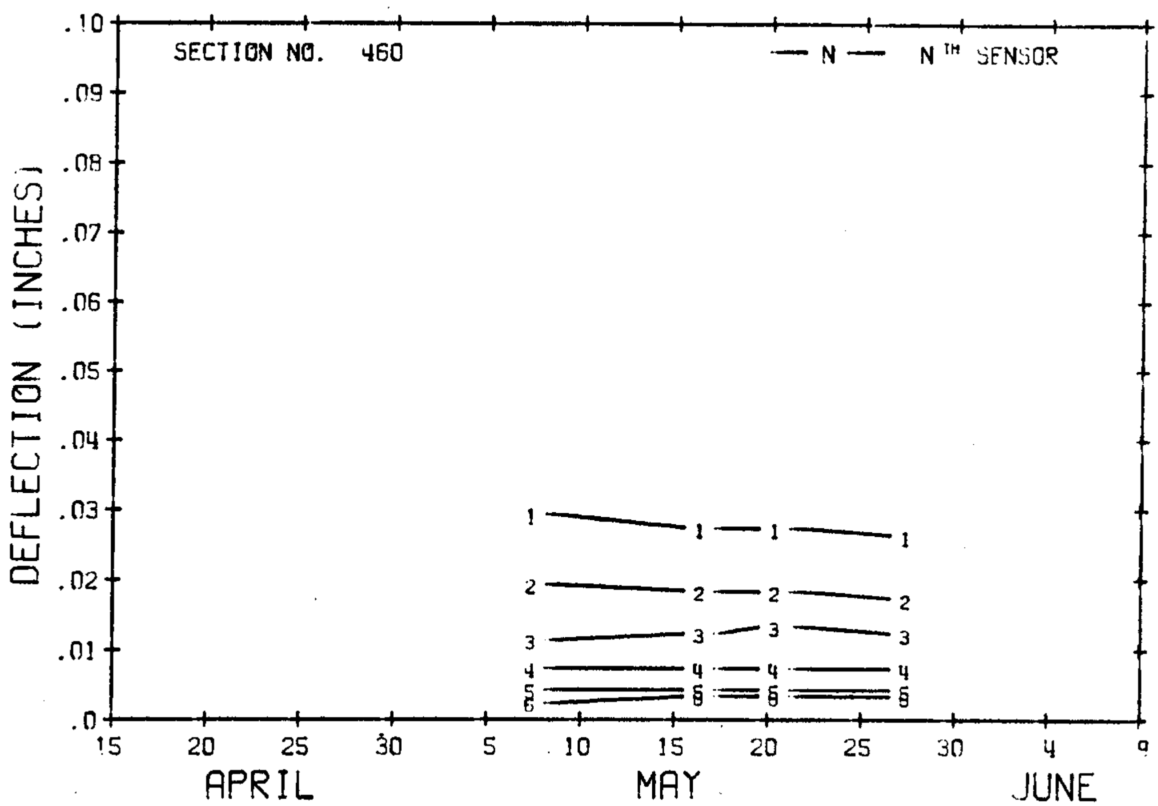




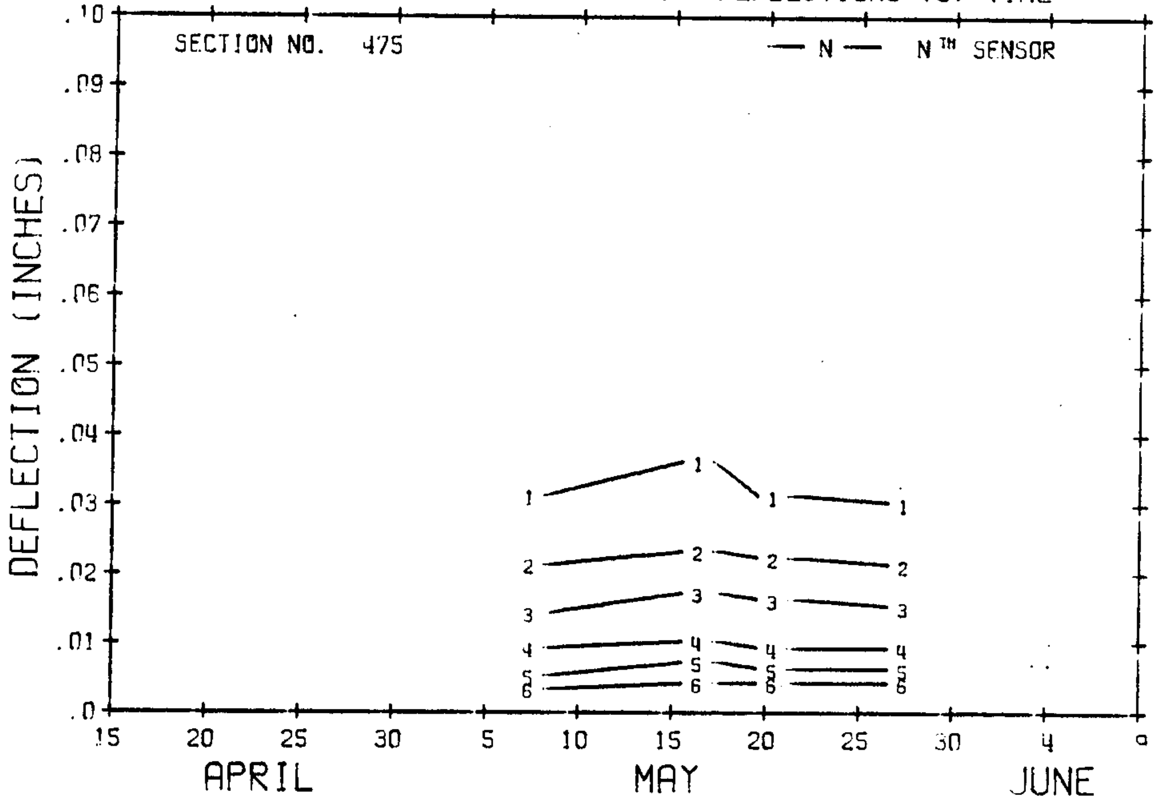

FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME
SECTION NO. 455
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

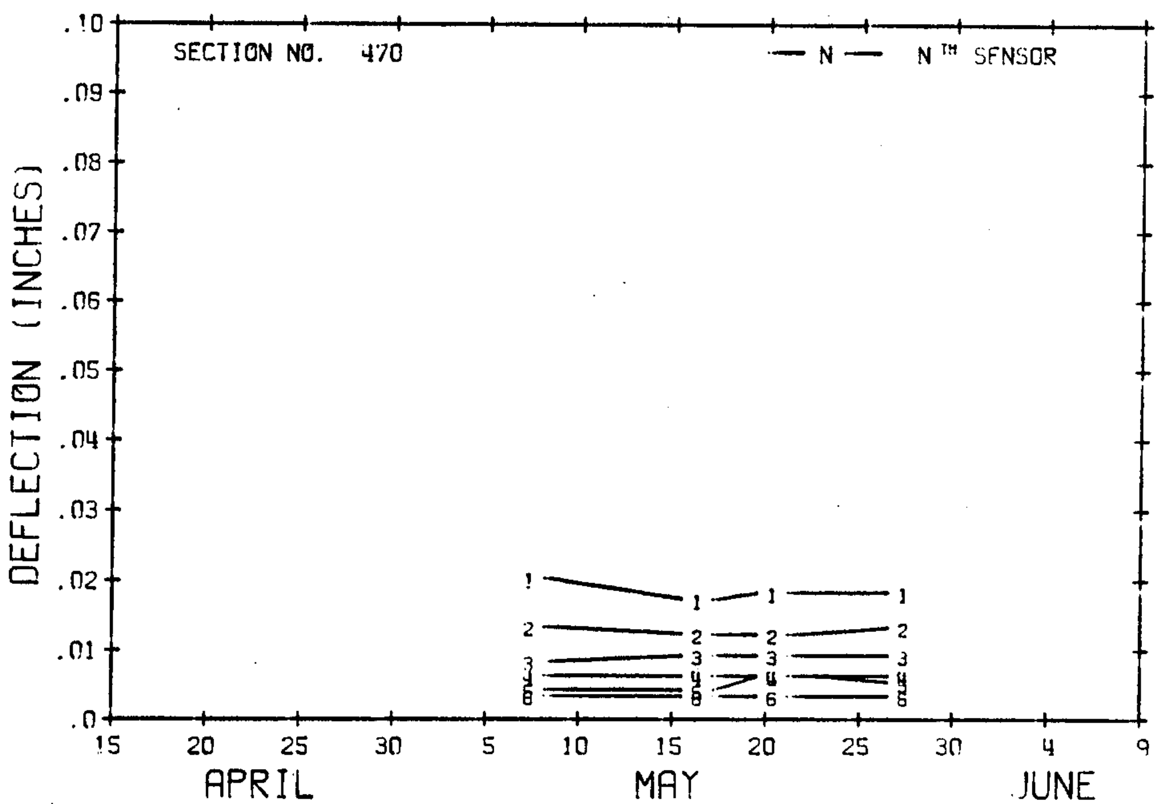

SECTION NO. 440
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE


FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME
SECTION NO. 465
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

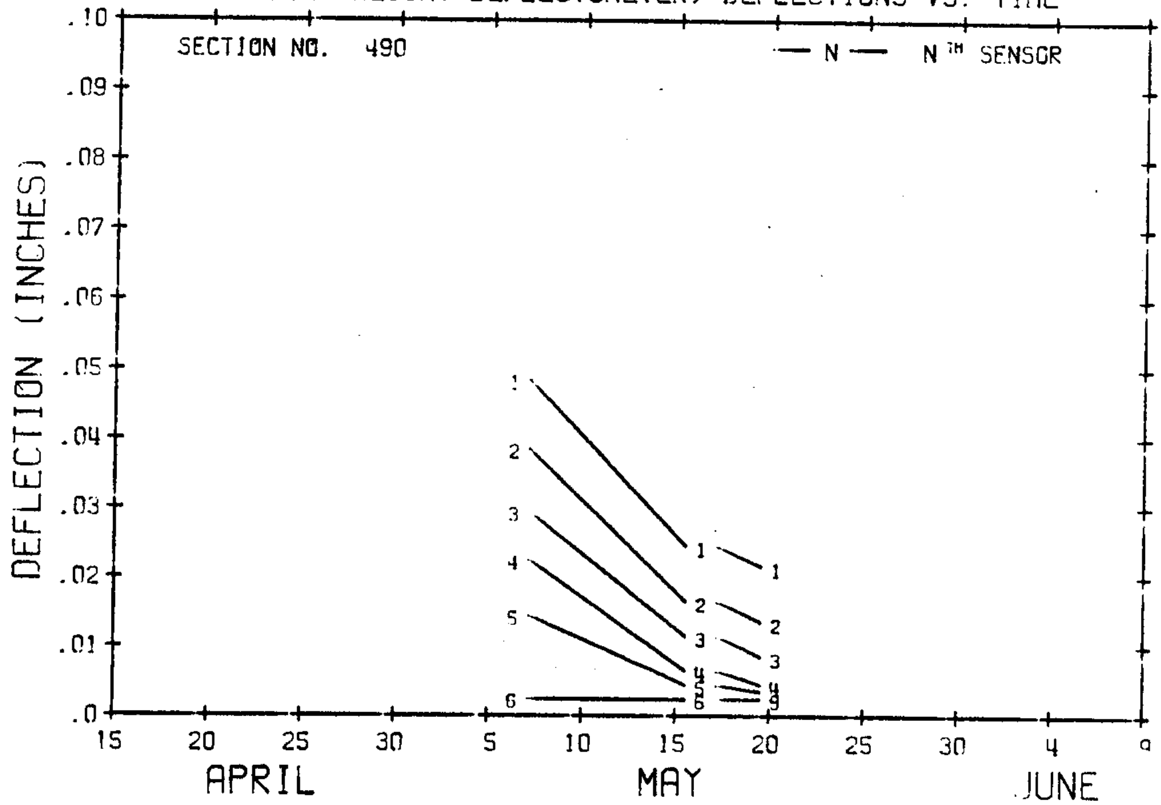

SECTION NO. 460
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

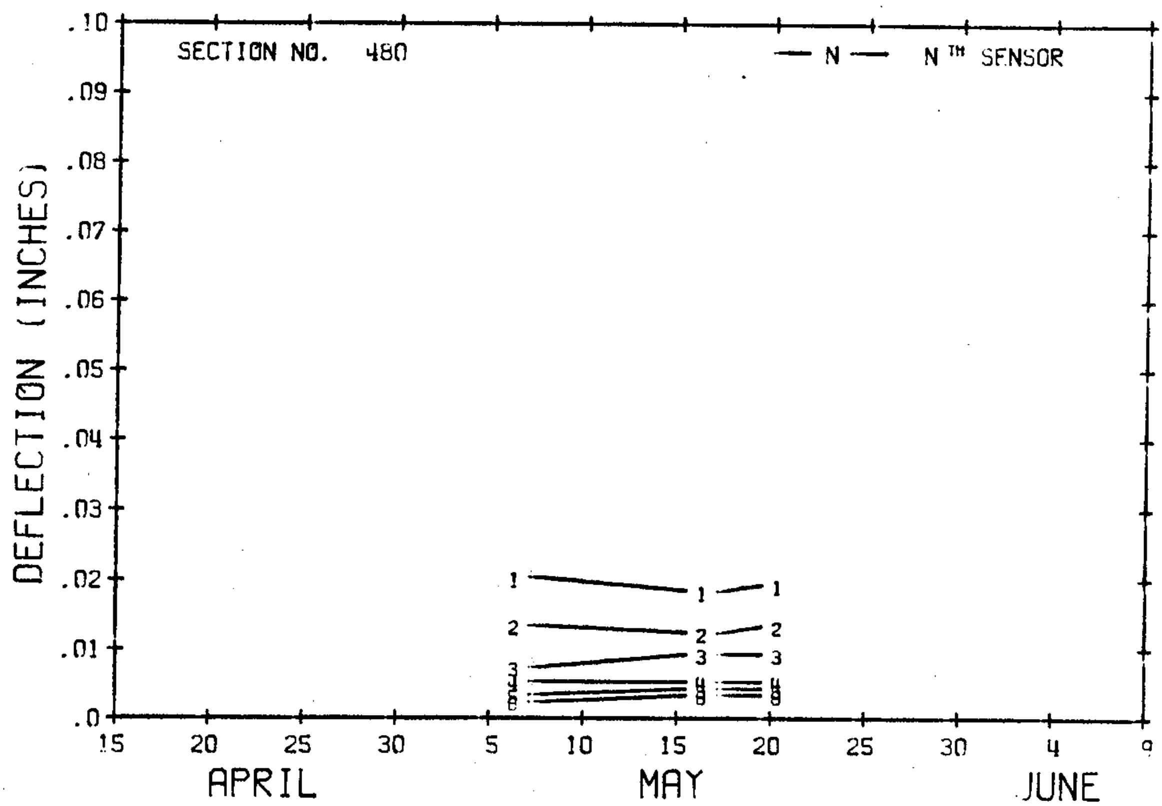
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

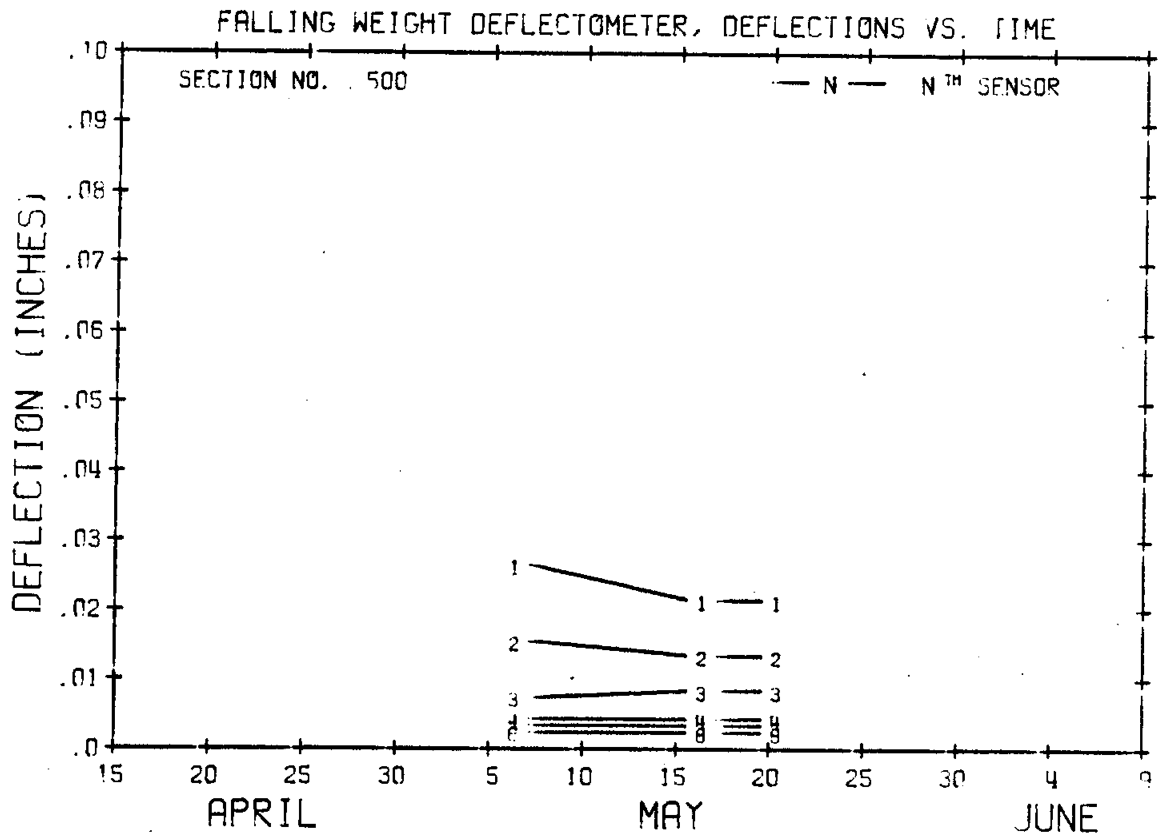


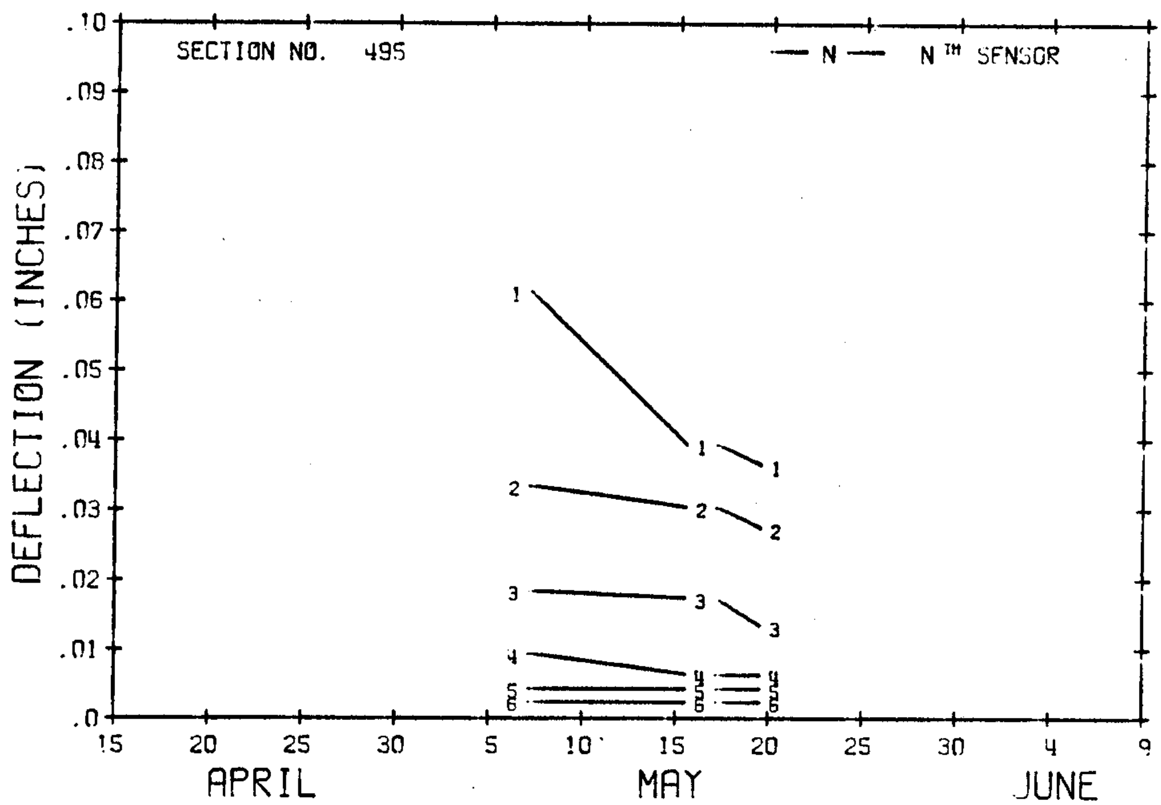


FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

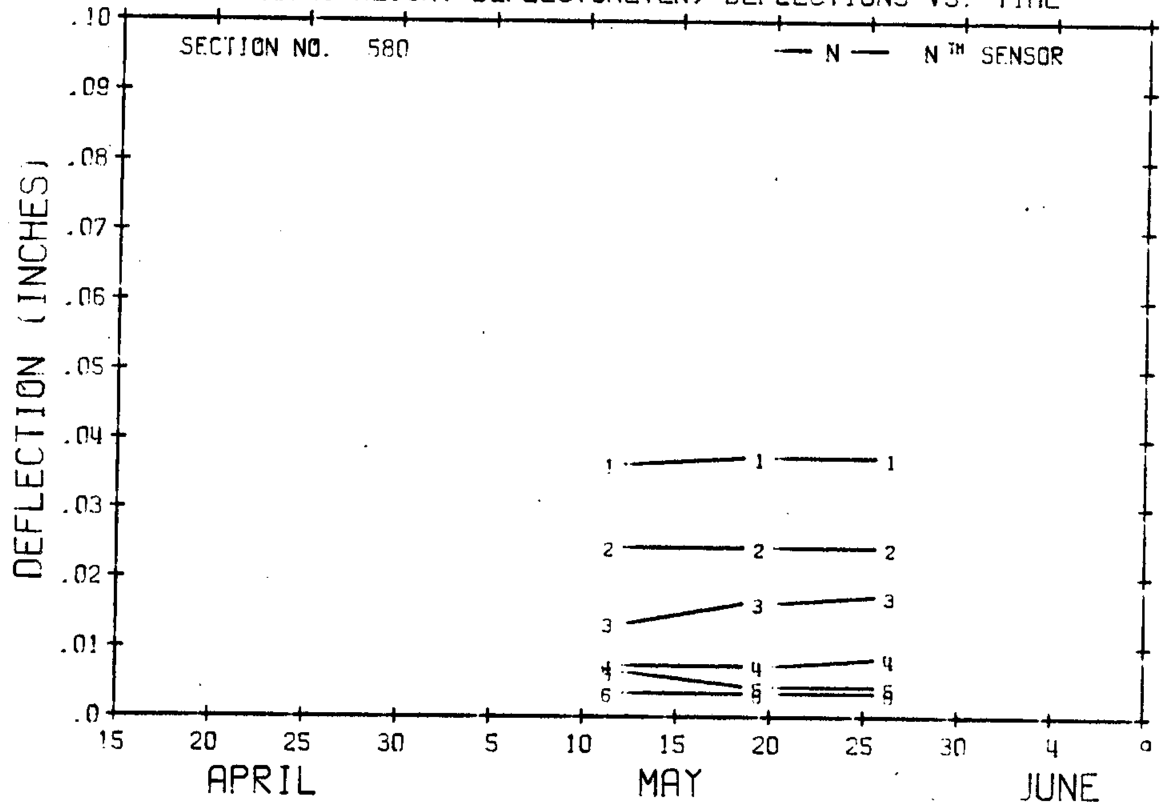


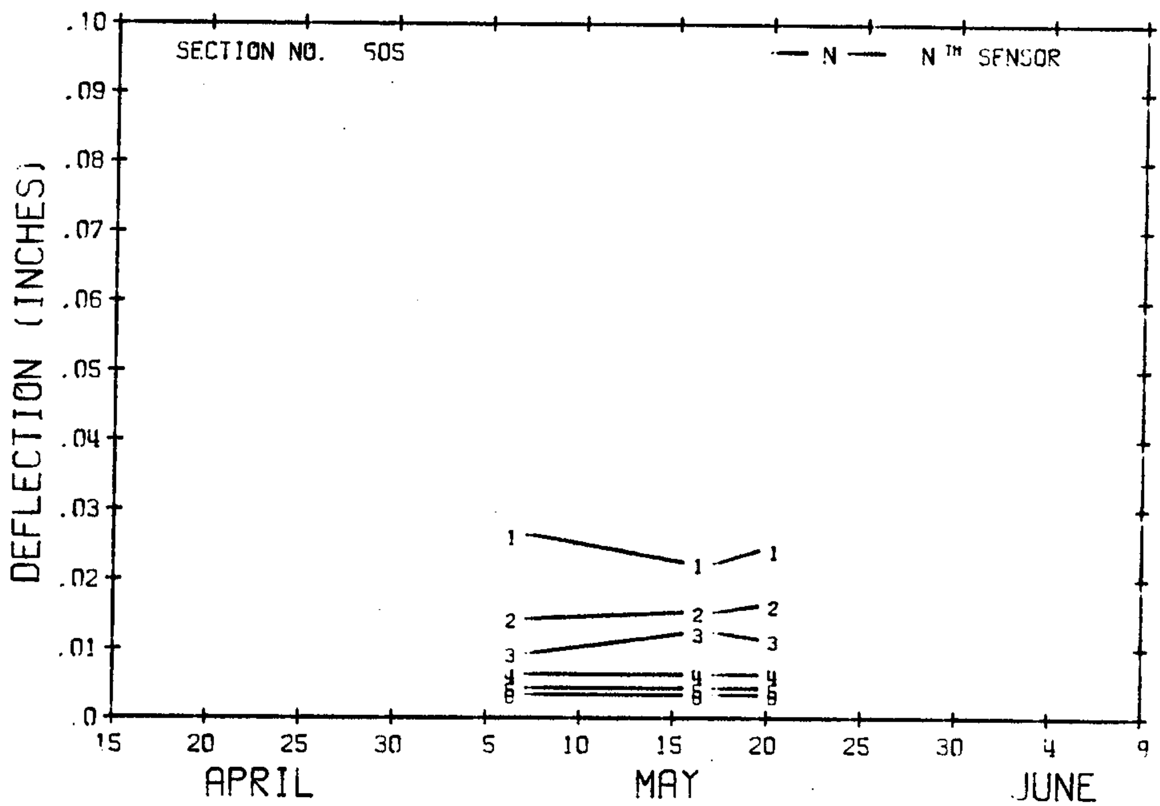


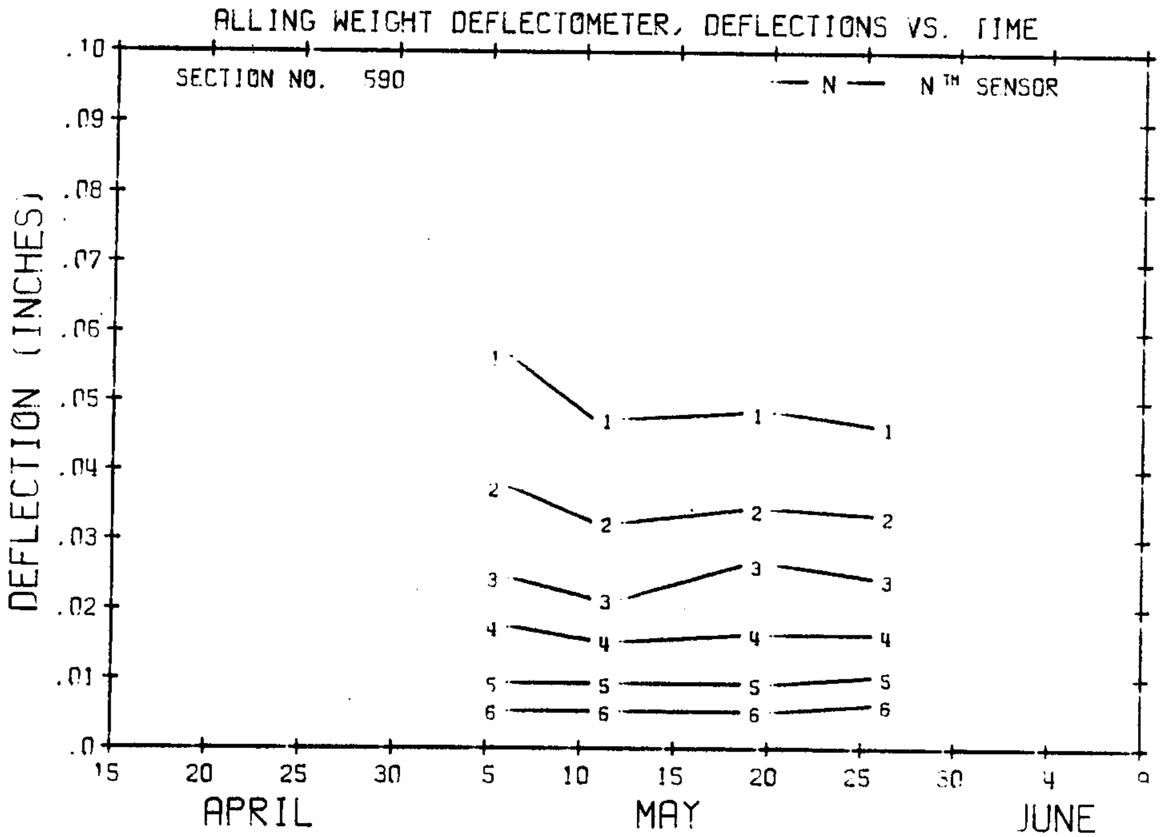

FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME
SECTION NO. 500
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

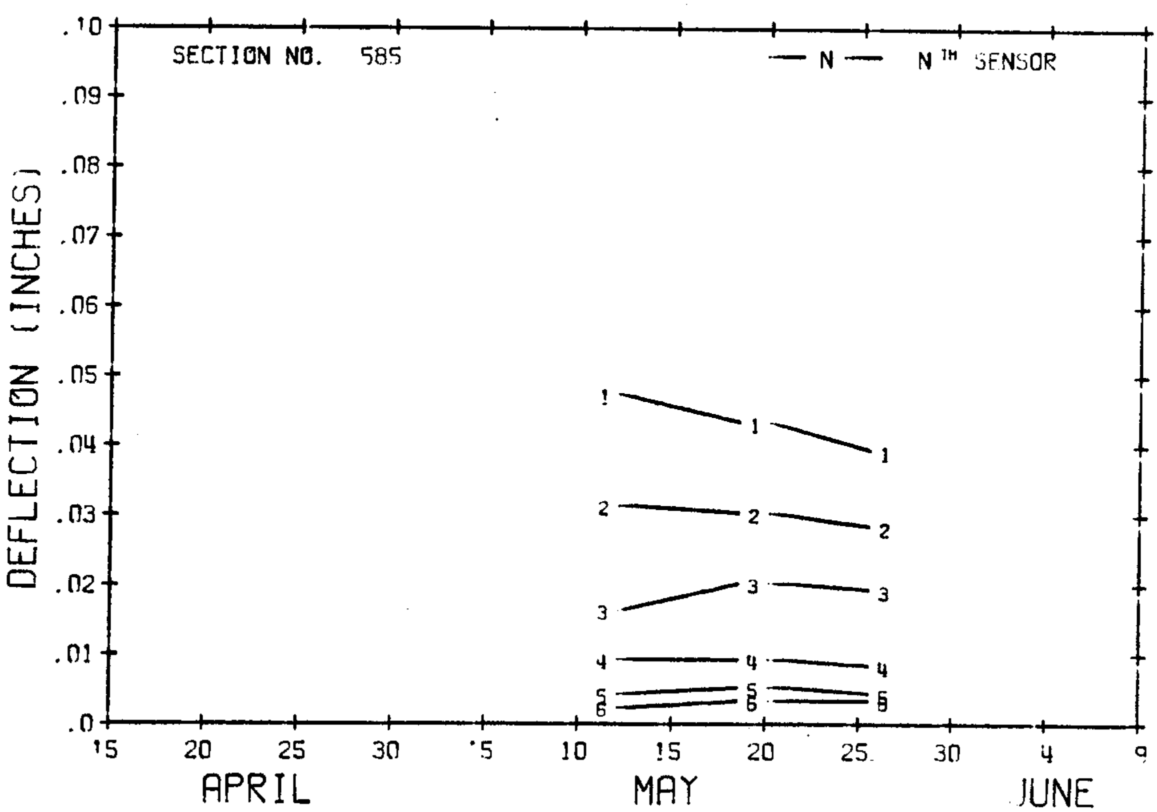

SECTION NO. 495
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15 20 25 30 5 10 15 20 25 30 4 9
APRIL
MAY
JUNE

FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME

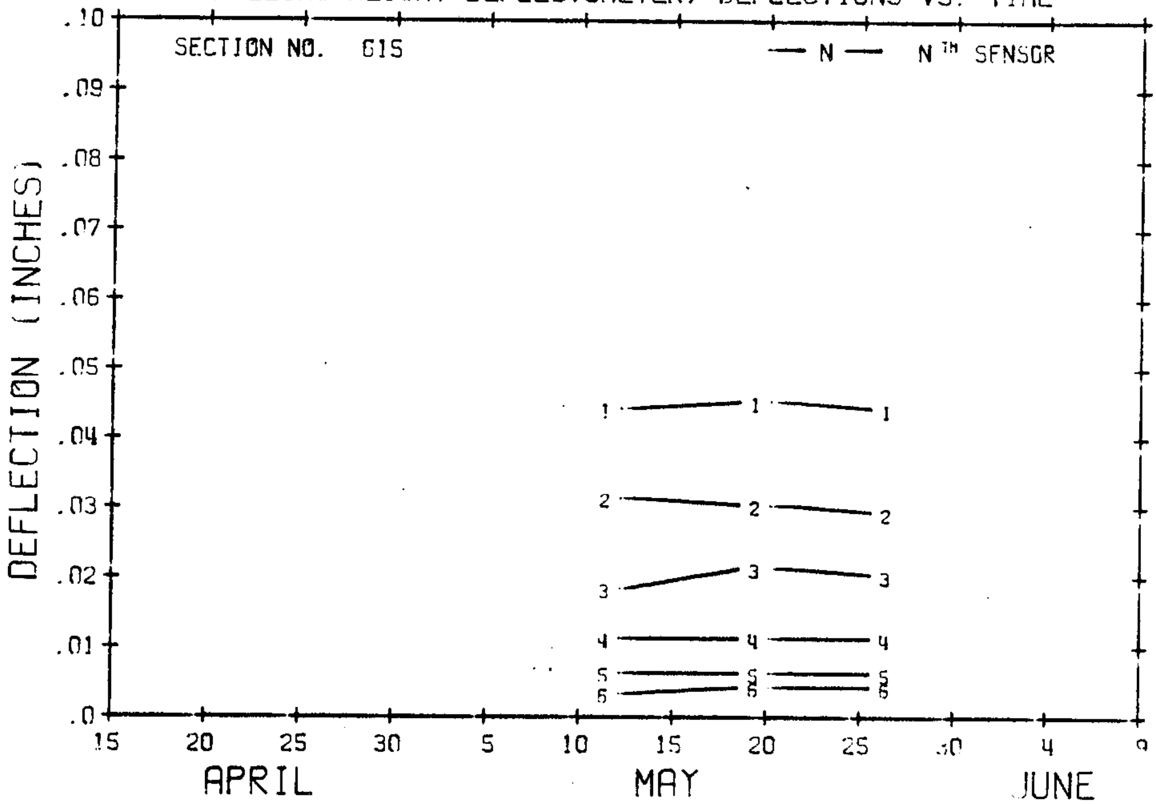


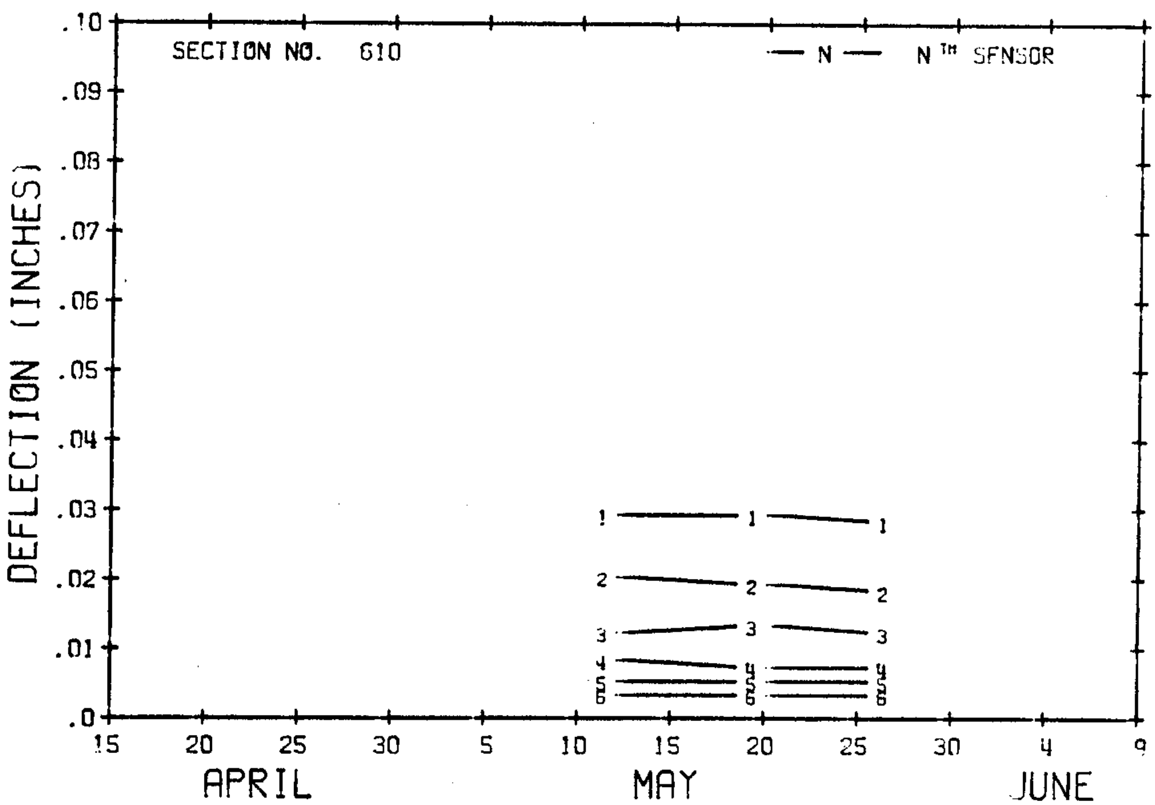



ALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME
SECTION NO. 590
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

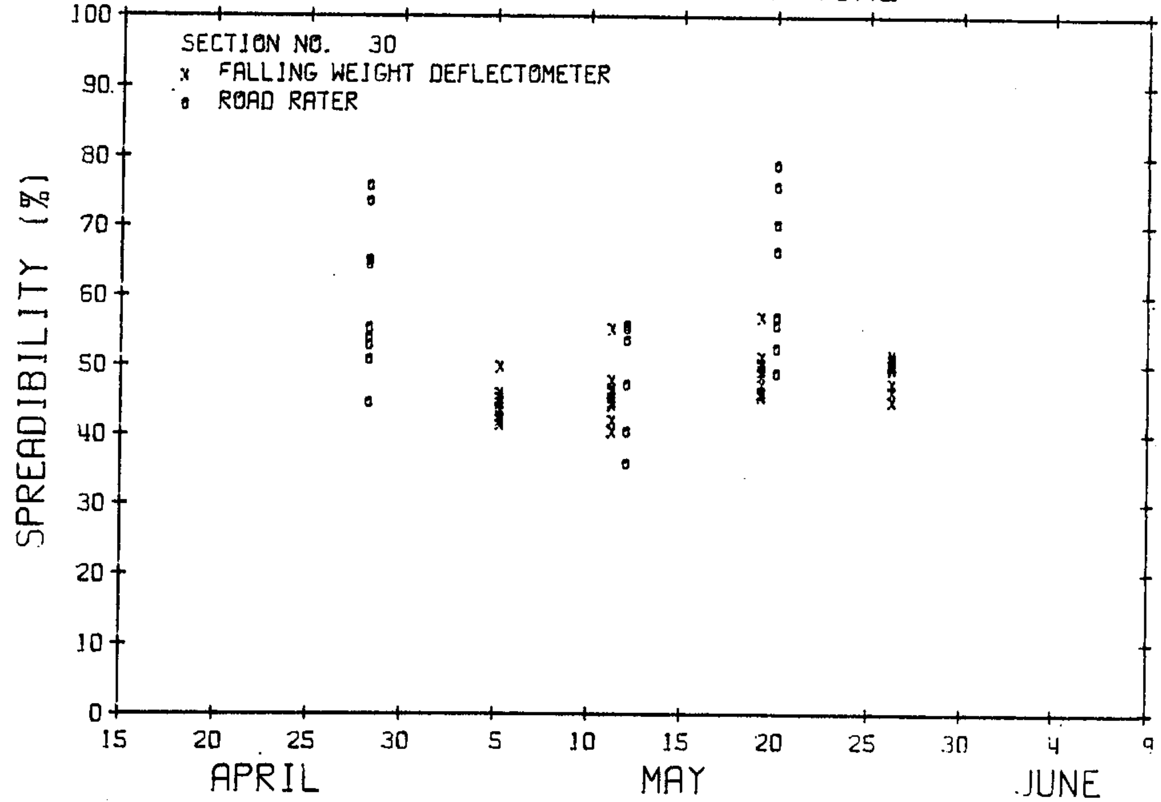

SECTION NO. 585
— N — N TH SENSOR
DEFLECTION (INCHES)
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

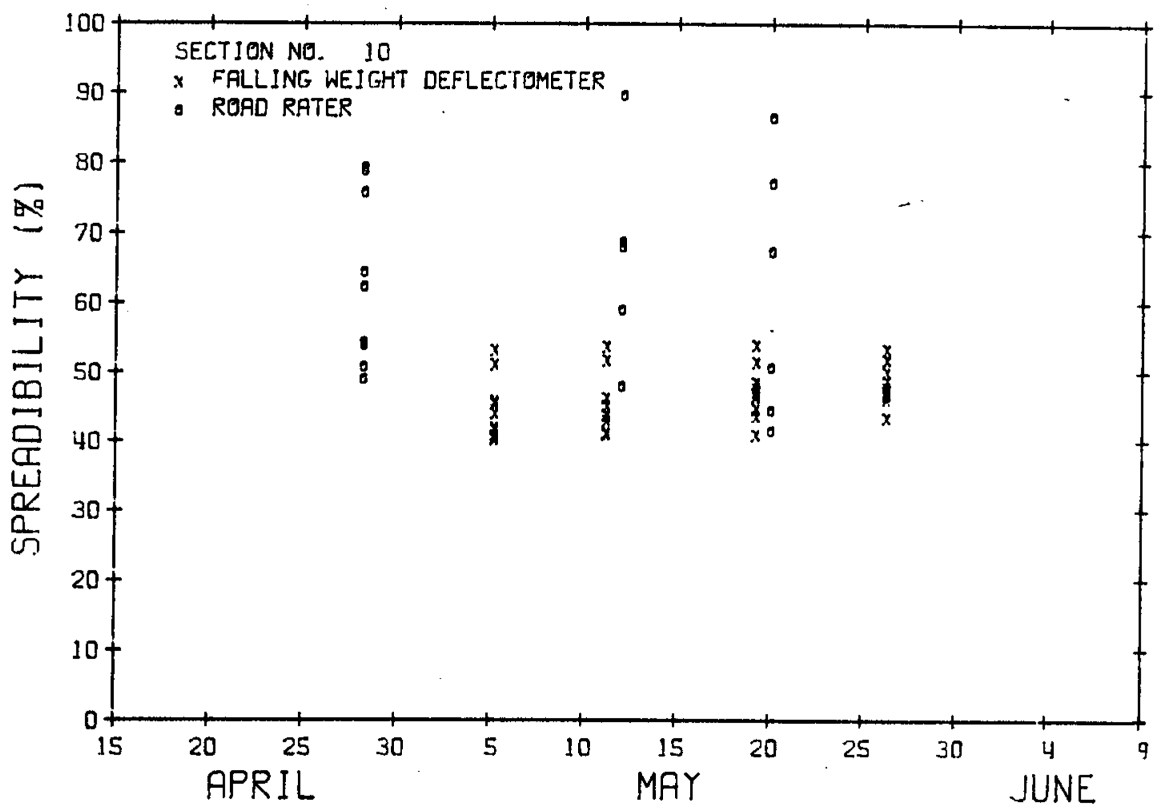
FALLING WEIGHT DEFLECTOMETER, DEFLECTIONS VS. TIME



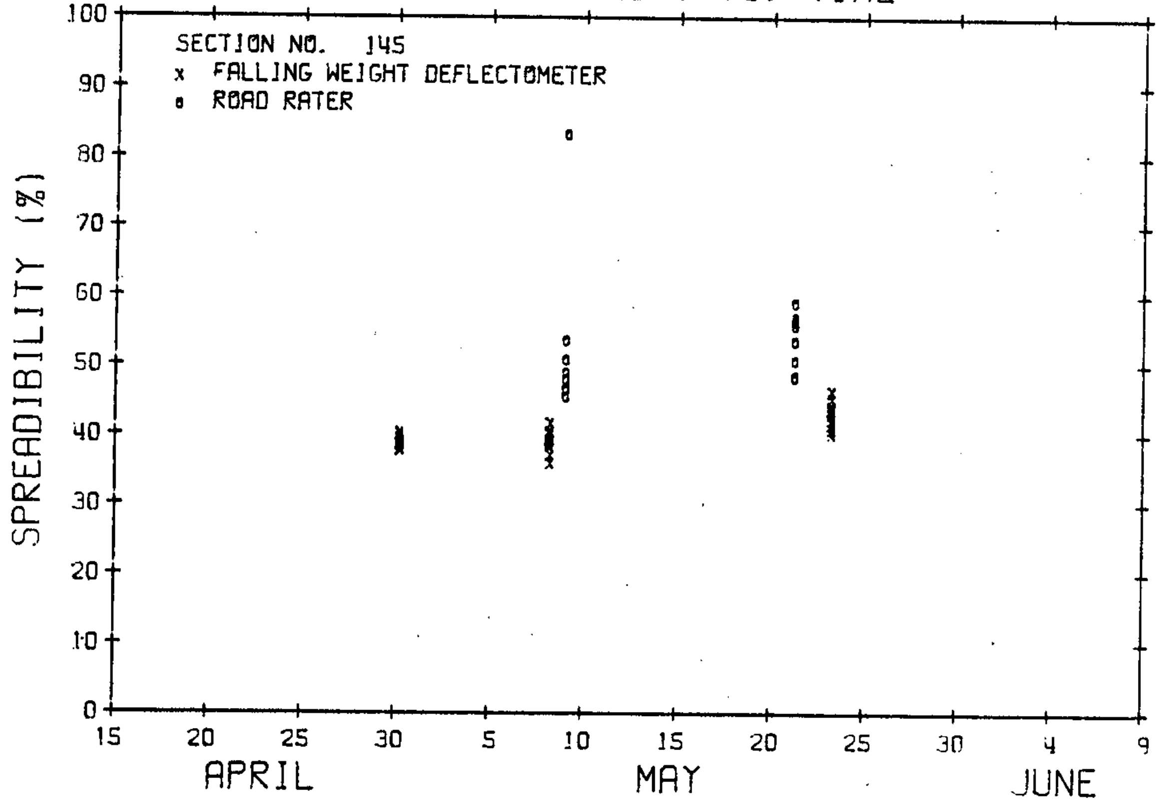


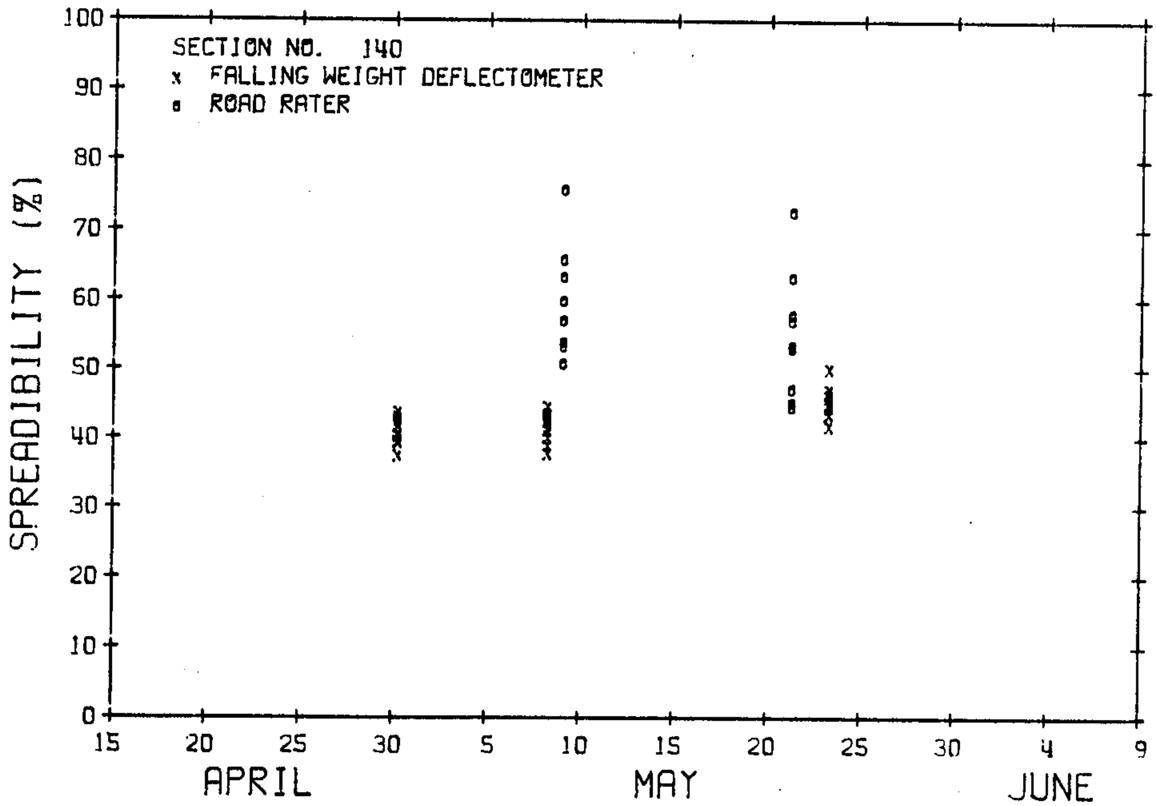
SPREADIBILITY VS. TIME



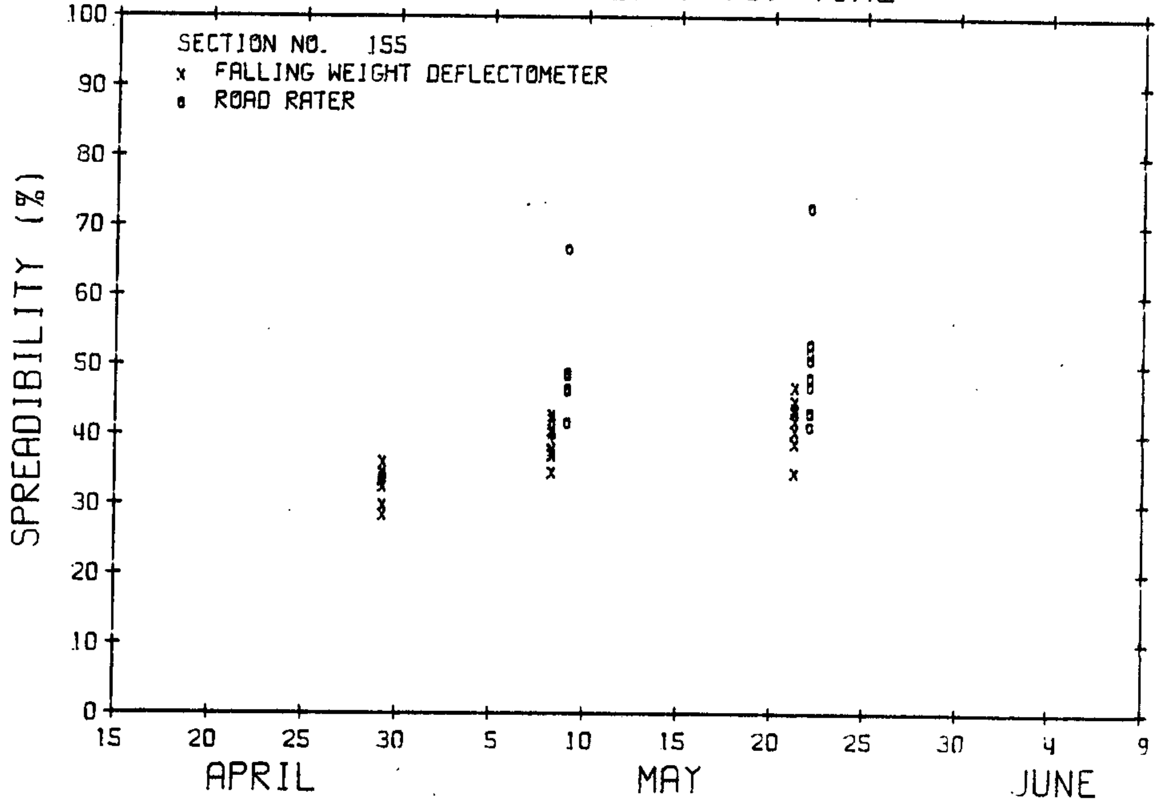


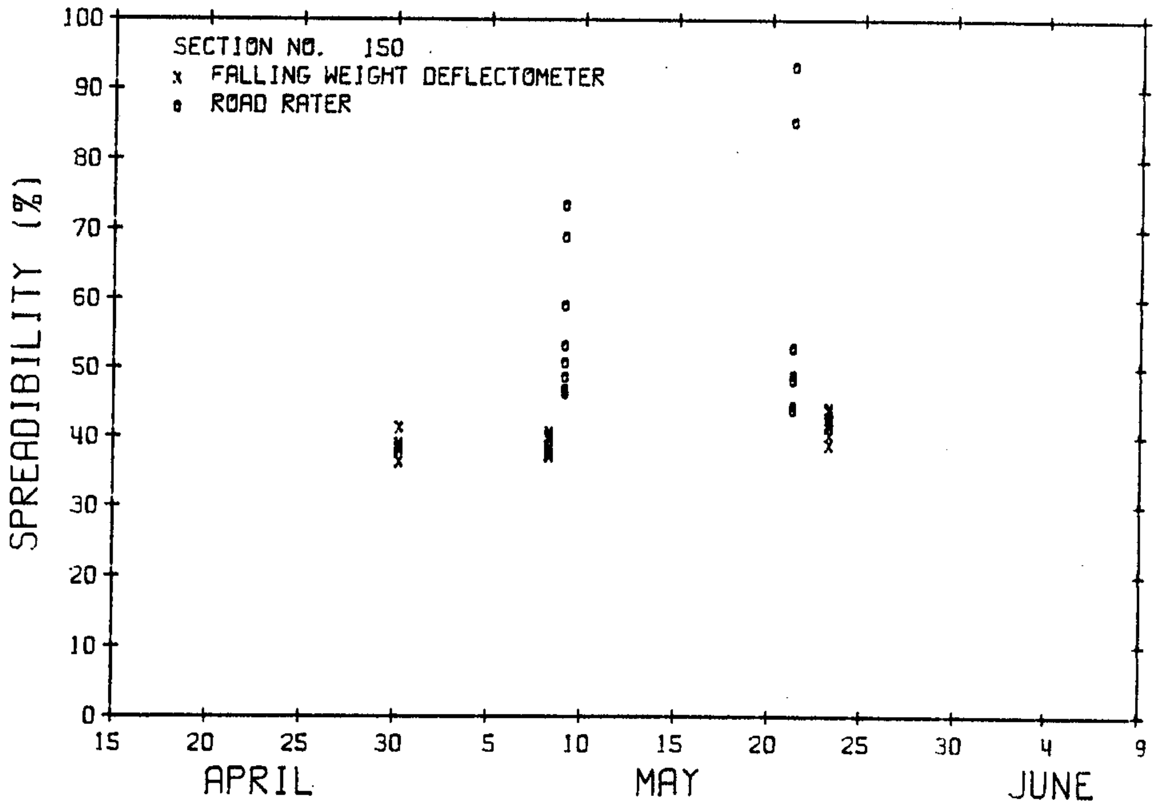
SPREADIBILITY VS. TIME



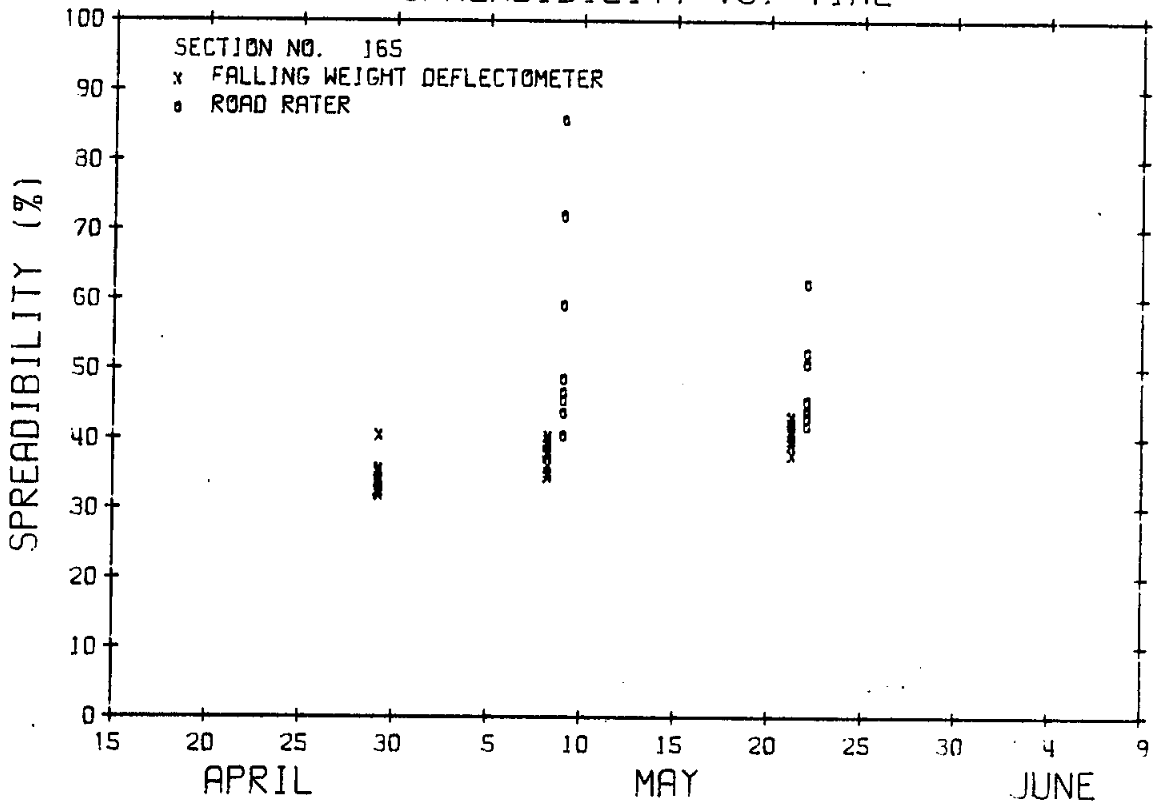


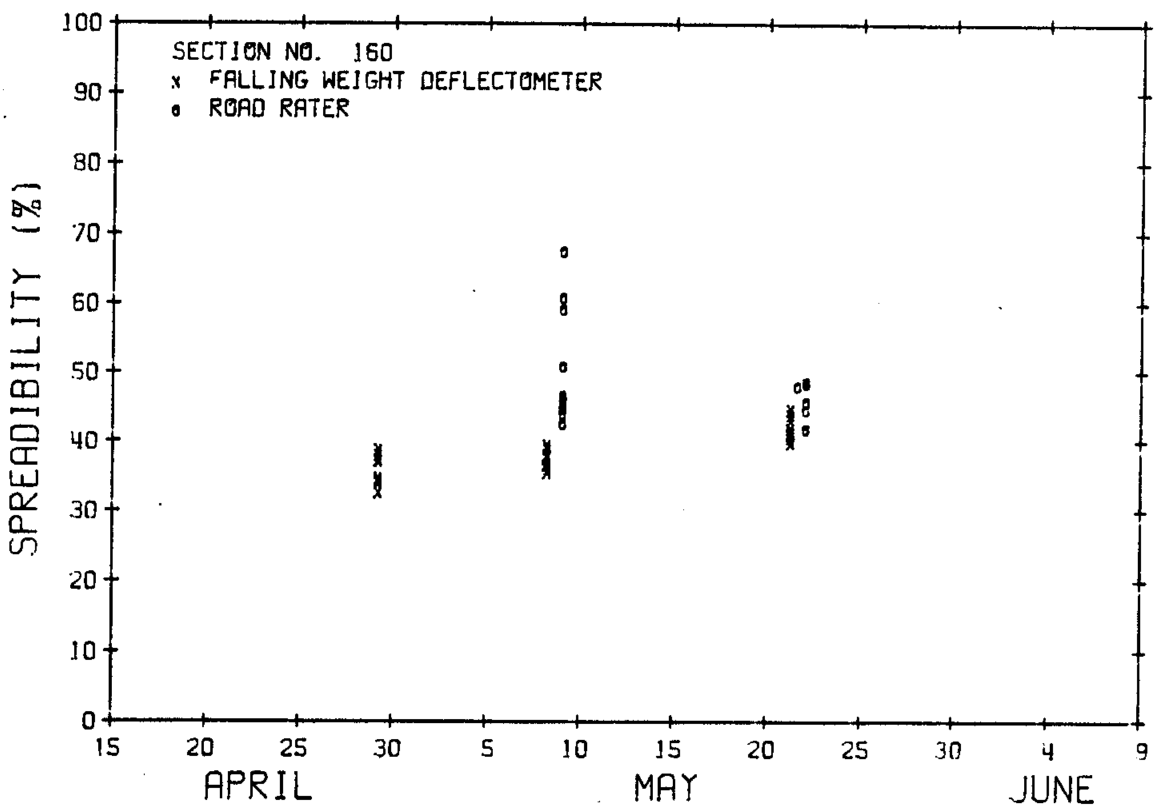
SPREADIBILITY VS. TIME



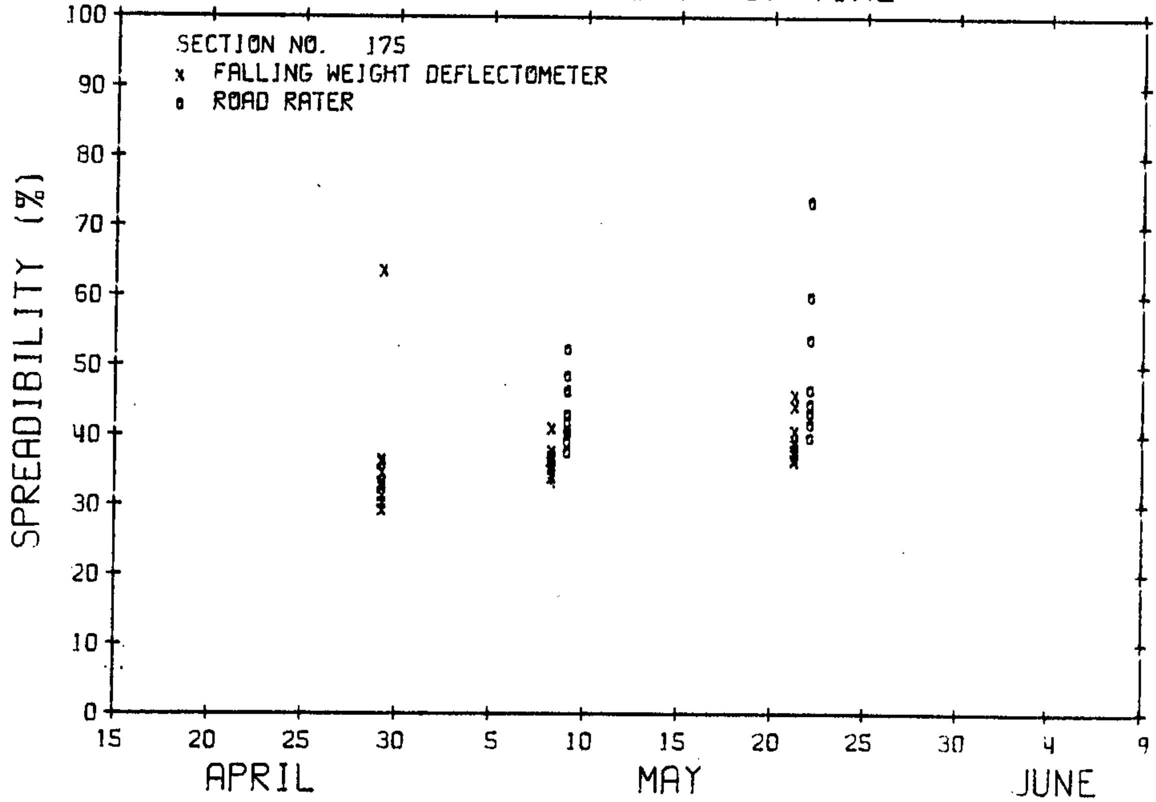


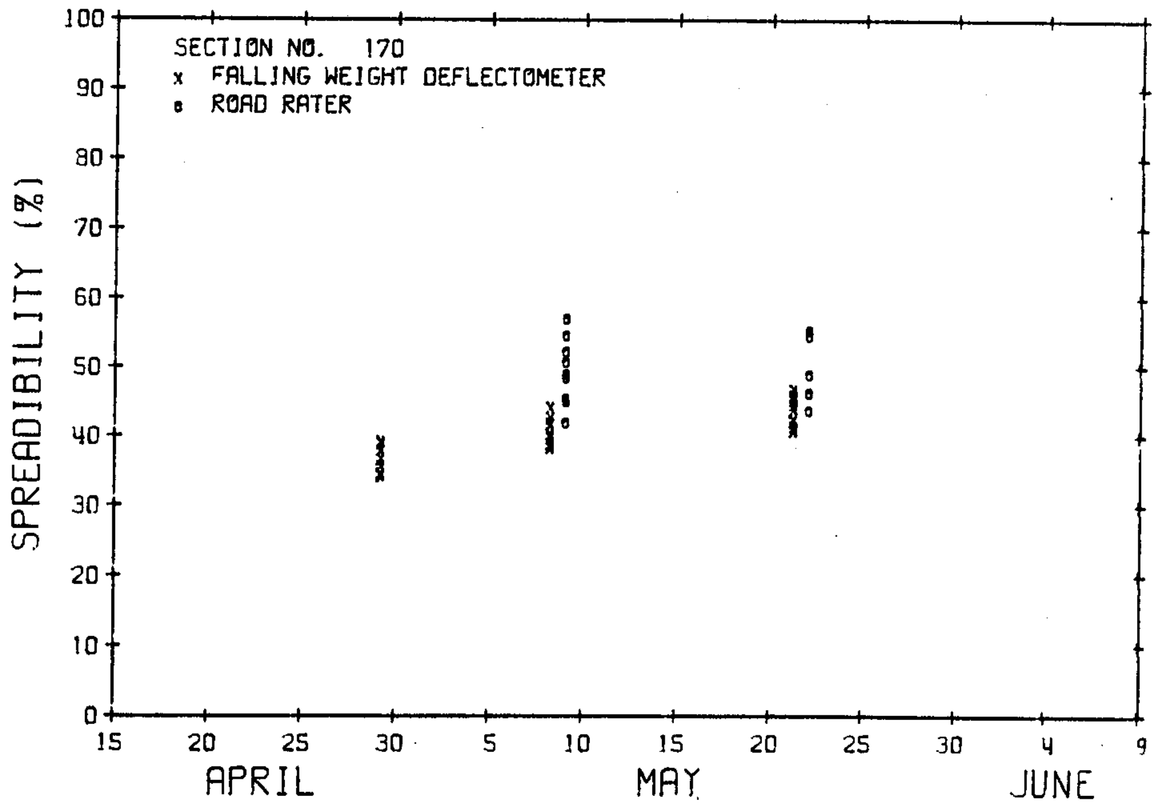
SPREADIBILITY VS. TIME

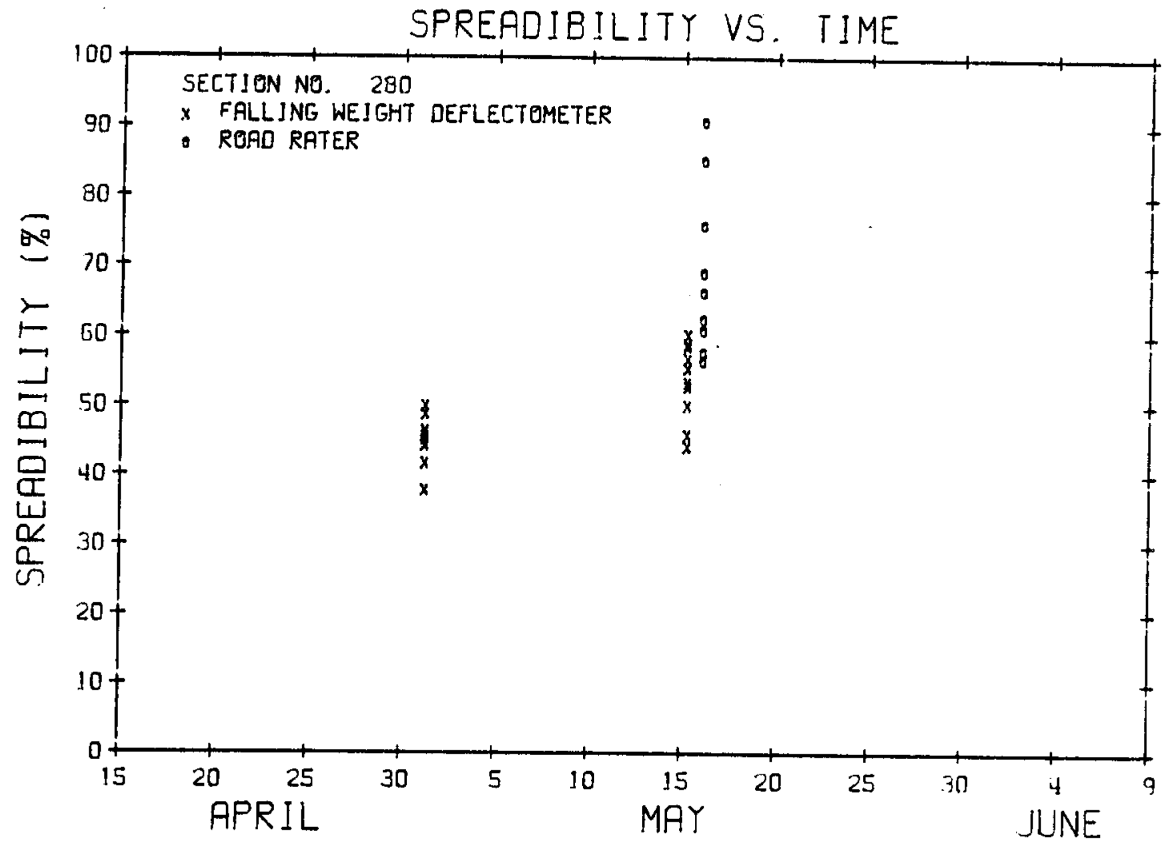


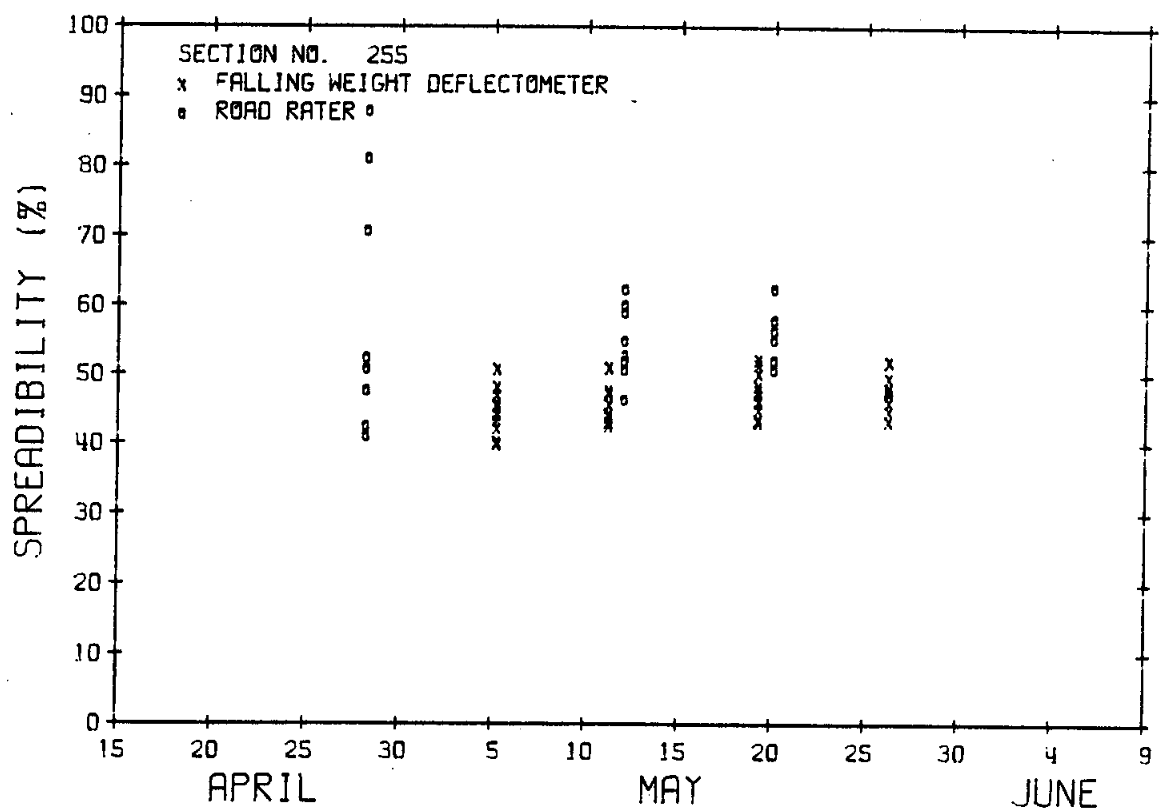


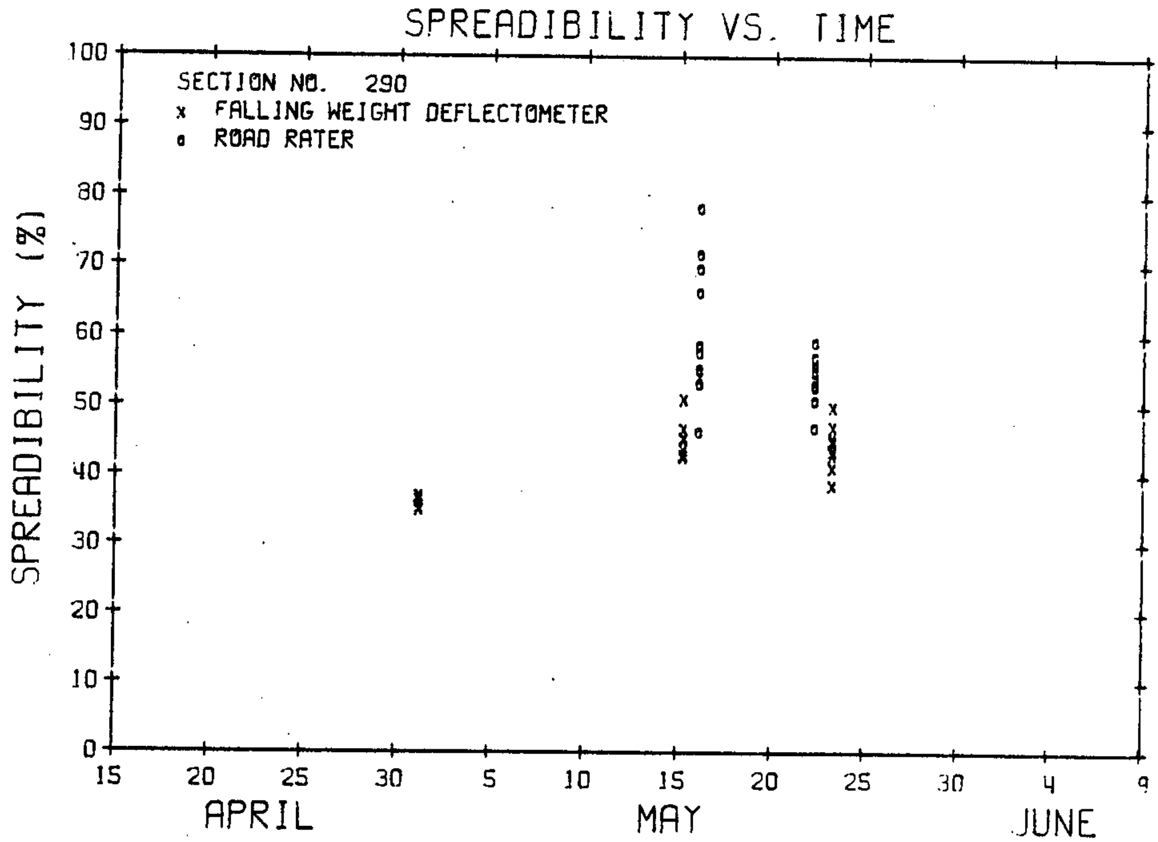
SPREADIBILITY VS. TIME

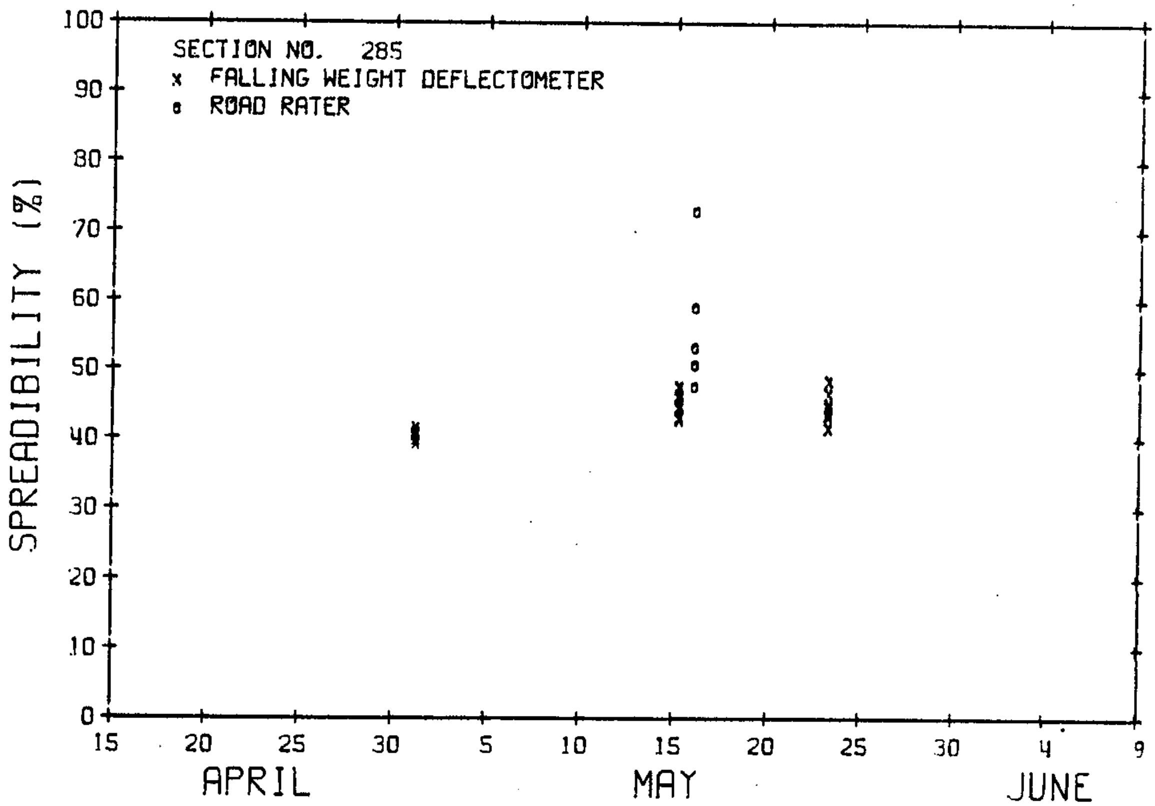


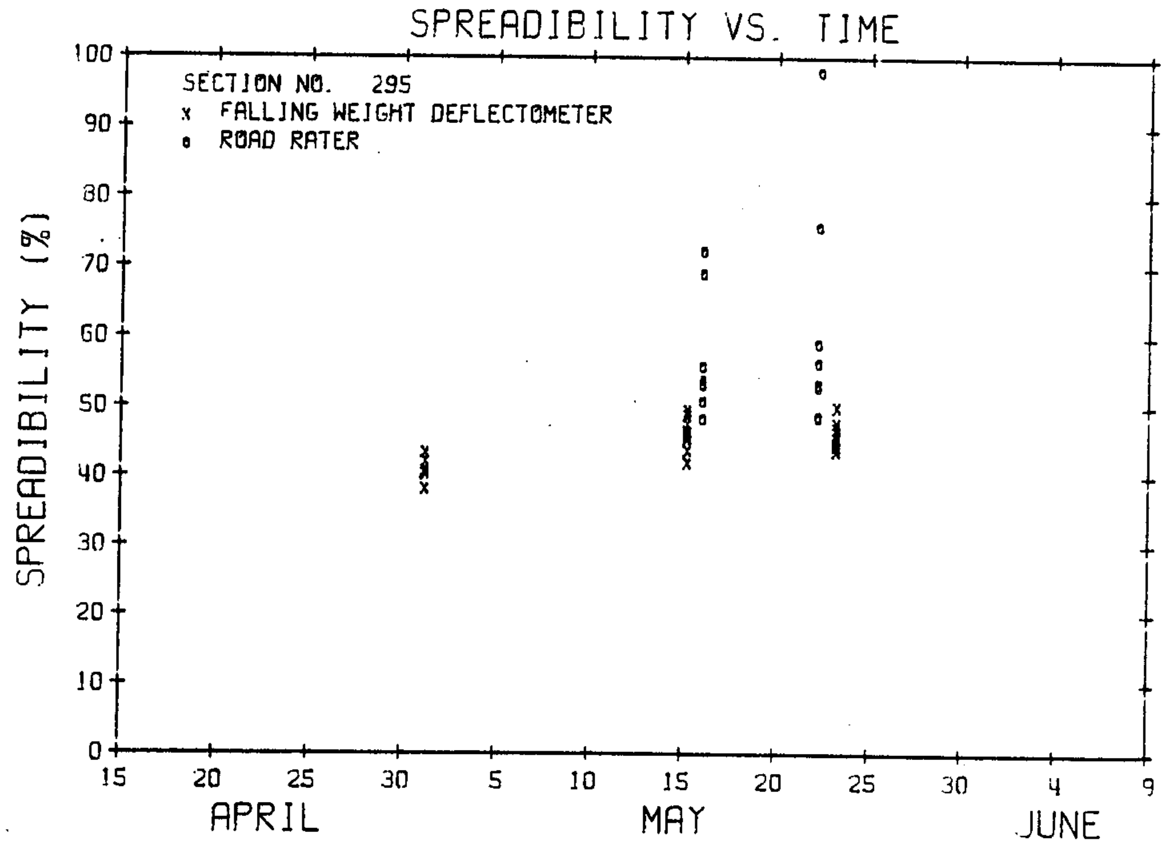



SPREADIBILITY VS. TIME
SECTION NO. 280
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SECTION NO. 255
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SPREADIBILITY VS. TIME
SECTION NO. 290
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SECTION NO. 285
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SPREADIBILITY VS. TIME
SECTION NO. 295
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
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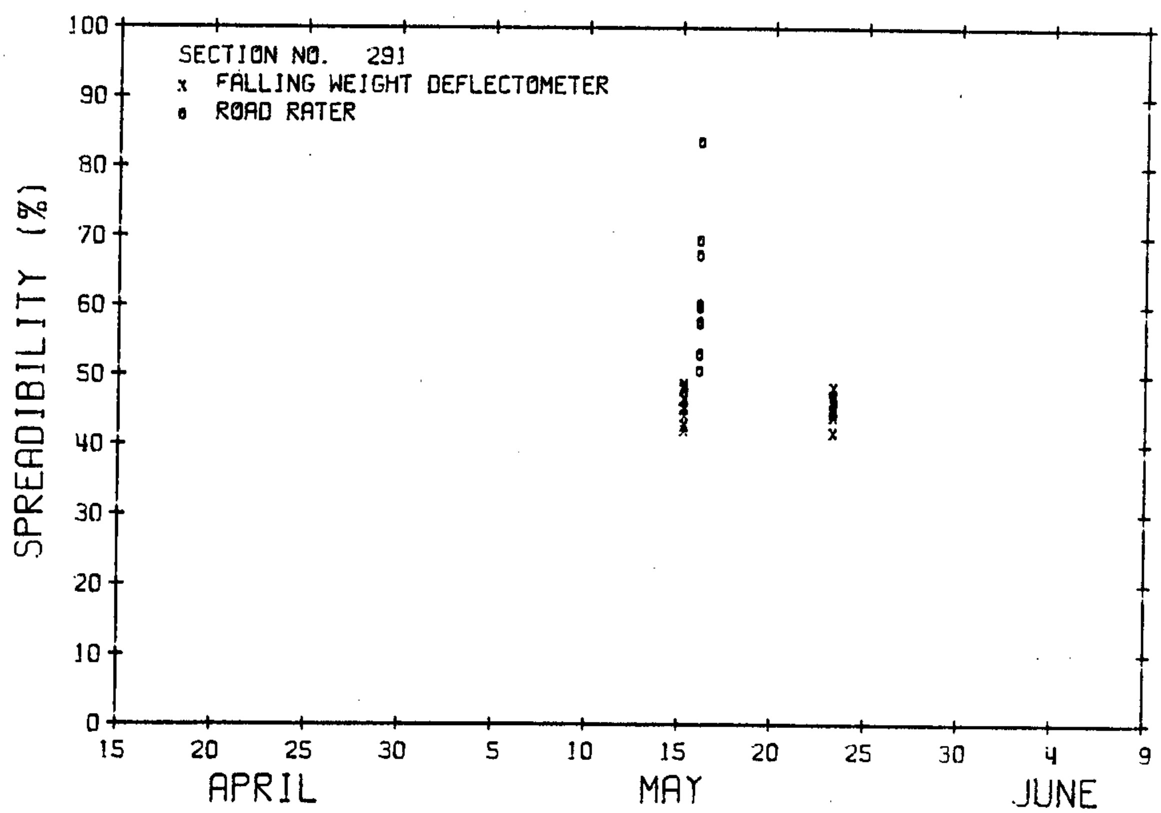
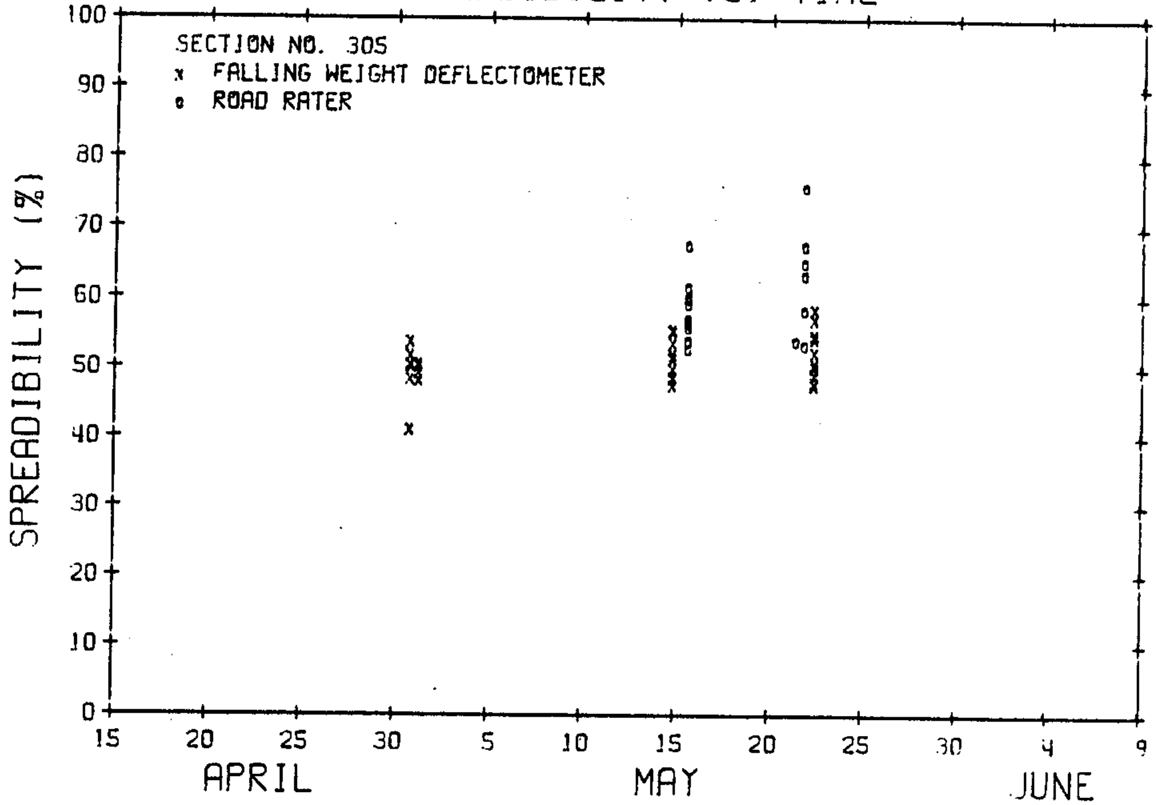
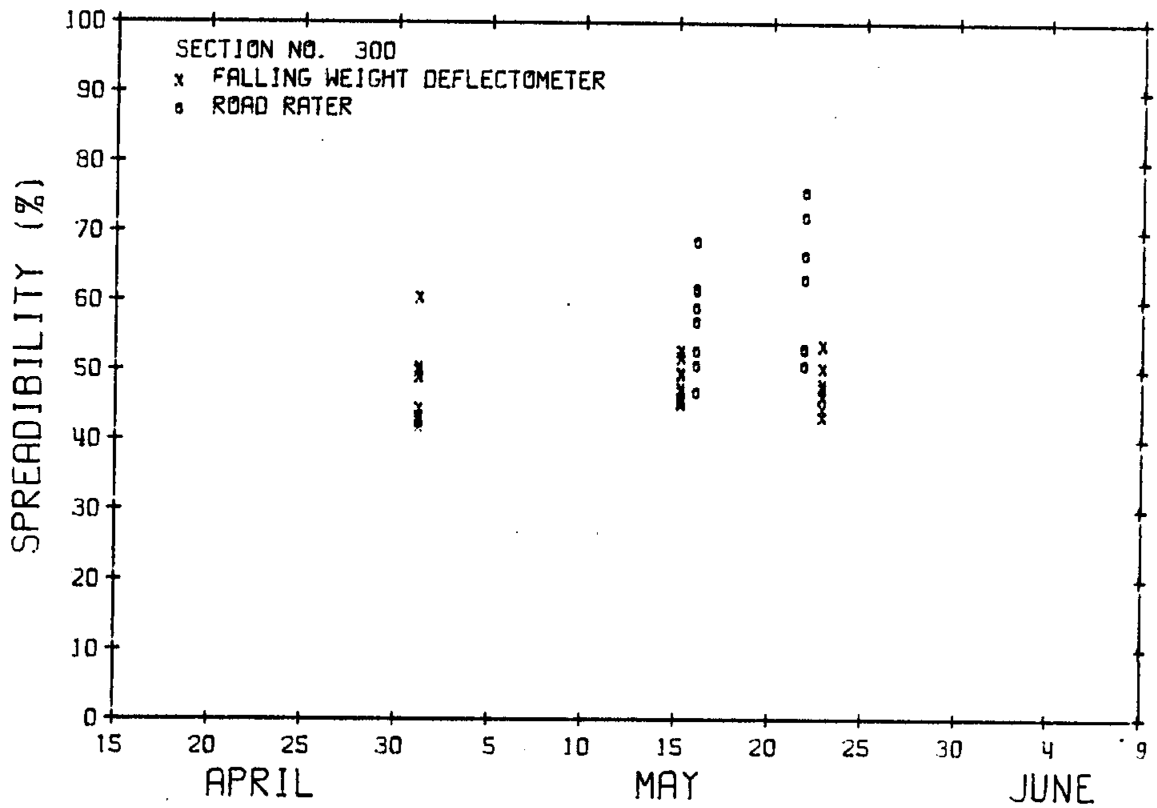
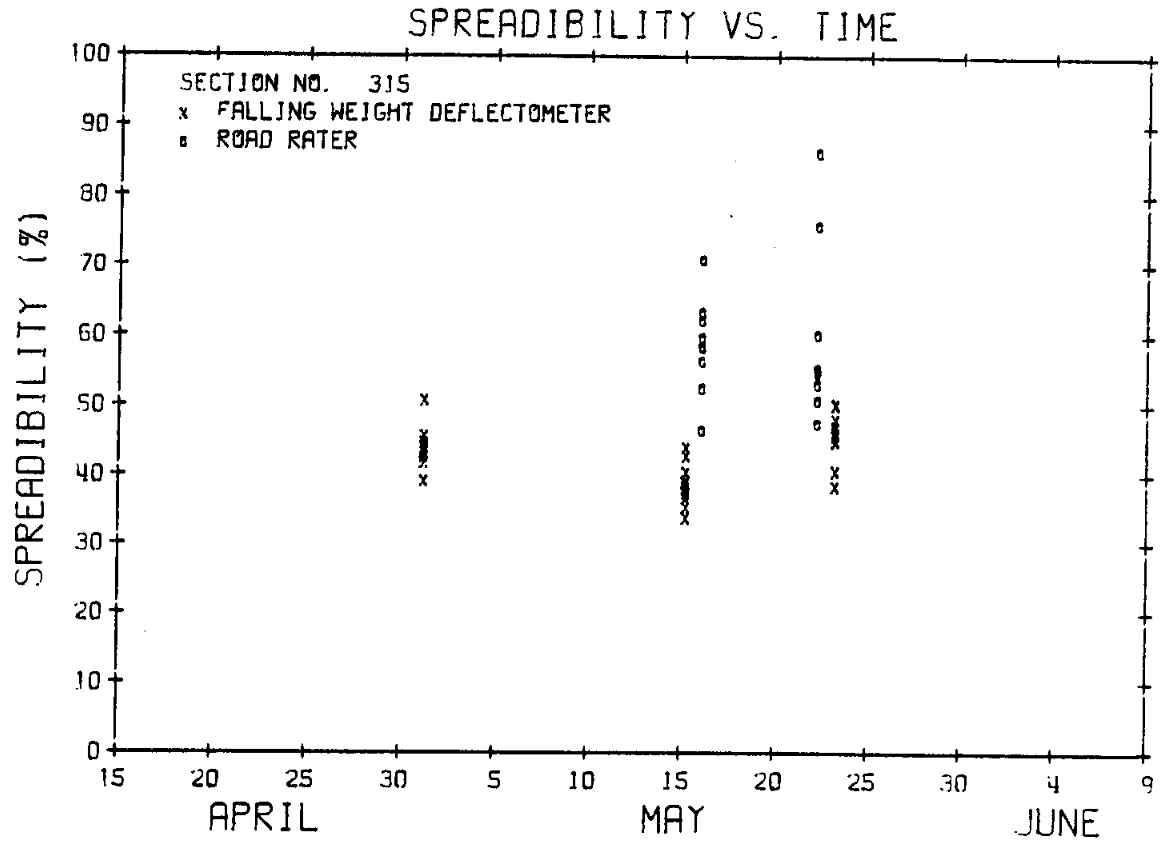
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

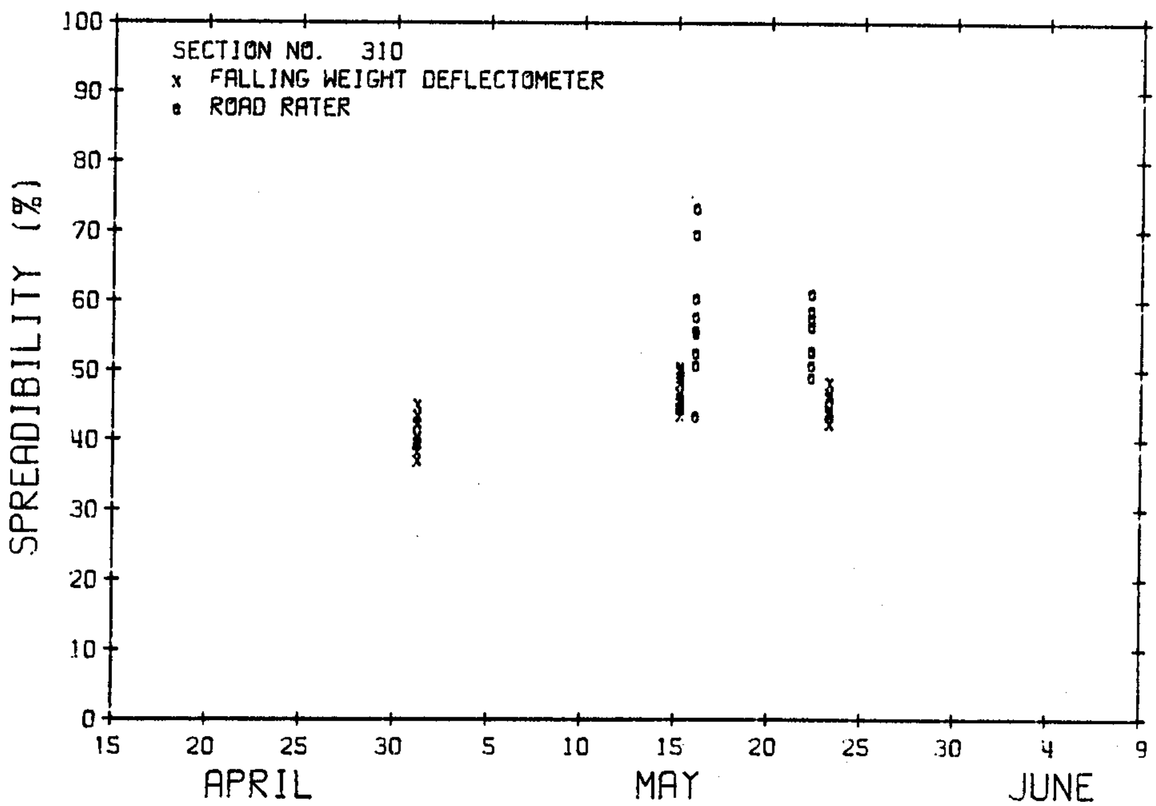

SECTION NO. 291
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

SPREADIBILITY VS. TIME






SPREADIBILITY VS. TIME
SECTION NO. 315
x FALLING WEIGHT DEFLECTOMETER
▫ ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SECTION NO. 310
x FALLING WEIGHT DEFLECTOMETER
▫ ROAD RATER
SPREADIBILITY (%)
100
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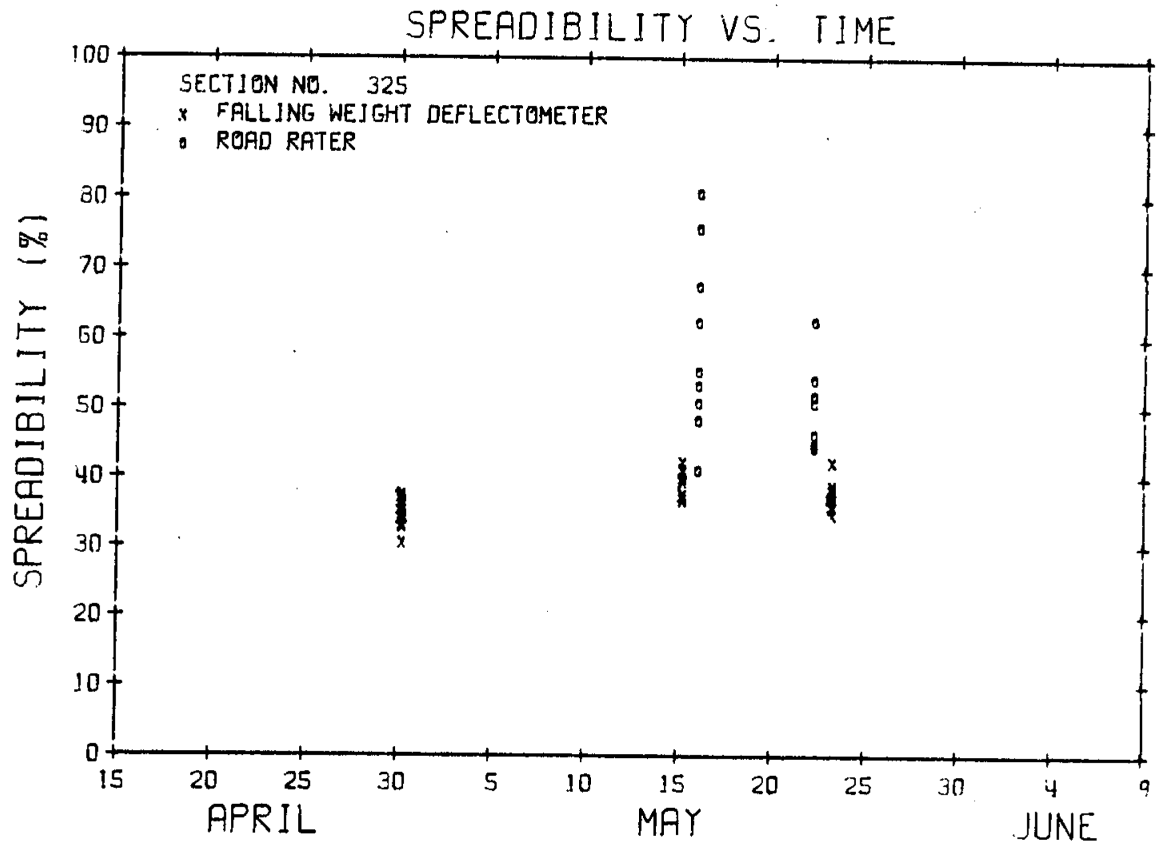
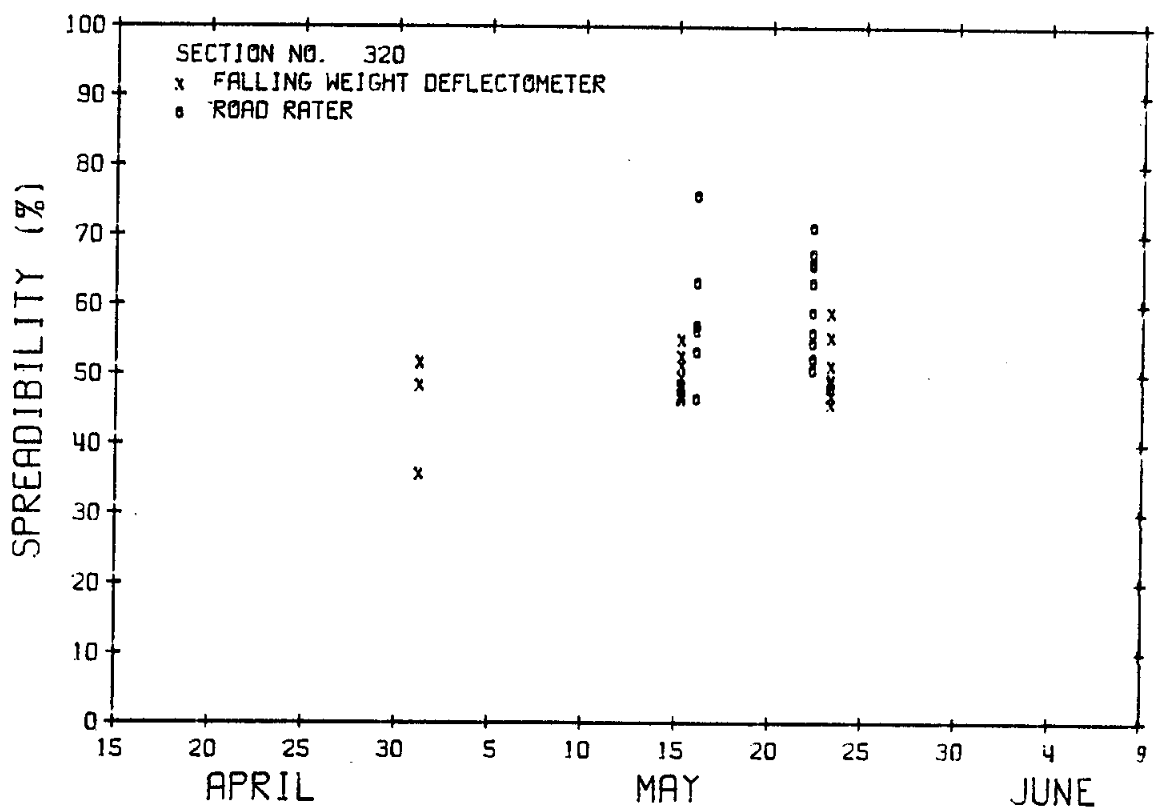
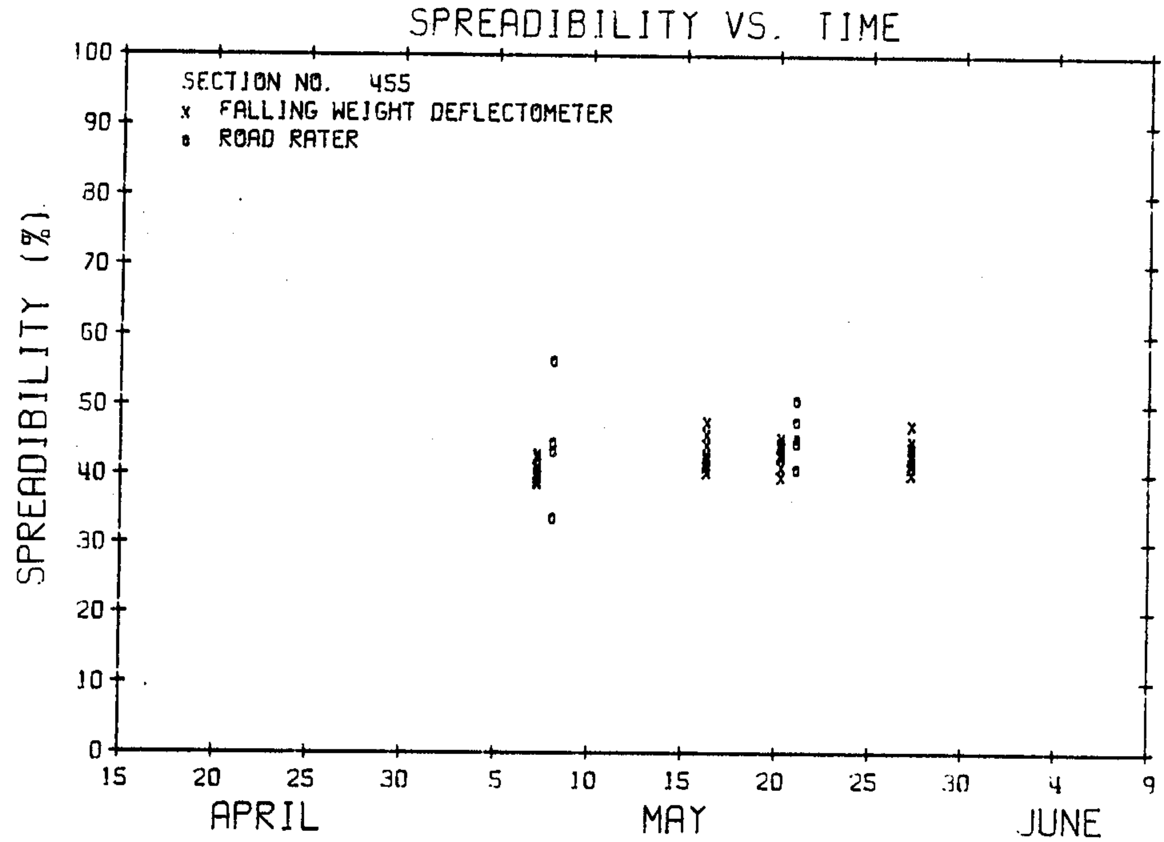
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SPREADIBILITY VS. TIME
SECTION NO. 325
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
0
10
20
30
40
50
60
70
80
90
100
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SECTION NO. 320
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
0
10
20
30
40
50
60
70
80
90
100
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SPREADIBILITY VS. TIME
SECTION NO. 455
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
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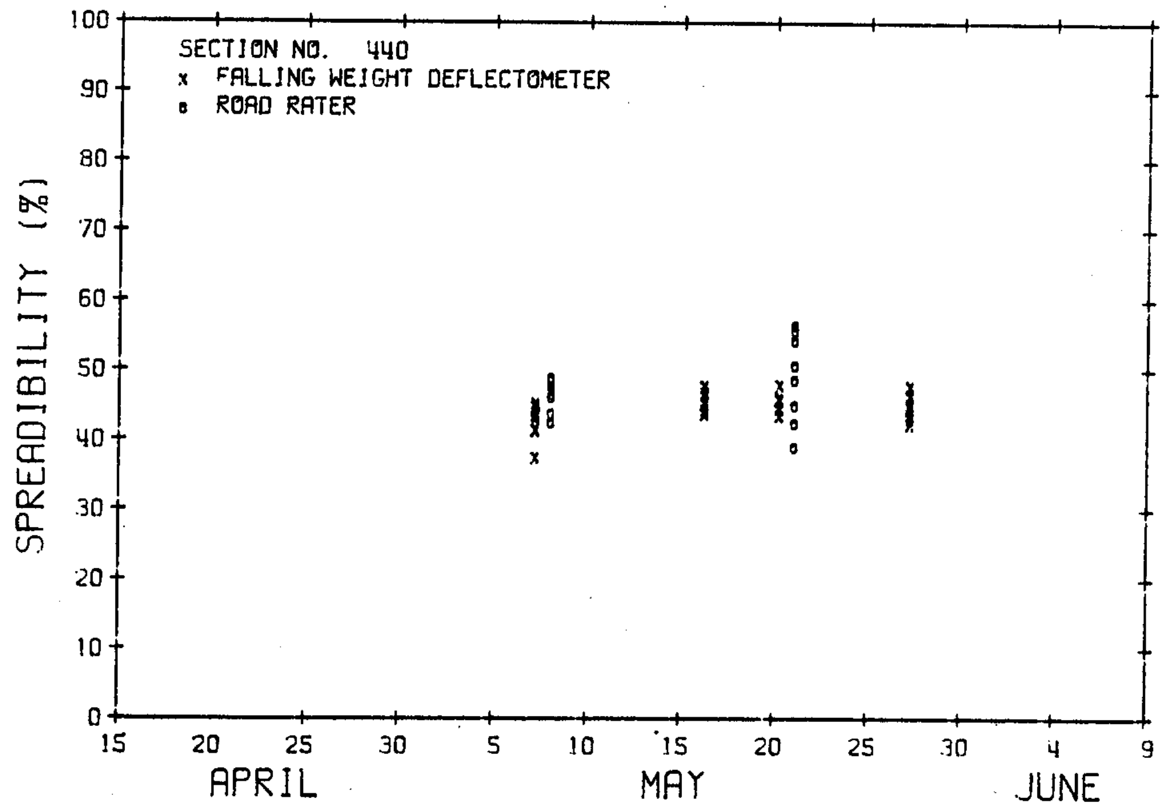
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SECTION NO. 440
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
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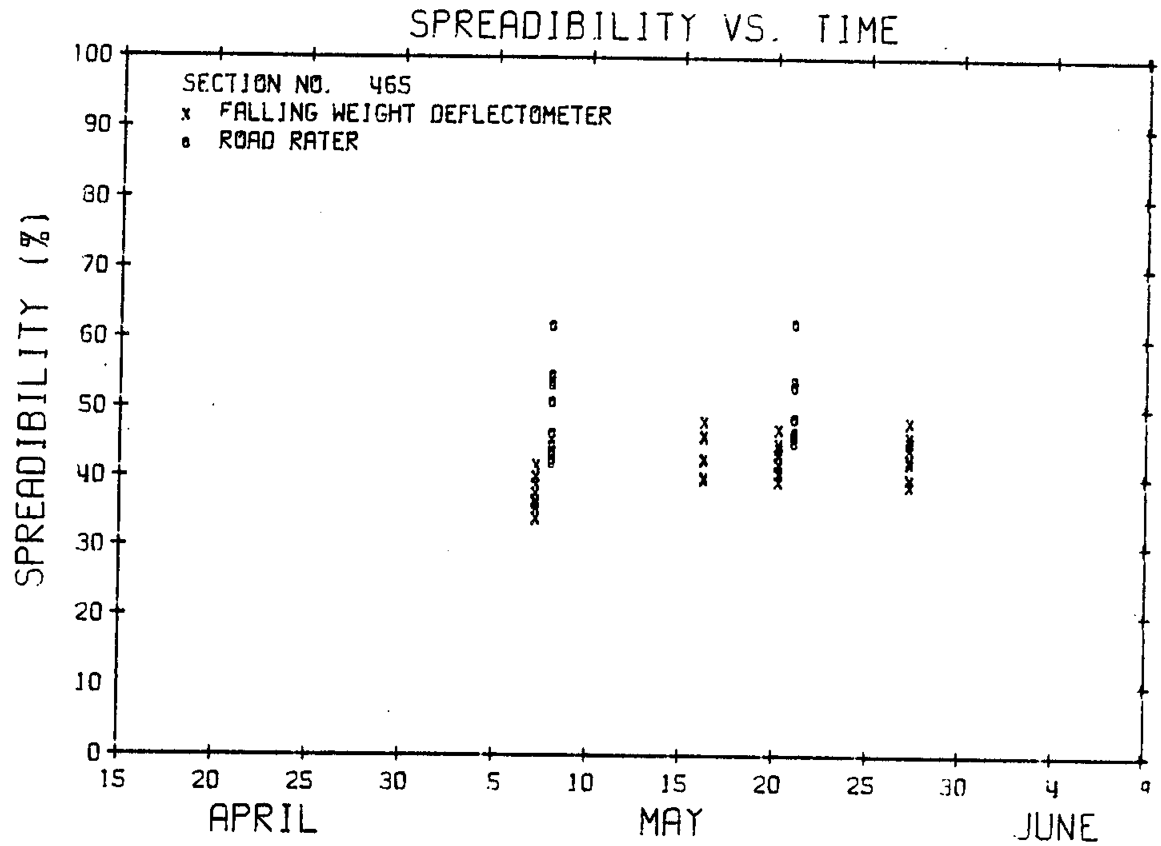
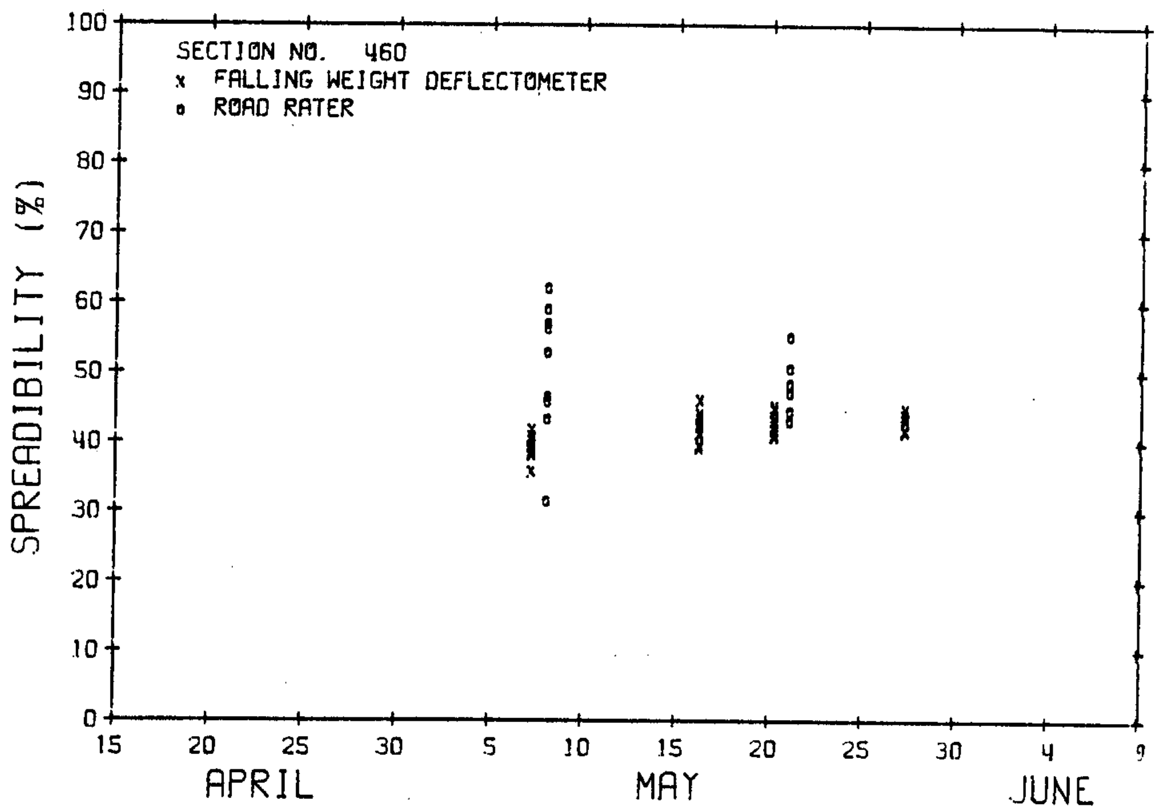
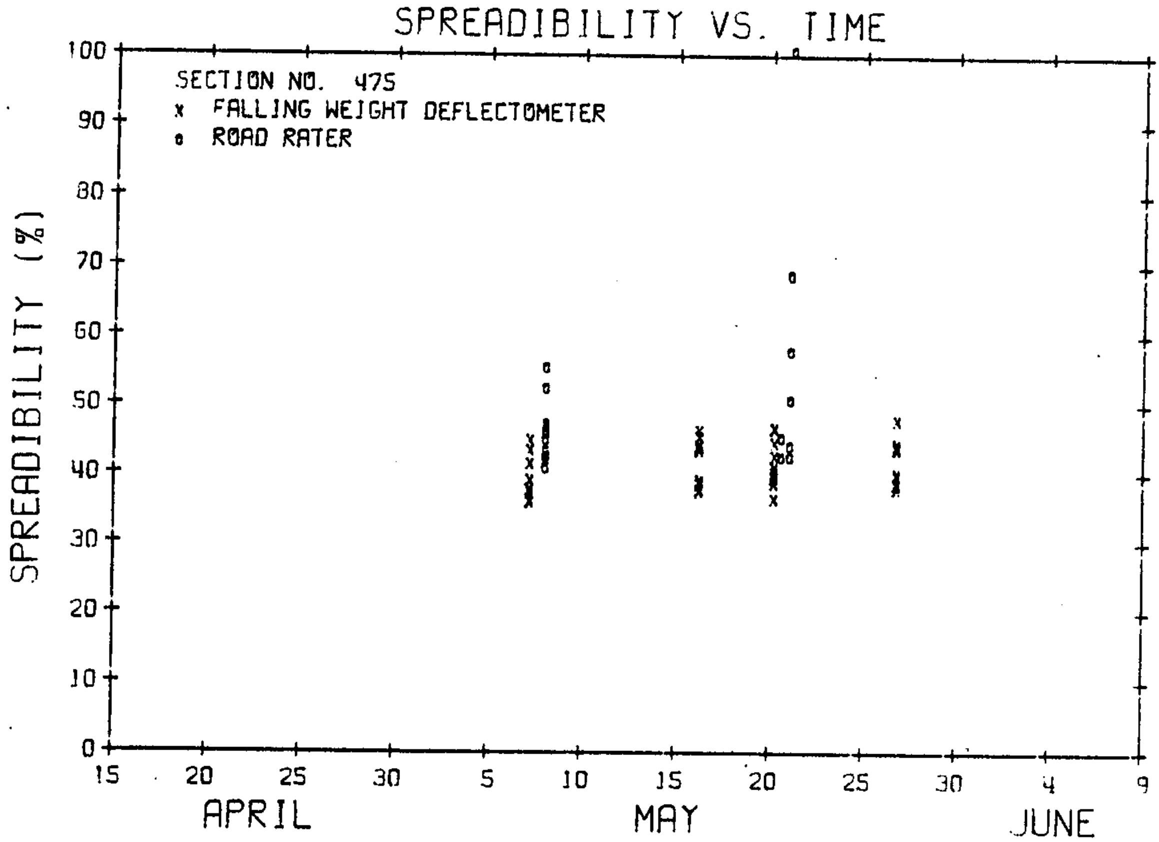
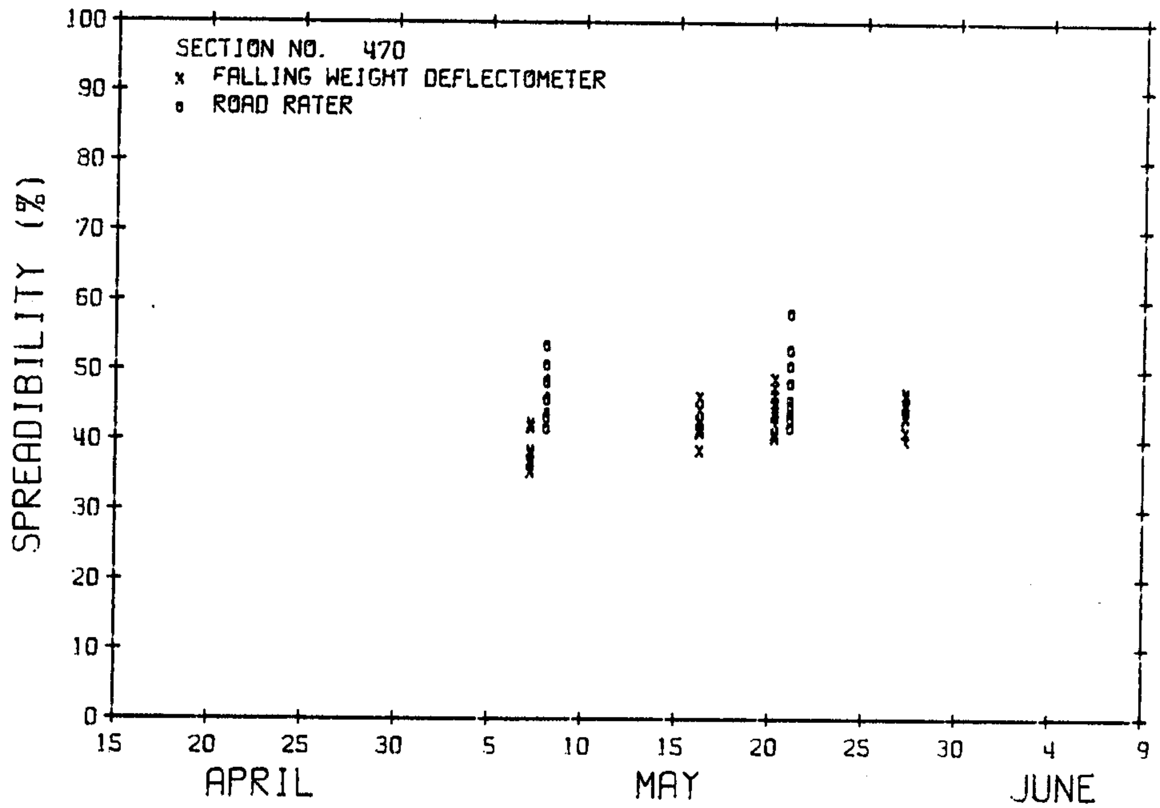
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SPREADIBILITY VS. TIME
SECTION NO. 465
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
0
10
20
30
40
50
60
70
80
90
100
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE


SECTION NO. 460
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
0
10
20
30
40
50
60
70
80
90
100
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

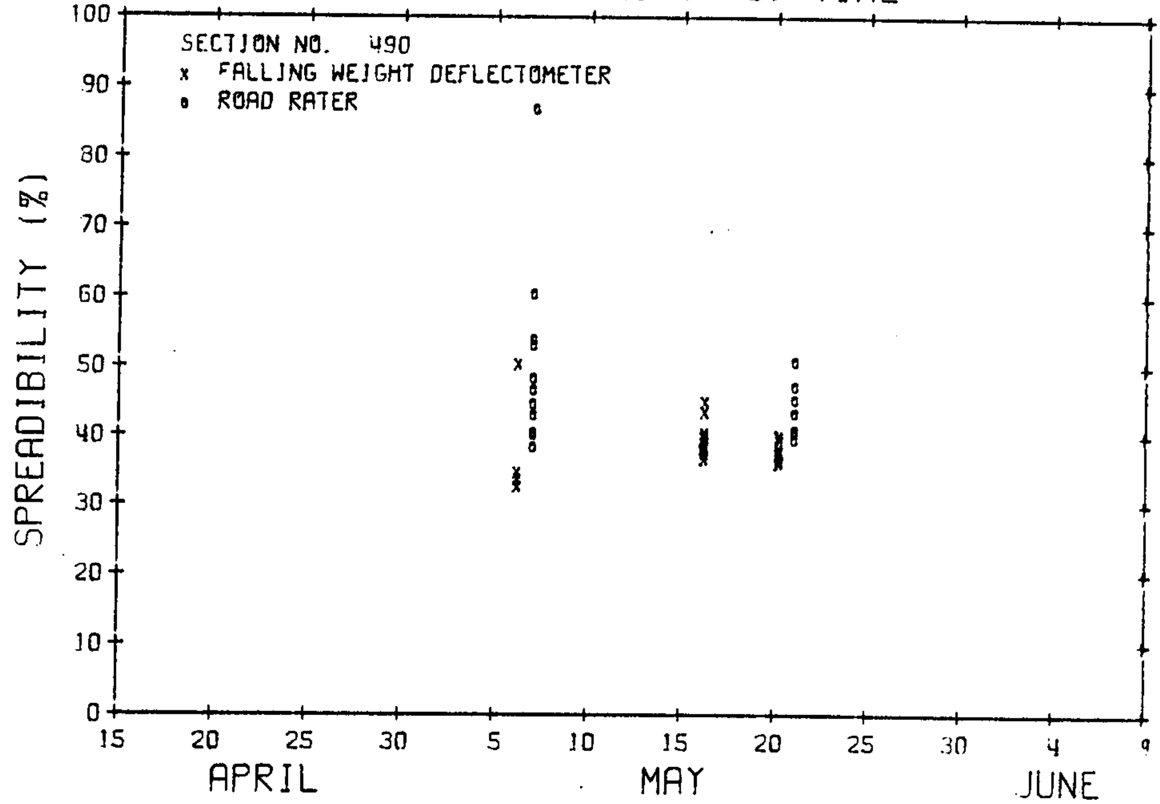


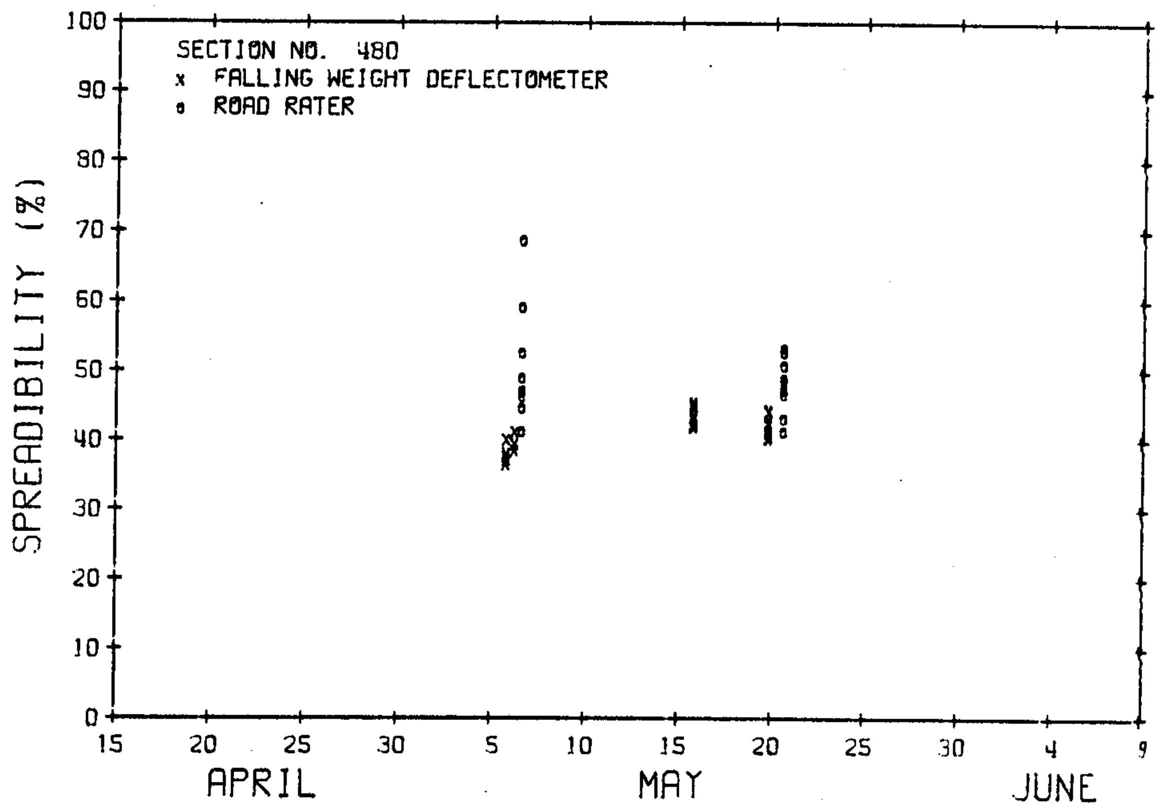
SPREADIBILITY VS. TIME
SECTION NO. 475
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE



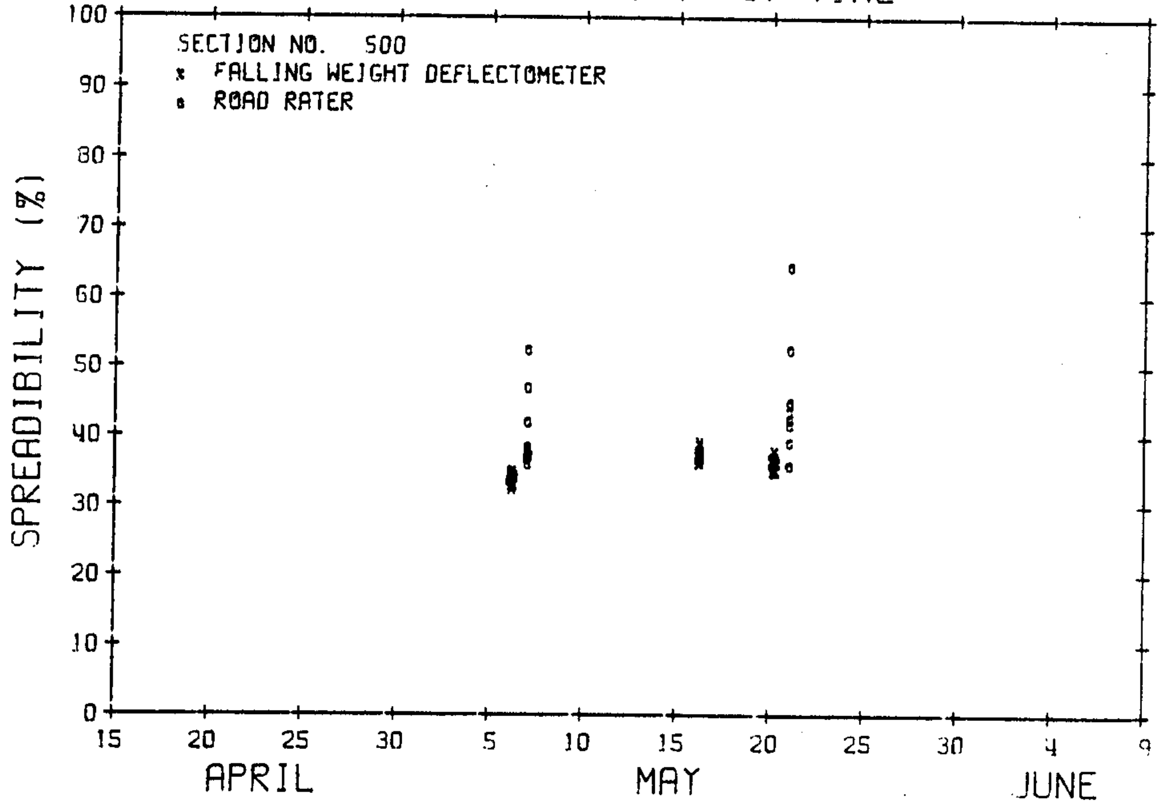
SECTION NO. 470
x FALLING WEIGHT DEFLECTOMETER
o ROAD RATER
SPREADIBILITY (%)
100
90
80
70
60
50
40
30
20
10
0
15
20
25
30
5
10
15
20
25
30
4
9
APRIL
MAY
JUNE

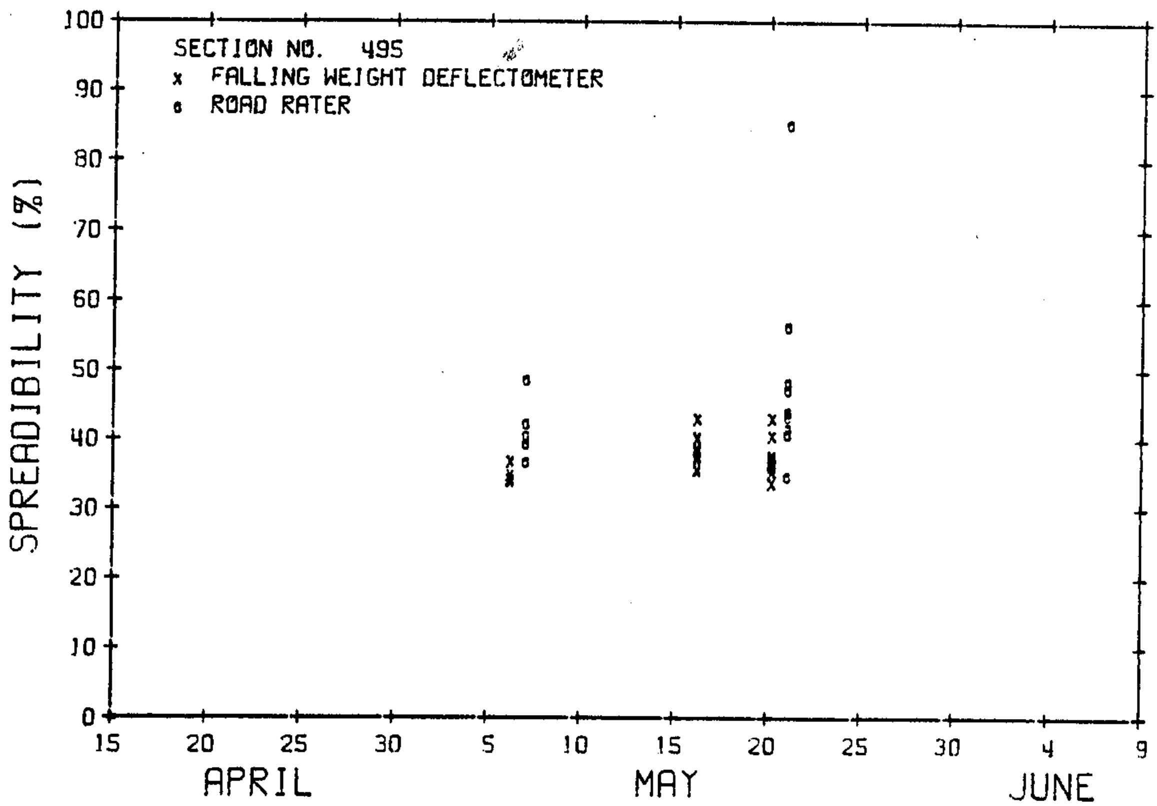
SPREADIBILITY VS. TIME



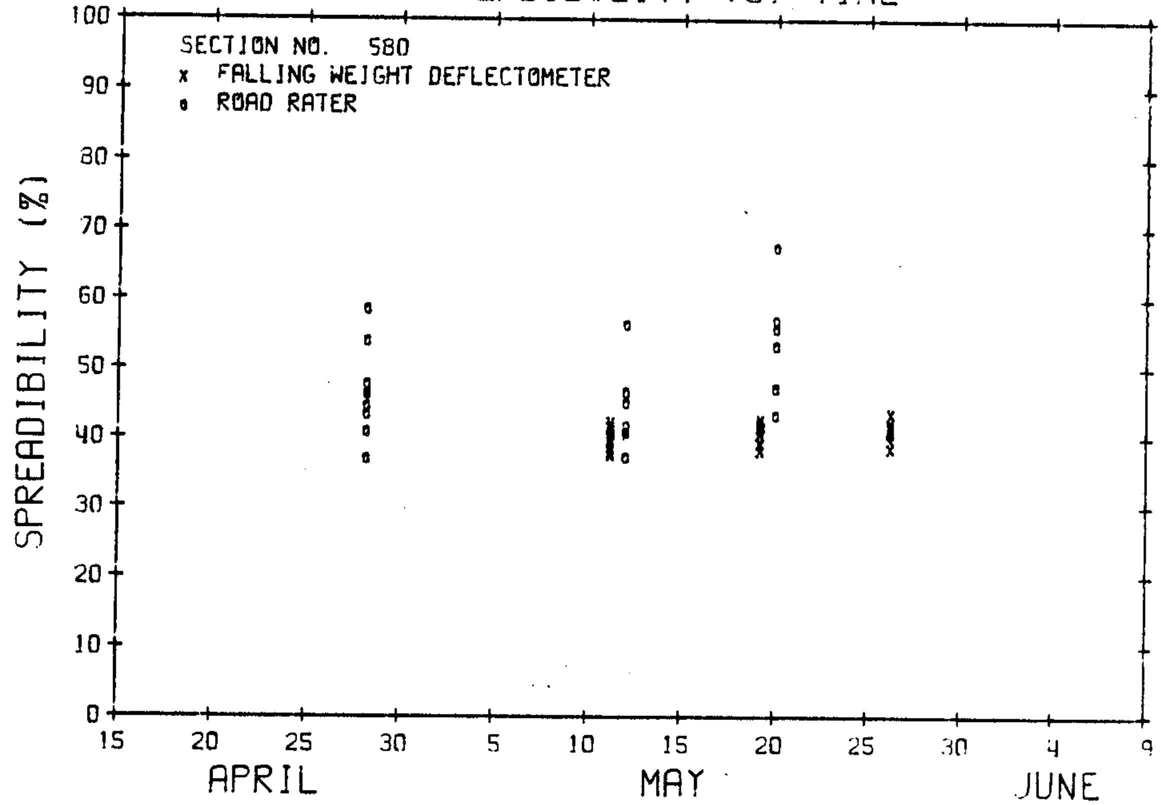


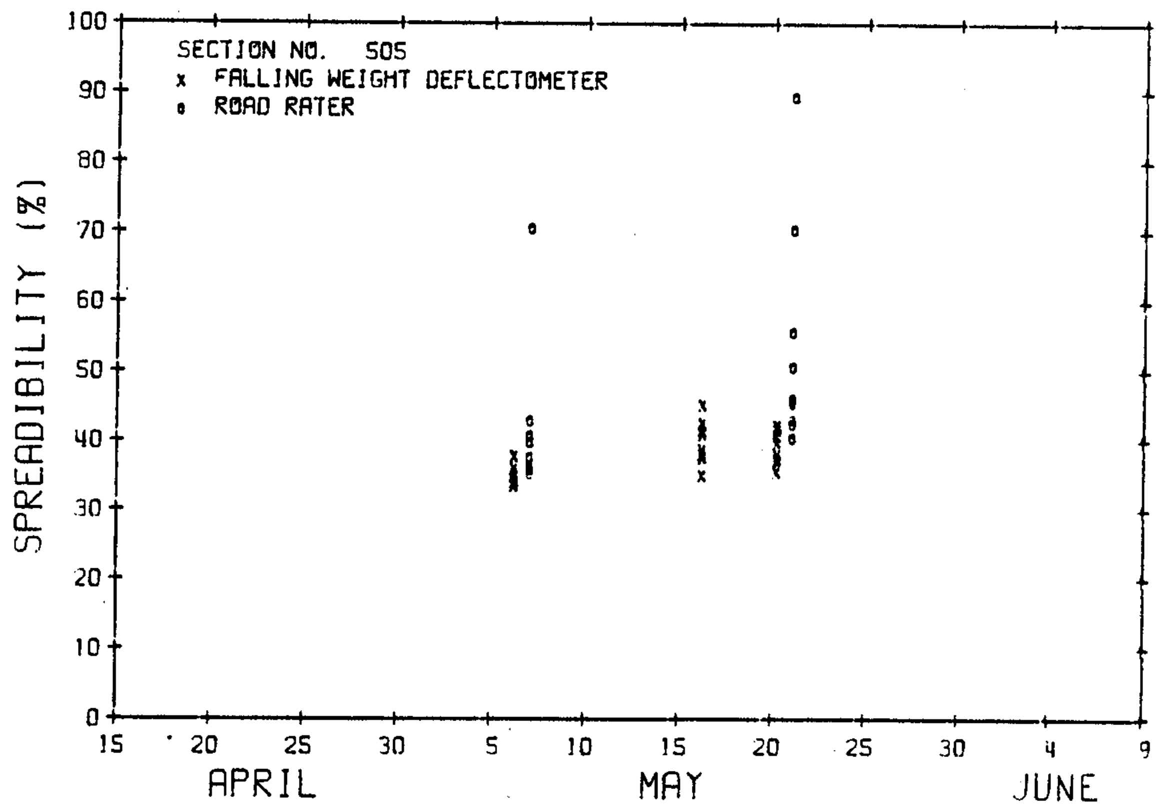
SPREADIBILITY VS. TIME



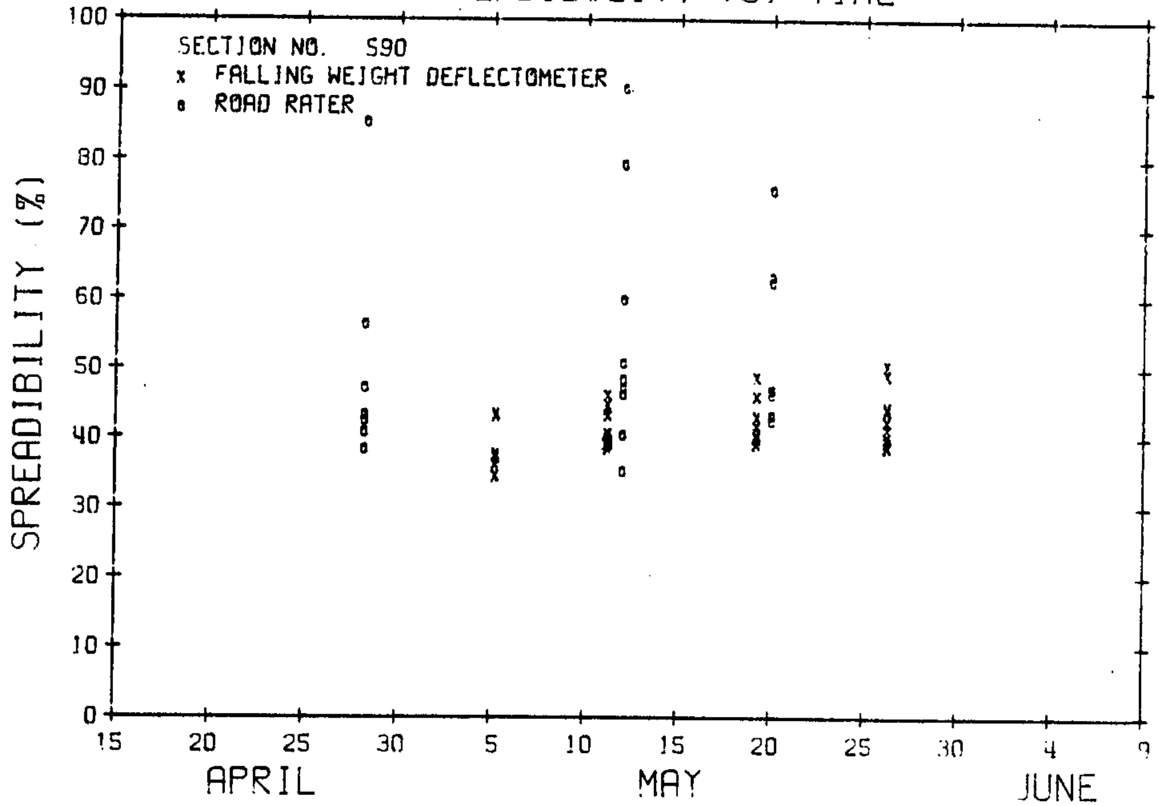


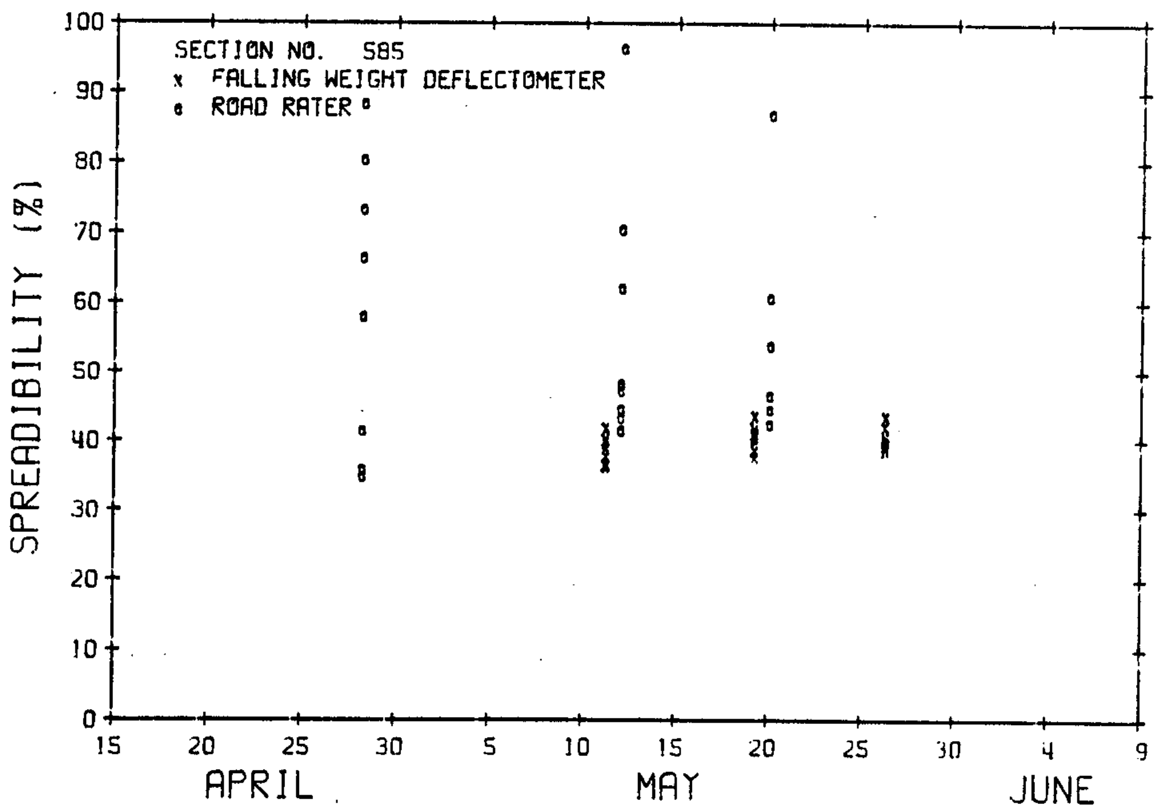
SPREADIBILITY VS. TIME



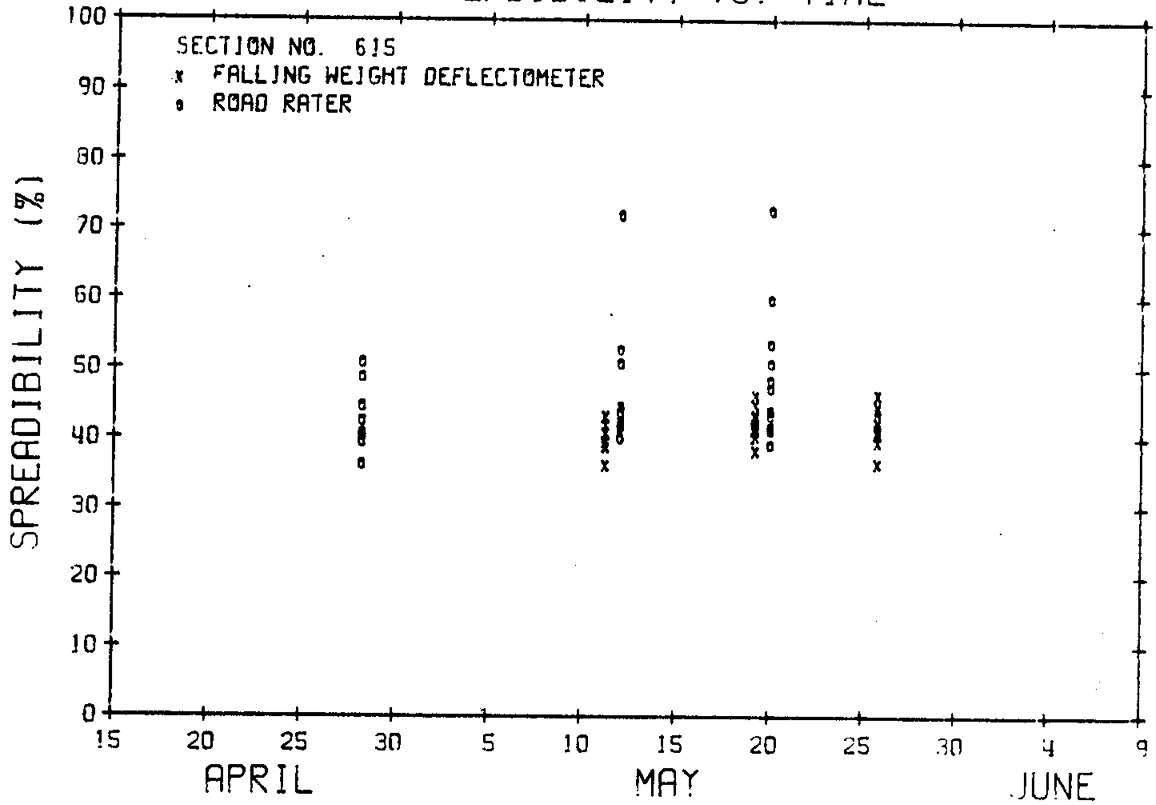


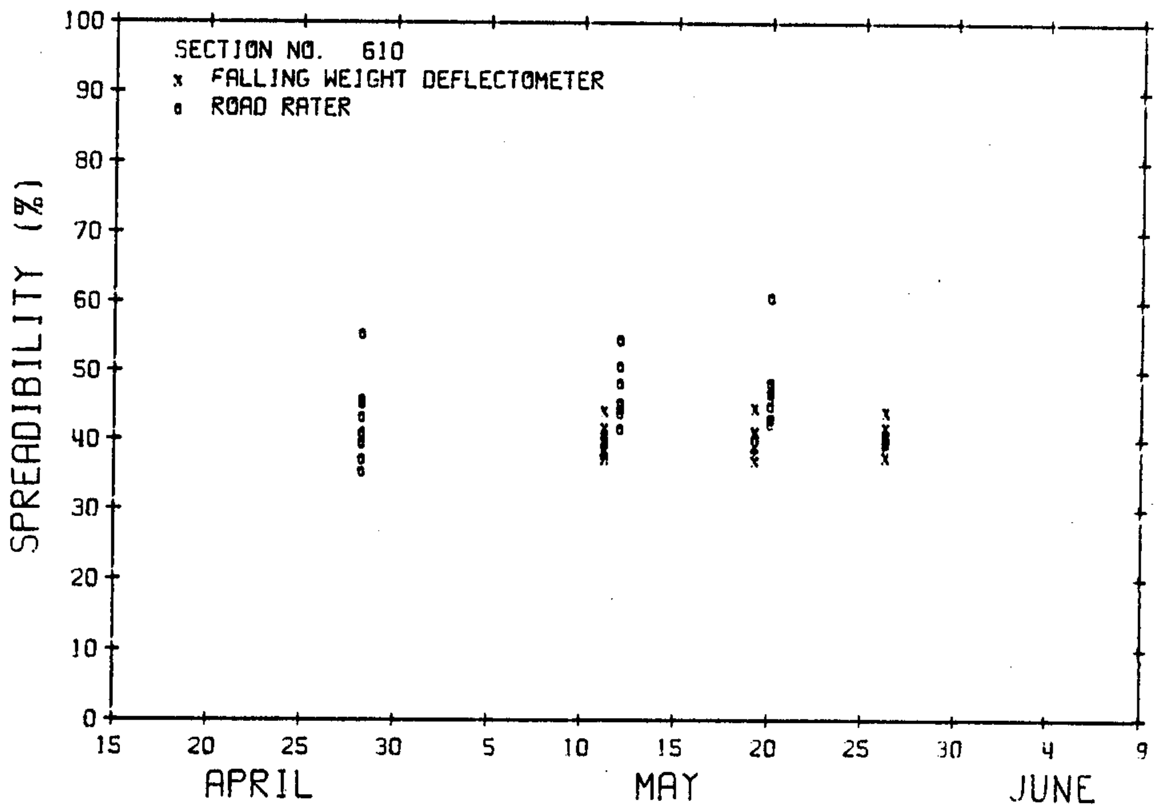
SPREADIBILITY VS. TIME





SPREADIBILITY VS. TIME





APPENDIX B

Table of Analysis of Variance (ANOVA)
for Spreadability Data

NOTE: While beyond the scope of this report, a complete discussion of the ANOVA test is given: Davis, John C., 1973 Statistics and Data Analysis in Geology, Wiley.

Notes on ANOVA

Null hypotheses:

Spreadability values for a given road section on day 1 = spreadability values for the same road section on day 2.

Alternate hypotheses:

Spreadability values for a given road section on day 1 = spreadability values for the same road section on day 2.

Section descriptions and locations:

Described in Appendix B of reference number 3.

Confidence level set for "F" for rejection of null hypotheses = 90%, i.e., rejection of the null hypotheses (cases where calculated F exceeds table value of F) will be in error no more than 10% of the time.

Category of Results:

1. Reject null hypotheses only for FWD data, i.e., FWD able to discriminate between spreadability values on different dates and RR not able to discriminate.

2. Reject null hypotheses for both FWD and RR data, i.e., FWD and RR both able to discriminate between between spreadability values and different dates.

3. Reject null hypotheses only for RR data, i.e., FWD not able to discriminate between spreadability values on different dates and RR able to discriminate.

4. Null hypotheses cannot be rejected for either FWD or RR data, i.e., neither the FWD nor the RR able to discriminate between spreadability values on different dates.

TABLE 1

ANOVA ANALYSIS SUMMARY

(Based on 1981 data)

	Road Rater		Falling Weight Deflectometer		Category of Results			
Section #	* F for Rejection	F Calculated	*F for Rejection	F Calculated	1	2	3	4
10	3.78	0.0073	2.97	2.17				X
30	3.78	35.60	2.97	6.20		X		
155	3.05	0.0030	3.01	6.40	X			
160	3.01	2.00	3.01	44.30	X			
165	3.10	1.10	2.97	21.90	X			
170	3.18	0.0005	2.97	13.30	X			
175	3.01	2.40	2.97	9.10	X			
440	3.18	0.23	2.97	16.80	X			
460	3.01	0.65	2.97	44.10	X			
465	2.97	0.05	2.97	28.30	X			
475	3.05	0.77	2.97	4.40	X			
480	2.97	0.29	2.97	35.60	X			
490	3.10	2.50	2.97	1.20				X
495	3.10	2.50	2.97	9.10	X			
500	3.01	2.20	2.97	73.60	X			
505	2.97	3.40	2.97	18.50		X		
580	3.01	5.50	3.01	5.90		X		
585	3.10	0.66	2.97	8.46	X			
610	3.05	0.32	2.97	1.13				X
615	2.97	0.35	2.97	7.04	X			

* F for rejection of the null hypotheses is at the 90% confidence level