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16. ABSTRACT

This report represents the results of the first 18 months of the statewide follow-up deflection study. The primary purpose of this study is the establishment of a tie between tolerable deflection levels, structural selections and traffic volumes. On this project 86 separate test sections, representing 25 different structural sections, are now subject to yearly deflection measurements, crack surveys, and rut depth measurements. In addition, asphalt concrete cores from each test section are taken and tested for properties of recovered asphalt on a biennial basis. The data resulting from two deflection cylcles and one asphalt testing cycle is presented and analyzed herein.

This report also presents the results of a continuing study on the deflection attenuation properties of various roadway materials. This data has, and continues to be accumulated by way of follow-up deflection measurements on projects subject to investigation and subsequent reconstruction.

A third objective of this study has been an evaluation of areas of influence of radius of curvature measurements for evaluation of pavement performance as compared to conventional lineal deflection measurements. Radius of curvature measurements obtained using the Dehlen "curvature meter" on a number of aggregate base and cements treated base projects are compared with conventional measurements over the same sections.

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STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

INTERIM REPORT ON STATEWIDE FOLLOW-UP DEFLECTION STUDY OF OVERLAYS AND ROADWAY RECONSTRUCTION

Prepared in Cooperation
with
The U.S. Department of Commerce
Bureau of Public Roads

AUGUST 1966

66-27

State of California
Department of Public Works
Division of Highways
Materials and Research Department

August 17, 1966

Exp. Auth 633128

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

AN

INTERIM REPORT

on

STATEWIDE FOLLOW-UP DEFLECTION

STUDY OF OVERLAYS AND ROADWAY

RECONSTRUCTION

Study made by . . . . Pavement Section
Under general direction of. . . . . Ernest Zube
Work supervised by. . . . . Raymond Forsyth
Report by . . . . Raymond Forsyth
Joseph Hannon

JOHN L. BEATON
Materials and Research Engineer

Attachments

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

SYNOPSIS

This report represents the results of the first 18 months of the statewide follow-up deflection study. The primary purpose of this study is the establishment of a tie between tolerable deflection levels, structural sections and traffic volumes. On this project 86 separate test sections, representing 25 different structural sections, are now subject to yearly deflection measurements, crack surveys, and rut depth measurements. In addition, asphalt concrete cores from each test section are taken and tested for properties of recovered asphalt on a biennial basis. The data resulting from two deflection cycles and one asphalt testing cycle is presented and analyzed herein.

This report also presents the results of a continuing study on the deflection attenuation properties of various roadway materials. This data has, and continues to be accumulated by way of follow-up deflection measurements on projects subject to investigation and subsequent reconstruction.

A third objective of this study has been an evaluation of areas of influence of radius of curvature measurements for evaluation of pavement performance as compared to conventional lineal deflection measurements. Radius of curvature measurements obtained using the Dehlen "curvature meter" on a number of aggregate base and cement treated base projects are compared with conventional measurements over the same sections.

INTRODUCTION

The forerunner of this project was initiated on March 12, 1962, under the title "Statewide Follow-up Deflection Study" (Auth. #3128). The purpose of the original project was to obtain deflection measurements over roadways after completion of reconstruction initially recommended on the basis of a deflection study, in order to determine if deflection level was reduced by the amount predicted. This also provided additional information on the deflection damping characteristics of various roadway materials. On May 7, 1964, the scope of the project was enlarged considerably along with a request for federal participation. It was proposed that along with a continuation of the original objective, a new phase be undertaken for the purpose of establishing a tie between tolerable deflection level, structural section, and traffic volume. The establishment of this relationship would permit consideration of variation in traffic loading in overlay design based upon deflection data. Another part of this project involves the determination and analysis of area of influence or radius of curvature of flexible pavement under load and its relationship to performance. This phase of the study was justified by the contention of many authorities that pavement performance and condition is more directly relatable to severity of bending or area of load influence than to lineal deflection.

Approval for the enlarged project was obtained on June 18, 1964.

Because the aforementioned three phases of this study are not relatable, they will be treated separately in the body of this report under the following headings:

I Traffic Index - Deflection Study

II Deflection Attenuation

III Radius of Curvature

The purpose of this report, therefore, is to present the results obtained after 18 months of operation. This could properly be considered the third progress report; the first* being submitted July 29, 1963, prior to the enlargement of the project and resulting federal participation. A second report** which contained the available data on deflection attenuation was prepared in the fall of 1965 for presentation to the Highway Research Board primarily to describe this department's test procedure in utilizing deflection test data for the design of reconstruction of existing roadways.

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*"Progress Report No. 1 on a Statewide Follow-up Deflection Study", R. A. Forsyth, July 29, 1963.

** "Flexible Pavement Maintenance Requirements as Determined by Deflection Measurements", Ernest Zube and Raymond Forsyth, presented to the 45th Annual meeting of the Highway Research Board, January, 1966.

FINDINGS

The data available from the first 18 months of this study indicate the following trends:

(1) Inspection of deflection data on new pavements one to four years of age indicate significant reductions in deflection occurring during the first three years of service. This is presumably due to the curing of the AC surfacing and some additional traffic compaction.

Approximately four years after construction, deflection levels tend to increase. This is presumably due to the presence of micro-cracks and changes in the moisture condition of the structural section.

(2) Penetration tests on the asphalt binder recovered from cores taken from 17 projects indicate that aging or hardness is generally relatable to percent of air voids and film thickness. Lack of a clear-cut correlation between these 3 variables indicates the relative importance of other factors which may include crude source, AC pavement permeability and hot plant temperature and mixing time.

(3) Radius of curvature of the AC surfacing as indicated by the Dehlen "curvature meter" is generally relatable to lineal deflection. Neither type of measurement demonstrates a clear-cut superiority as a predictor of pavement performance. The curvature meter however does exhibit greater sensitivity and thus will be subject to further evaluation.

(4) The highest benefit in deflection reduction occurs with relatively thin corrective treatments. The rate of deflection attenuation tends to diminish as the gravel equivalence of reconstruction increases even though, in absolute units, deflection reduction increases with gravel equivalence.

(5) In absolute terms, reduction in deflection resulting from a given corrective treatment is dependent on the initial deflection level i.e., reduction in absolute units of deflection is significantly greater for high initial deflection levels than at low initial deflection levels even though the percent reduction may be the same in each case. It, therefore, appears more realistic to estimate the reduction in deflection in terms of percent of initial deflection rather than absolute units per inch of reconstruction.

(6) The reduction in deflection resulting from cement treatment of an inplace material is somewhat greater than presently indicated by California Division of Highways gravel equivalence factors.

I. TRAFFIC INDEX - DEFLECTION STUDY

At the present time this study involves 24 different projects throughout the State plus a series of streets in the City of Woodland, California. These roadways have various structural sections and traffic volumes. A listing of the projects presently included in the study, their structural sections, design Traffic Indices* (T.I.'s), and deflection ranges are presented by Table 1. The following criteria have been used in the selection of the roads and individual test sections:

1. As wide a range in pavement deflection as is practicably possible.

2. Availability of accurate traffic information.

3. As wide a range of structural sections as is practicably possible.

4. Roadways which have not been in operation more than two years and presently undistressed.

Selection of projects which satisfy the above criteria has been extremely difficult. The principal problem has been locating newly constructed roadways with a wide range of deflection levels, a portion of which preferably should be well in excess of existing criteria for the structural section under consideration. Where suitable deflection ranges have been noted, the roadway often times has a thin structural section or is very lightly traveled. It has been necessary, therefore, to compromise the above criteria in the selection of test roadways. The evaluation and selection for tests of newly constructed roadways will undoubtedly continue for at least a year.

The difficulties encountered in the selection of suitable test roadways can perhaps best be illustrated by examination of Table 2 which presents a listing of projects dropped from the study, with the reasons for elimination. Table 2 does not include the large number of facilities which were rejected from further consideration based upon visual inspection and a certain amount of deflection scanning.

On each test roadway, 3 to 5 individual sections 1000' in length are selected depending on size of project and number of lanes. Each section represents a high, medium, and low deflection area for the project. The field phase consists of

*The Traffic Index (T.I.) is an exponential function of total EWL anticipated on the highway between the time construction is completed and the end of the design period. Refer to Calif. Test Method No. 301-B.

yearly pavement deflection measurements with the traveling deflectometer over each test section during the spring of the year. In addition, all distress is carefully mapped and measurement of rut depths in both wheel tracks is made at 100' intervals. Once every two years 4" and 12" diameter AC cores are taken in and between wheel tracks. AC core samples are tested for: (1) extraction and grading, (2) center point loading (beams cut from 12" diameter core), (3) water permeability, (4) stability, (5) cohesion, (6) density and % voids, (7) properties of asphalt binder recovered by the Abson process, including penetration, ductility and softening point.

Traffic information on existing projects is available only for the years 1960 and 1963. Information resulting from the most recent statewide traffic count will be available in the spring of 1966. Because the majority of the projects included in this study were constructed between 1962 and 1964, accumulative annual equivalent 5000 lb. wheel loads will be based upon projection of the 1963 and 1966 data. On certain city streets and county roads special traffic counts will be necessary in support of this project.

Because the 1966 traffic count data was not available at the time this report was prepared, no accumulative annual EWL's will be presented with this report. However, a qualitative appraisal of the traffic volume for each project may be determined from the design TI information presented by Table I.

Analyses of Data

The data thus far available from one typical test section from each project is presented graphically by Figures 1 through 24.

Examination of all test data thus far available, including that presented by Table 1 indicates that 10 of the 24 projects currently a part of the TI deflection study have ranges of deflections in excess of the levels considered critical for the particular structural sections involved. Also, the properties of the recovered asphalt binder from 8 projects have reached what may be considered critical hardness (penetration of 30 mm or below and ductility of less than 50 cm). However, only one project (Project No. 1) falls into both the high deflection and the critical AC categories. Based upon this data, therefore, we would expect Project No. 1 (03-Col-45) to manifest early distress. Projects 2, 10, 15, and 21 have, at the present time, marginal deflection levels and critical properties of the recovered asphalt. It would appear that further examination of the performance of the 24 test roads will present an excellent opportunity to determine which variable or combinations of variables has the greatest effect on roadway performance.

Based upon the data available from two deflection runs and one AC testing cycle, the following general conclusions are warranted:

As noted in earlier investigations, a significant reduction in pavement deflections usually occurs during the first one to three years of service. This is presumably due to the effect of traffic compaction and curing of the AC surfacing. After this initial period, the level of pavement deflection remains either unchanged or tends to increase. The cause of this increase may be due to micro-cracks in the surfacing which are not readily apparent, or to a gradual increase in moisture content in the basement soil or structural section as a result of capillary action. A comparison of the change in deflection levels between the 1964 and 1965 deflection cycles indicated that almost without exception, average deflection diminished for pavements in operation less than three years. For pavement in service more than four years, a consistent increase in deflection levels was noted.

A review of deflection data from the 23 test sections shown by Figures 1 through 23 reveals that for this two year cycle under consideration, 80% of the pavements in service less than 3-1/3 years either diminished or remained constant in deflection levels. 87% of the pavements in service more than 3-1/2 years either increased or remained constant in deflection levels.

Of the 13 projects on which two cycles of rut depth measurements have been taken, a slight but consistent increase in rut depth was noted, amounting to an average of 0.005' or approximately 1/16". Based upon the limited amount of data available, it appears that there is a slight trend for greater permanent deformation on those projects with higher transient deflection levels. Thus far, the yearly mapping of distress has yielded only very minor and isolated cracking on two projects. This data is not considered significant due to its isolated nature.

Examination of the test data on recovered asphalt by the Abson process confirms the findings of several past investigations, in that penetration from recovered samples tended to increase with film thickness. Also penetration was found to decrease with an increase in percent of air voids. However, no clear-cut correlation, even on individual projects, is shown between the variables of penetration, film thickness and percent of air voids. These data indicate, therefore that penetration is significantly affected by other factors which probably include crude source, permeability, hot plant temperature, and mixing time.

It appears that, based upon the results of subsequent testing cycles, the fatigue resistance of an AC surfacing as manifested by a function of visible surface distress can be analyzed by considering the primary variables of penetration of the recovered AC binder, traffic volume, deflection level, and AC thickness. This can best be accomplished, in view of the range and volume of data which will be available, by computer analyses. In addition, the effect of void ratio, film thickness, crude source of asphalt, and age of pavement will be related to the prime variable which appears to best reflect the propensity of an AC surfacing to fatigue crack, i.e., penetration. Here also computer analyses will be used to determine the relative effect of each of the secondary variables on the primary.

II. DEFLECTION ATTENUATION

Field Procedure

Accumulation of deflection attenuation data has, and continues to be accomplished, by two methods; the first of which has been follow-up measurements over projects constructed subsequent to deflection studies. Projects selected specifically for peculiarities in the structural section also provide a very important source of attenuation test data. From May, 1960 until April, 1966, some 100 separate deflection studies of an operational nature were conducted by the Materials and Research Department involving deflection measurements and recommendations for corrective treatment on approximately 300 roadways. A large portion of this work has been accomplished within the last two years. As a result of this experience, the Materials and Research Department continues to accumulate a considerable amount of data on deflection attenuation. A plot reflecting a sum total of our experience to date with 19 completed projects is presented by Figure 25. Average percent reduction in deflection is plotted against increase in inches of gravel equivalence*. This plot is the basic tool for planning reconstruction of roadways based upon deflection measurement since it not only establishes a general trend in the deflection reduction afforded by various thicknesses of bases and surfacing but also indicates the results of specific types of reconstruction on individual projects. A listing of projects utilized in the formulation of this plot is presented by Table 4 which also shows the average percent reduction in deflection level obtained through varying increase of gravel equivalence*. The data presented by Table 4 and Figure 25 indicates average percent reduction after a curing period of from three to six months.

Analyses of Data

The data thus far available permits the following general conclusions: (1) In absolute terms, the reduction in deflection afforded by a given thickness of material is to a large extent dependent upon the initial deflection level. Stated another way, the reduction in absolute units of deflection resulting from the placement of an AC layer is substantially greater at high deflection levels than at low deflection levels even though the percentage reduction might be the same in each case. It is, therefore, more realistic to estimate deflection reduction in terms of per cent of initial deflection rather than in terms of 0.001" per inch of resurfacing. (2) A significant reduction in deflection usually occurs during the first year of operation. This is presumably due to the additional curing of the asphalt concrete surfacing and traffic compaction. (3) The most economical reconstruction involves, insofar as is possible, complete utilization of an existing structural section even though the surfacing may be badly cracked and spalled.

*The thickness of gravel necessary to produce a load distributing and soil restraining effect equal to that produced by the slab action of the thickness of the material being considered. Refer to Calif. Test Method No. 301-B.

(4) The highest rate of deflection reduction occurs with relatively thin treatments. This rate of attenuation tends to diminish with an increase in gravel equivalence. (5) The reduction in deflection resulting from the cement treatment of an in-place material is somewhat greater than indicated by existing California Division of Highways' gravel equivalent factors.

III. RADIUS OF CURVATURE

Field Procedure

The third area of study involves the determination and analysis of area of influence or radius of curvature of a pavement under load, and the relationship of these entities to pavement performance. It would seem entirely reasonable, as many authorities contend, that pavement performance and condition are related more directly to severity of bending or area of influence than to lineal deflection alone. A proponent of the "radius of curvature" concept presented a paper at the International Conference on Flexible Pavement Design at the University of Michigan in August, 1962, on a new device for measuring the radius of curvature along with data obtained from its use. This device, called a curvature meter, is an aluminum bar approximately one foot in length with an Ames dial and probe fixed in the center (see Figure 26). By placing it between the wheels, it is possible to measure the middle ordinate of a curve, having a chord length of one foot, in the deflected basin from which a radius of curvature can be calculated.

A device of this design has been fabricated by the Materials and Research Department and used on a number of projects in conjunction with conventional measurements. Radius of curvature measurements are also being made on all projects which are part of the Traffic Index-Deflection study in the hope that more precise information on the critical radius of curvature may be obtained as these projects begin to show distress.

Analyses of Data

The data thus far accumulated are shown graphically in Figures 27 and 28. In Figure 27, radius of curvature calculated from curvature meter measurements versus lineal deflection are plotted for cement treated base construction. The open circles represent unfailed areas, with the closed dots representing cracked sections of the roadway from which the measurements were taken. Although relatively little data is available, it appears that lineal deflection is the best predictor of cement treated base performance since there is a clear-cut demarcation between cracked and uncracked measurements at the 0.012" deflection level. For radius of curvature, this demarcation is less clear-cut; however, a critical radius appears to be in the range of from 500 to 700 feet.

A similar plot for untreated aggregate base structural sections is shown by Figure 28. In this case, the radius of curvature appears to be the best forecaster of pavement performance, with a critical radius of curvature of approximately 200 feet. The critical zone for lineal deflection occurs at approximately 0.020", although there is a considerable overlapping between 0.020" and 0.030". Based upon the limited amount of data presented by Figures 27 and 28, it would be difficult to determine whether lineal deflection or radius of curvature manifests a clear-cut superiority as an indicator of future pavement performance. Because of it simplicity and compactness, in addition to its sensitivity in a very critical zone of the deflected basin, further evaluations of the instrument will be made on projects subject to deflection study.

Attempts made to relate various functions of deflectometer trace shape to pavement condition have so far proved inconclusive. This is possibly due to the fact that the zone of critical bending is confined to a very small portion of the trace, thus reducing sensitivity.

TABLE 1

TRAFFIC INDEX-DEFLECTION TEST PROJECTS

	Project	Date Completed	Structural Section	T.I. (10 yr.)	Date of First Test Measurements	Test Sections	Pavement Deflection Range (1964-1965)
1)	03-Col-45 (61-3T13C20)	9/6/61	0.25' AC 0.50' AB 0.83' AS	6.1	2/6/64	4	0.010" to 0.040"
2)	03-Gle-162 (60-14TC22-F)	6/5/61	0.25' AC 0.50' AB 0.75' AS	7.9	2/5/64	2	0.007" to 0.022"
3)	03-Gle-162 (64-14T13C6)	4/22/64	0.30' AC 0.50' AB 1.08' AS	7.0	2/5/64	2	0.008" to 0.036"
4A)	03-Sac-99 (60-3TC20)	10/22/59	0.30' AC 0.67' CTB Exist. Pvmt.	8.0	3/2/64	5	0.007" to 0.018"
4B)	03-Sac-99 (61-3TC9)	9/23/60	0.55' AC 0.50' AB Exist. Pvmt.	8.0	3/2/64	6	0.012" to 0.025"
4C)	03-Sac-99 (61-3TC9)	9/23/60	0.30' AC 1.00' AB Exist. Pvmt.	8.0	3/2/64	1	0.016" to 0.026"
5)	03-Yol-99 (61-3T13C31)	4/27/61	0.29' AC 0.67' AB 1.17' AS	8.5	1/16/64	3	0.008" to 0.021"
6)	04-Nap-121, 29 (62-4T13C5-F)	2/2/62	0.25' AC 0.67' CTB 1.50' AS	8.2	2/20/64	4	0.001" to 0.039"

TABLE 1 (Cont)

TRAFFIC INDEX-DEFLECTION TEST PROJECTS

	Project	Date Completed	Structural Section	T.I. (10 yr.)	Date of First Test Measurements	Test Sections	Pavement Deflection Range (1964-1965)
7)	05-Mon-101 (62-5T13C3-F)	7/16/63	0.36' AC 0.25' ACB 0.50' AB 1.25' AS	9.3	2/27/64	5	0.008" to 0.016"
8)	05-Mon-101 (60-14TC1-F)	12/13/60	0.59' AC 0.50' AB 0.92' AS	9.0	2/10/65	5	0.004" to 0.017"
9)	05-Mon-101 (62-5T13C4)	7/26/62	0.25' AC 0.67' CTB 0.75' AS	8.3	3/9/64	3	0.001" to 0.013"
10)	05-SB-246 (61-5V13C9)	4/17/61	0.31' AC 0.50' AB	7.9	3/11/64	3	0.006" to 0.031"
11)	05-SBt-156 (62-5T13C2)	1/4/62	0.31' AC 0.67' AB 1.00' AS	7.9	2/26/64	3	0.006" to 0.019"
12)	05-SBt-156 (61-5TC3)	6/5/61	0.31' AC 0.50' CTB 0.17' AB 0.75' AS	7.3	2/25/64	3	0.000" to 0.012"
13)	05-SLO-1 (61-5V13C12)	8/15/63	0.27' AC 0.67' AB 1.00' AS	7.7	3/10/64	3	0.010" to 0.035"
14)	06-Ker-204 (64-6V13C2-F)	5/5/64	0.29' AC 0.67' AB 0.83' to 1.04' AS	8.2	3/1/65	4	0.014" to 0.047"

TABLE 1 (Cont)

TRAFFIC INDEX-DEFLECTION TEST PROJECTS

Project	Date Completed	Structural Section	T.I. (10 yr.)	Date of First Test Measurements	Test Sections	Pavement Deflection Range (1964-1965)
15) 06-Kin-198 (62-6T13C4)	6/26/63	0.25' AC 0.50' CTB 0.67' AS 0.33' IB	7.9	3/27/64	4	0.002" to 0.021"
16) 06-Kin,Tul-43 (63-6T13C2-P)	2/4/63	0.25' AC 0.50' CTB Exist.Pvmt.	7.5	1/14/63	4	0.001" to 0.021"
17) 06-Fre-811-CR (64-6Y24C19-P)	9/29/64	0.25' AC 0.50' AB 1.17' AS	--	3/8/65	2	0.016" to 0.035"
18) 06-Fre-1329-CR (64-6Y24C20-P)	10/7/64	0.25' AC 0.50' AB 0.92' to 1.00' AS	--	3/4/65	3	0.013" to 0.029"
19) 06-Fre-33 (60-6TC13-FP)	3/18/61	0.29' AC 0.50' AB 1.21' AS	7.5	3/5/65	3	0.016" to 0.030"
20) 10-Cal-49 (64-10T13C14)	8/12/64	0.25' AC 0.50' AB 1.00' AS	7.0	12/17/64	2	0.009" to 0.034"
21) 10-Sol-680 (60-10TC18-FI)	6/14/61	0.39' AC 0.67' CTB 1.00' ISM 1.00' Per. Matl.	8.7	7/13/64	5	0.001" to 0.013"

TABLE 1 (Cont)

TRAFFIC INDEX-DEFLECTION TEST PROJECTS

Project	Date Completed	Structural Section	T.I. (10 yr.)	Date of First Test Measurements	Test Sections	Pavement Deflection Range (1964-1965)
22A) City of Woodland	1962	0.17' AC 0.50' AB O.G.	--	1/17/62	3	0.018" to 0.052"
22B) City of Woodland	1962	0.33' AC O.G.	--	2/6/63	1	0.022" to 0.042"

TABLE 2

Projects Eliminated from Study

Dist.-Co.-Rte.-Sec.	Structural Section	Date Eliminated	Reason
03-But-1336	0.20' AC 0.50' AB 0.50' AS	2/18/65	Low T.I. and possibly low deflections
03-Nev-89	0.25' AC 0.50' AB 0.75' AS	3/1/65	In remote area subject to freeze-thaw action.
03-Sac-50	0.05' OGAC 0.33' AC 0.34' CTB(A) 0.33' " (B) 1.00' AS	7/2/64	Low deflections
05-SLO-41	0.06' OGAC 0.21' AC 0.50' AB 0.67' AS	2/16/65	Low deflections
05-SB-Vand	0.29' AC 0.67' AB 0.83' AS	2/17/65	Low deflections
05-SB-1181(4)-CR	0.25' AC 0.67' AB 0.50' AS	1/22/66	Low deflections
06-Ker-43	0.29' AC 0.50' AB 1.21' AS	1/22/66	Low deflections
06-Ker-178	0.29' AC 0.50' AB 0.92' AS	3/1/65	Low deflections
06-Tul-198 (Noble Avenue)	0.29' AC 0.50' AB 0.75' Sel. Matl.	3/4/65	Low deflections
06-Tul-63	0.29' AC 0.50' AB 0.54' AS	3/3/65	Low deflections
10-Tuo-120,49	0.25' AC 0.50' CTB 0-1.00' AS	1/22/66	Low deflections and T.I.

TABLE 3

Thickness of Pavement	Type of Pavement	Maximum Permissible Deflection for Design Purposes
8-in.	Portland Cement Concrete	0.012-in.
6-in.	Cement Treated Base (Surfaced with Bituminous Pavement)	0.012-in.
4-in.	Asphalt Concrete on Gravel Base	0.017-in.
3-in.	" " " " "	0.020-in.
2-in.	" " " " "	0.025-in.
1-in.	Road Mix on Gravel Base	0.036-in.
½-in.	Surface Treatment	0.050-in.

TABLE 4

ATTENUATION PROPERTIES OF VARIOUS STRUCTURAL SECTION ELEMENTS

Project	Structural Element	Gravel Equivalence (Inches)	Reduction In Deflection Level (%)
03-But-162 (64-3T15C1)	0.08' AC Blanket	1.9	43
03-ED-50 (63-3T15C2)	" " "	"	37
03-Gle-45 (64-3T15C1)	" " "	"	24
03-Sac-50 (63-3T15C2)	" " "	"	37
03-Sut-99 (63-3T15C2)	" " "	"	10
05-SBt-156 (63-5T15C1)	" " "	"	7
06-City of Coalinga (Buchanan St.)	" " "	"	26
03-Sac-50 (63-10T15C1)	0.12' AC Blanket	2.9	54
04-Nap-121	" " "	"	35
05-SLO-101 (63-5V13C3)	0.15' AC Blanket	3.3	23
04-CC Co. (San Pablo Dam Rd.)	0.17' AC Blanket	3.8	27

TABLE 4 (Contd)

Project	Structural Element	Gravel Equivalence (Inches)	Reduction In Deflection Level (%)
05-Mon-101 (60-14TC-1)	0.17' AC Blanket	3.8	38
05-Mon-101 (62-5T13C4)	" " "	"	44
05-SBt-156 (62-5T13C2)	0.21' AC Blanket	4.8	45
03-Sut-99 (61-3T13C18)	0.25' AC Blanket	5.7	41
West Sacramento (Harbor Blvd.)	" " "	"	38
04-Contra Costa Co. (Third Street)	" " "	"	43
04-SC1-152 (64-4T13C8)	" " "	"	36
05-Mon-183-Sal (64-5T13C1)	" " "	"	46
05-SB-101 (05-045704)	" " "	"	47
05-SBt-101 (65-5T13C30604)	" " "	"	33
04-SCr-17 (63-4T13C6)	" " "	"	27
05-SLO-101 (64-5V13C2)	0.29' AC "	6.7	60

TABLE 4 (Contd)

Project	Structural Element	Gravel Equivalence (Inches)	Reduction In Deflection Level (%)
05-SB-246 (61-5V13C9)	0.31' AC Blanket	7.1	51
05-Mon-101 (60-14TC-1)	0.33' AC "	7.6	40
05-SBt-156 (63-5T13C4)	" " "	"	32
05-Mon-101 (60-14TC-1)	0.58' AC "	13.3	61
03-Col-1301 (60-3DDC31-P)	0.12' AC 0.50' AB (overlay)	8.9	45
05-SB-246 (61-5V13C9)	0.31' AC 0.50' AB (overlay)	13.1	58
03-Sac-99 (61-3TC9)	0.54' AC 0.50' AB (overlay)	18.3	62
03-Sac-99 (61-3TC9)	0.29' AC 1.00' AB (overlay)	18.7	68
03-Sut-99 (61-3T13C18)	0.25' AC 0.67' AB 0.50' AS (overlay)	19.7	46
06-Kin,Tul-43 (63-6T13C2-P)	0.25' AC 0.50' Cl."B" CTB (overlay)	14.7	72
04-Nap-121	0.25' AC 0.67' Cl."C" CTB (overlay)	15.3	67

TABLE 4 (Contd)

Project	Structural Element	Gravel Equivalence (Inches)	Reduction In Deflection Level (%)
03-Sac-99 (60-3TC20)	0.29' AC 0.67' Cl. "A" CTB (overlay)	20.3	81
05-Mon-183-Sal (64-5T13C1)	0.25' AC 0.67' AB (0.92' Digout)	4.2	18
City of Coalinga (California St.)	0.17' AC 0.50' AB (0.67' Digout)	5.8	33
05-SLO-101 (63-5V13C3)	0.31' AC 0.67' Cl."D" CTB (0.75' Digout)	16.2	79
04-SCr-17 (63-4T13C6)	0.25' AC 0.83' Cl."D" CTB (0.83' Digout)	17.9	61
04-Nap-121	0.12' AC 1.00' Cl."A" CTB (1.00' Digout)	17.3	70
05-SLO-101 (64-5V13C2)	0.40' AC 0.83' Cl."D" CTB (1.00' Digout)	19.2	90

TABLE 5

PROJECTS REDESIGNED AND CONSTRUCTED BY DEFLECTION ANALYSIS

Project	Corrective Treatment		Mean Deflection Level				Reduction in Mean Deflection Level (%)	
			Before Reconstruction		After Reconstruction			
	Recommended	As Built	OWT	IWT	OWT	IWT	Actual	Desired*
03-Yol-W.Sacto. (Harbor Blvd.)	0.25' AC	0.25' AC(1/66)	0.039"	0.031"	0.024"	0.014"	38	38
04-SCl-152 (64-4T13C8)	0.25' AC	0.25' AC(12/63)	0.022"	--	0.014"	--	36	10
04-SM-35 (65-04T13C289104)	0.33' AC 0.67' Cl."D"CTB	0.25' AC(11/64)	0.048"	0.041"	0.022"	0.021"	52	55
05-SLO-101 (64-5V13C2)	0.06' OG AC 0.33' AC 0.67' Cl."D"CTB	0.06' OG AC 0.33' AC 0.83' Cl. "D"CTB (8/63)	0.031"	0.029"	0.004"	0.002"	90	70
05-SLO-101 (64-5V13C2)	0.06' OG AC 0.17' AC	0.06' OG AC 0.21' AC(8/63)	0.013"	0.011"	0.007"	0.003"	60	--
05-SBt-101 (65-5T13C30604)	0.25' AC	0.25' AC(6/64)	0.027"	--	0.018"	--	33	25
05-Mon-183-Sal (64-5T13C1)	0.29' AC 0.67' AB 0.83' AS (1.79' Digout)	0.25' AC 0.67' AB (0.92' Digout 6/63)	0.057"	0.051"	0.048"	0.041"	18	70
05-Mon-183-Sal (64-5T13C1)	0.25' AC	0.25' AC(6/63)	0.042"	0.035"	0.022"	0.020"	46	45

* Reduction necessary to reduce deflections to a tolerable level based on the recommended treatment.

TABLE 5 (Contd)

PROJECTS REDESIGNED AND CONSTRUCTED BY DEFLECTION ANALYSIS

Project	Corrective Treatment		Mean Deflection Level				Reduction in Mean Deflection Level (%)	
			Before Reconstruction		After Reconstruction			
	Recommended	As Built	OWT	IWT	OWT	IWT	Actual	Desired *
05-SLO-101 (63-5V13C3)	0.06' OG AC 0.25' AC 0.67' Cl."D"CTB	0.06' OG AC 0.25' AC 0.67' Cl."D"CTB (6/62)	0.026"	0.032"	0.008"	0.005"	79	60
05-SLO-101 (63-5V13C3)	0.06' OG AC 0.08' AC	0.06' OG AC 0.08' AC(6/62)	0.013"	--	0.010"	--	23	--
05-Mon-101**	0.17' AC	0.17' AC	0.025"	--	0.014"	--	44	40
05-SBt-156** (62-5T13C2)	0.06' OG AC 0.25' AC 0.50' Cl."A"CTB or 0.06' OG AC 0.25' AC 0.67' Cl."D"CTB	0.06' OG AC 0.17' AC (8/61)	0.061"	0.050"	0.030"	0.031"	45	80
05-SBt-156 (63-5T13C4)	0.21' AC 0.50' Cl."D"CTB	0.33' AC (1/63)	--	0.028"	--	0.019"	32	55
05-SBt-156 (63-5T15C1)	0.06' OG AC 0.25' AC	0.08' AC	0.032"	0.026"	0.031"	0.023"	7	30
05-SB-246** (61-5V13C9)	0.06' OG AC 0.25' AC	0.06' OG AC 0.25' AC (4/61)	0.038"	0.042"	0.025"	0.014"	51	40

* Reduction necessary to reduce deflections to a tolerable level based on the recommended treatment.
** Included in T.I. - Deflection Study.

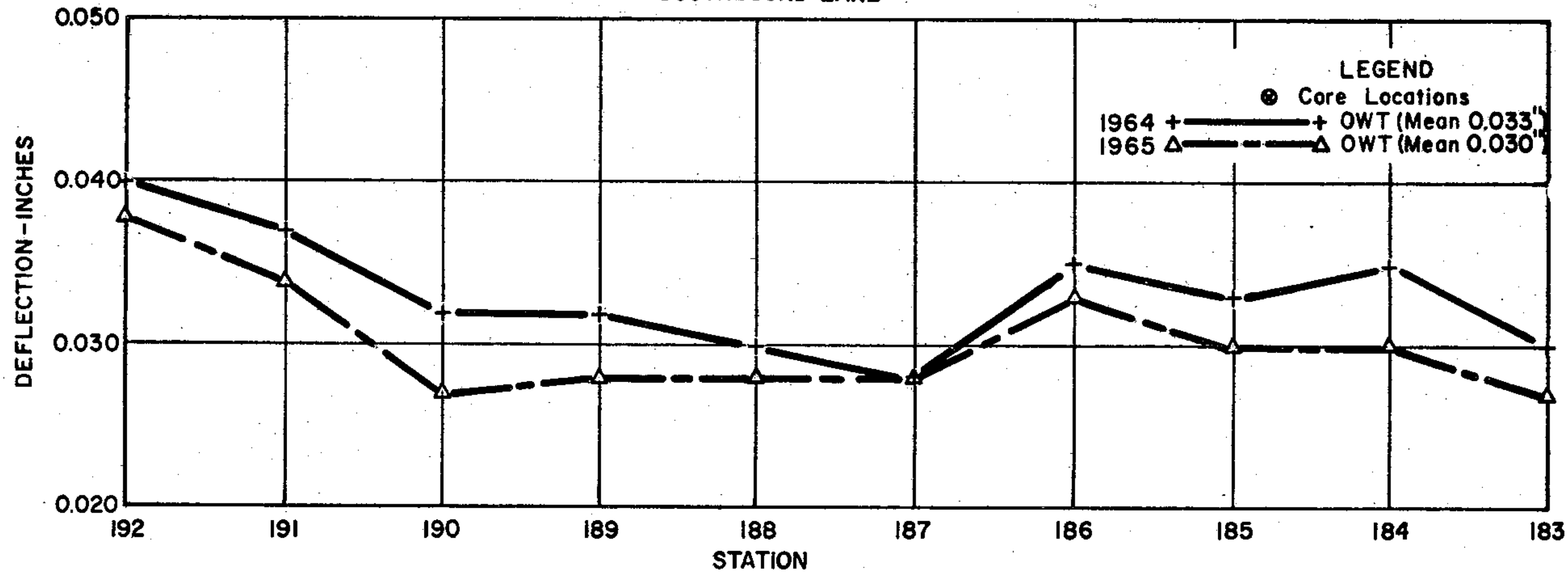
TABLE 5 (Contd)

PROJECTS REDESIGNED AND CONSTRUCTED BY DEFLECTION ANALYSIS

Project	Corrective Treatment		Mean Deflection Level				Reduction in Mean Deflection Level (%)	
			Before Reconstruction		After Reconstruction			
	Recommended	As Built	OWT	IWT	OWT	IWT	Actual	Desired *
05-SB-246** (61-5V13C9)	0.06' OG AC 0.25' AC 0.50' AB	0.06' OG AC 0.25' AC 0.50' AB (4/61)	0.067"	0.070"	0.029"	0.029"	58	65
06-Kin,Tul-43 (63-6T13C2-P)	0.25' AC 0.67' Cl."D"CTB	0.25' AC 0.50' Cl."B"CTB (1/63)	0.039"	--	0.011"	--	72	70
06-City of Coalinga (Buchanan St.)	0.17' AC 0.50' Cl."C"CTB (0.67' Digout)	0.08' AC (Summer 64)	0.066"	0.074"	0.049"	0.044"	26	70
06-City of Coalinga (California St.)	"	0.17' AC 0.50' AB (0.67' Digout Fall 64)	0.052"	0.032"	0.035"	0.027"	33	70

* Reduction necessary to reduce deflections to a tolerable level based on the recommended treatment.
** Included in T.I. - Deflection Study.

PROJECT 1
03—Col—45
CONT. 61-3T13C20
SOUTHBOUND LANE



Station	192	191	190	189	188	187	186	185	184	183
Rut Depth 1964*	0	4	0	0	0	4	4	0	8	0
Rut Depth 1965*	9	9	6	11	3	8	11	5	7	4

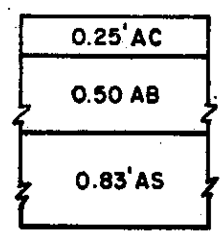
⊗ T4-4-7
⊗ T4-4-8

TEST DATA

	T4-4-7	T4-4-8
% Asphalt	3.7	—
Pen. at 77°F	18	33
S.P. (F°)	160	146
Duct. at 77°F (Cm)	8.9	96.9

* Measured to nearest 0.001' in outer wheel track.

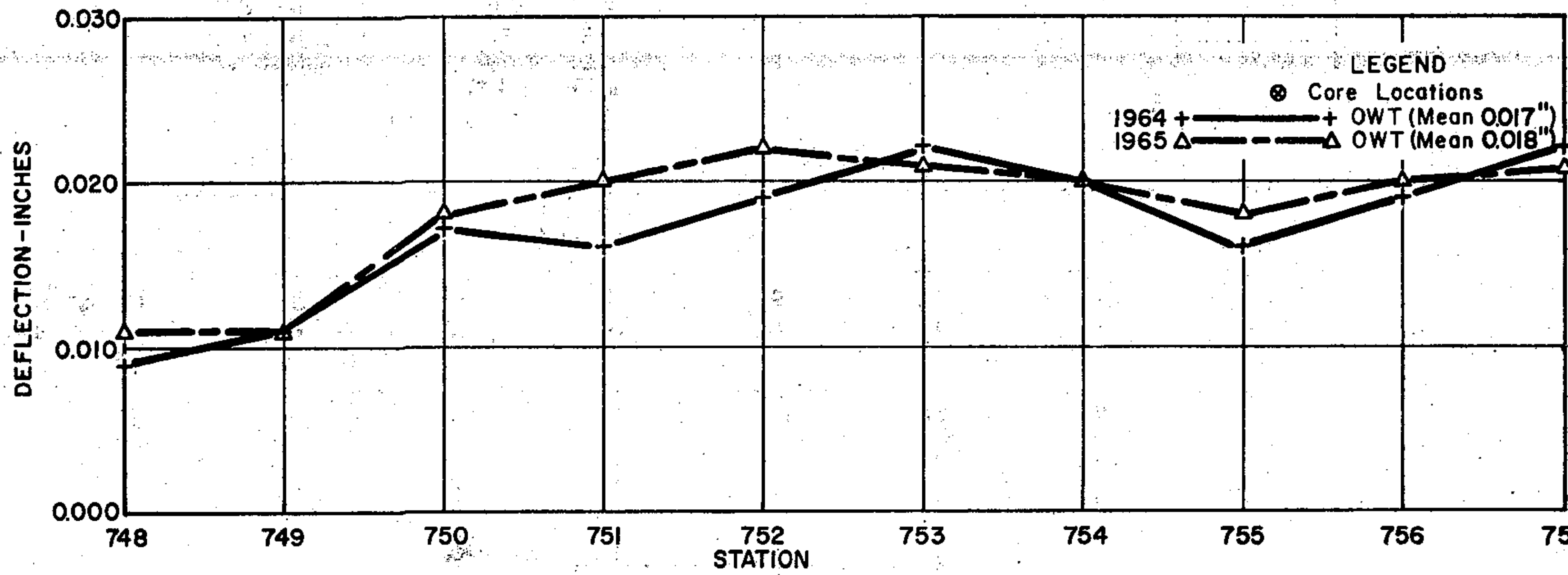
STRUCTURAL SECTION



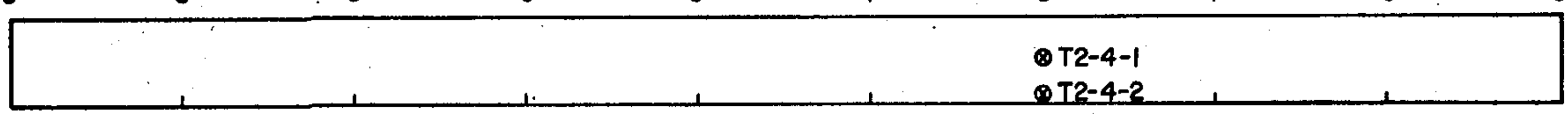
Completed 9/6/61

FIGURE 1

PROJECT 2
03 – Gle – 162
CONT. 60-14TC22-F
EASTBOUND LANE



	748	749	750	751	752	753	754	755	756	757
Rut Depth 1964*	0	–	0	0	0	0	0	0	0	4
Rut Depth 1965*	5	5	3	0	3	7	5	4	5	5



TEST DATA

	T2-4-1	T2-4-2
% Asphalt	3.9	4.3
Pen. at 77°F	22	14
S.P. (F°)	149	155
Duct. at 77°F (Cm)	41.5	9.8

STRUCTURAL SECTION

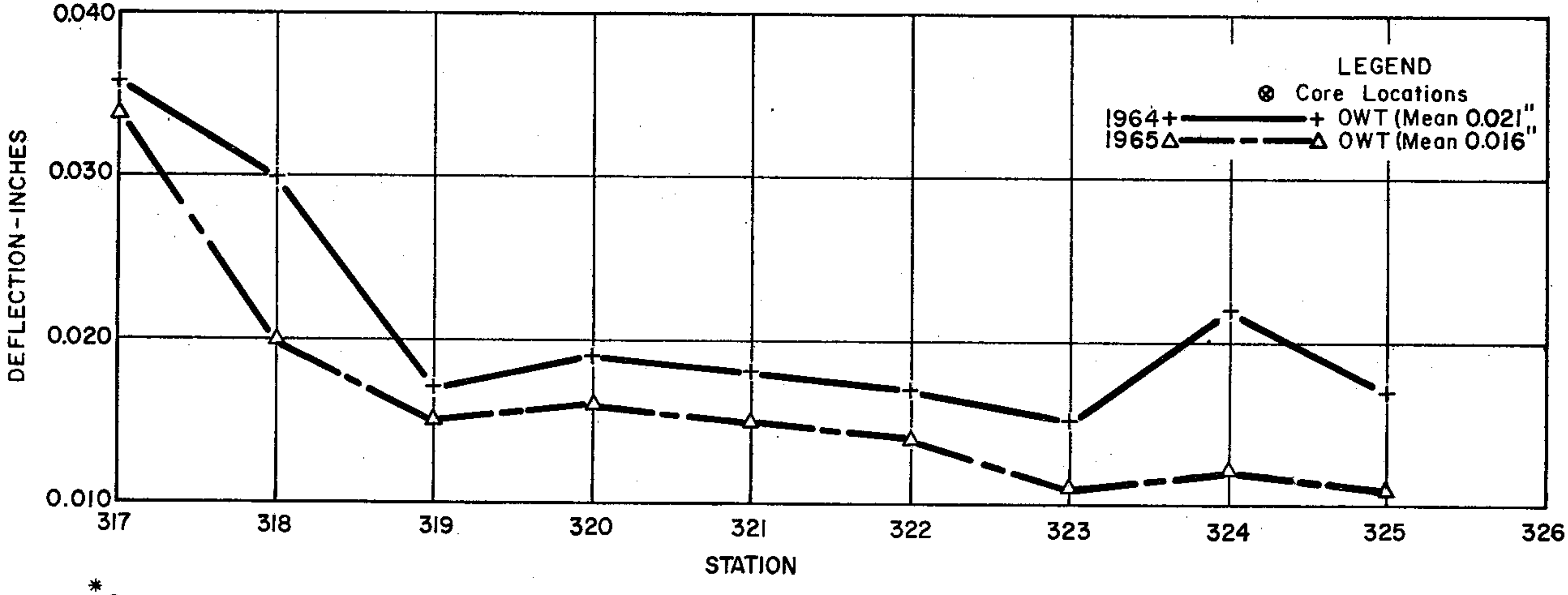
0.25' AC
0.50' AB
0.75' AS

Completed 6/5/61

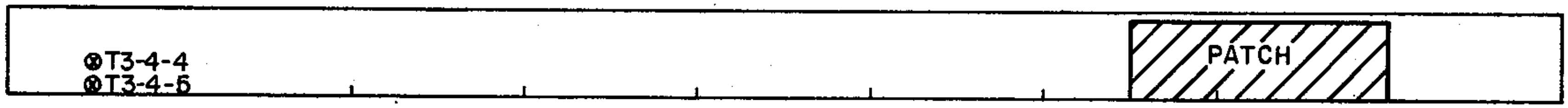
* Measured to nearest 0.001' in outer wheel track.

FIGURE 2

PROJECT 3
03 - Gle - 162
CONT. 64-14T13C6
EASTBOUND LANE



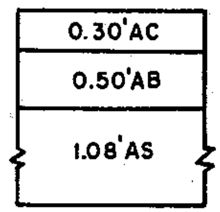
	317	318	319	320	321	322	323	324	325
Rut Depth 1964*	0	0	0	0	0	0	0	25	0
Rut Depth 1965*	11	5	10	2	7	4	3		



TEST DATA

	T3-4-4	T3-4-5
% Asphalt	—	3.8
Pen. at 77°F	94	60
S.P. (F°)	121	129.5
Duct. at 77°F (Cm)	100+	100+

STRUCTURAL SECTION

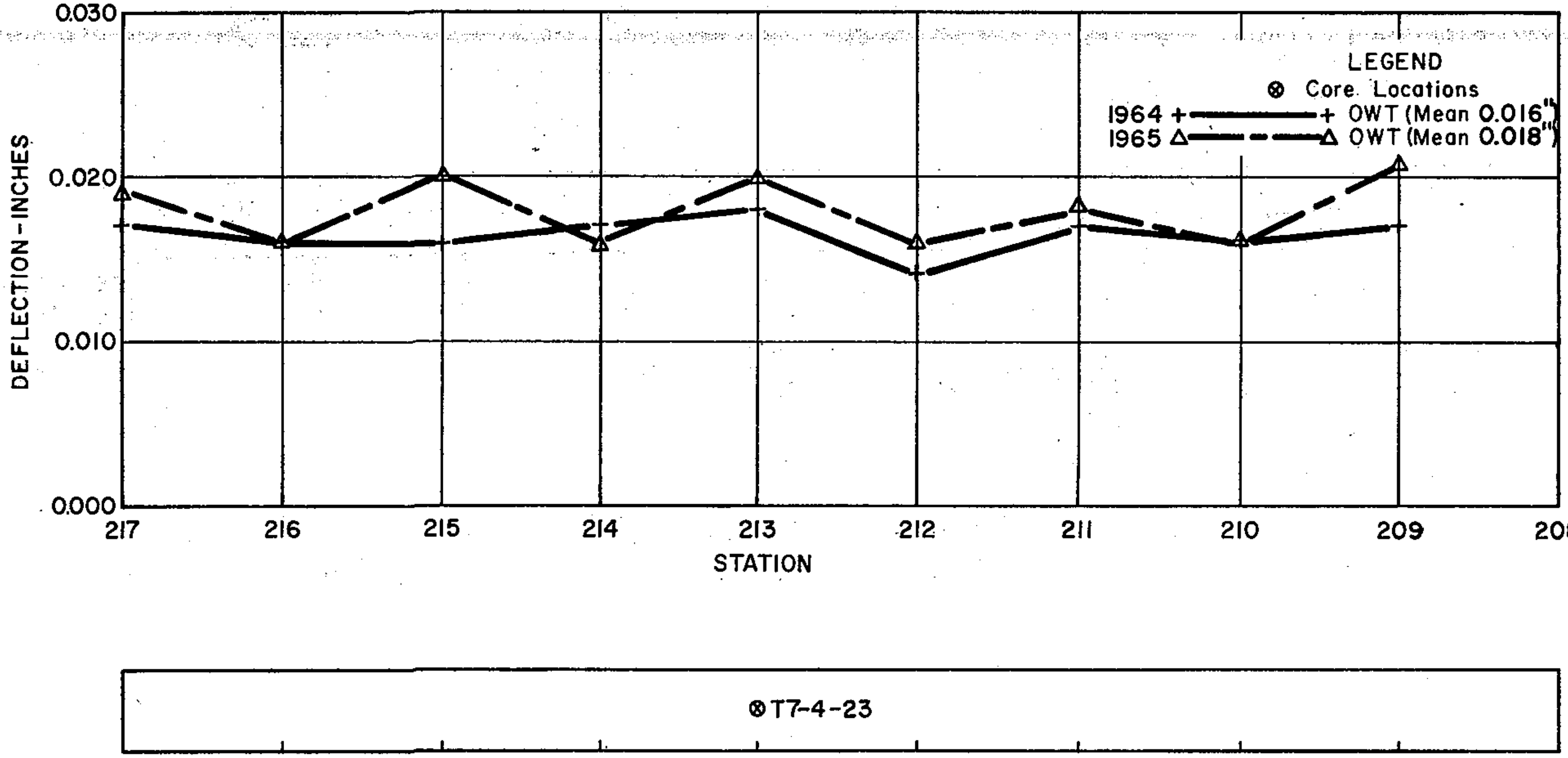


Completed 4/22/64

* Measured to nearest 0.001' in outer wheel track.

FIGURE 3

PROJECT 4A
03 — Sac — 99
CONT. 60-3TC-20
SOUTHBOUND LANE



TEST DATA

	T7-4-23
% Asphalt	5.2
Pen. at 77°F	24
S.P. (F°)	139.5
Duct. at 77°F (Cm)	100+

STRUCTURAL SECTION

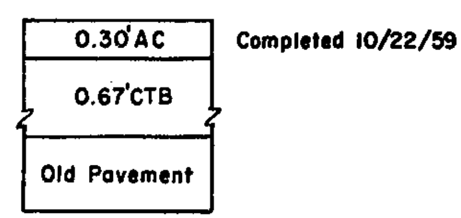
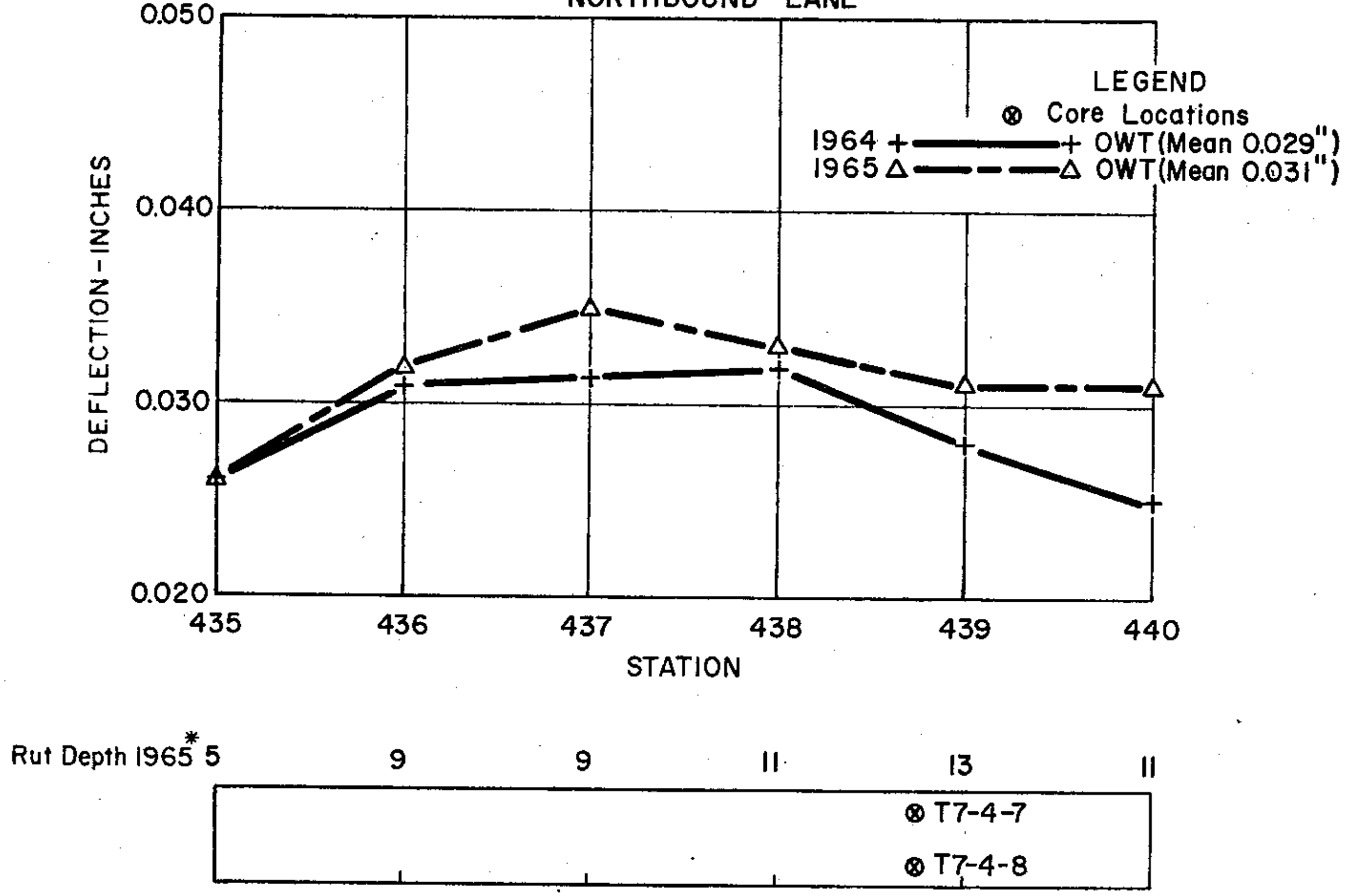


FIGURE 4

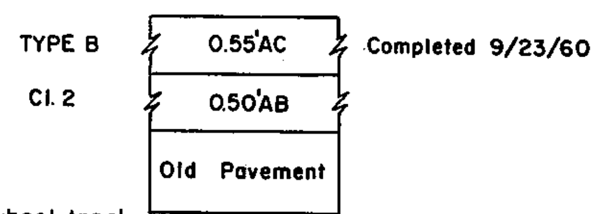
PROJECT 4B
03-Sac-99
CONT. 61-3TC9
NORTHBOUND LANE



TEST DATA

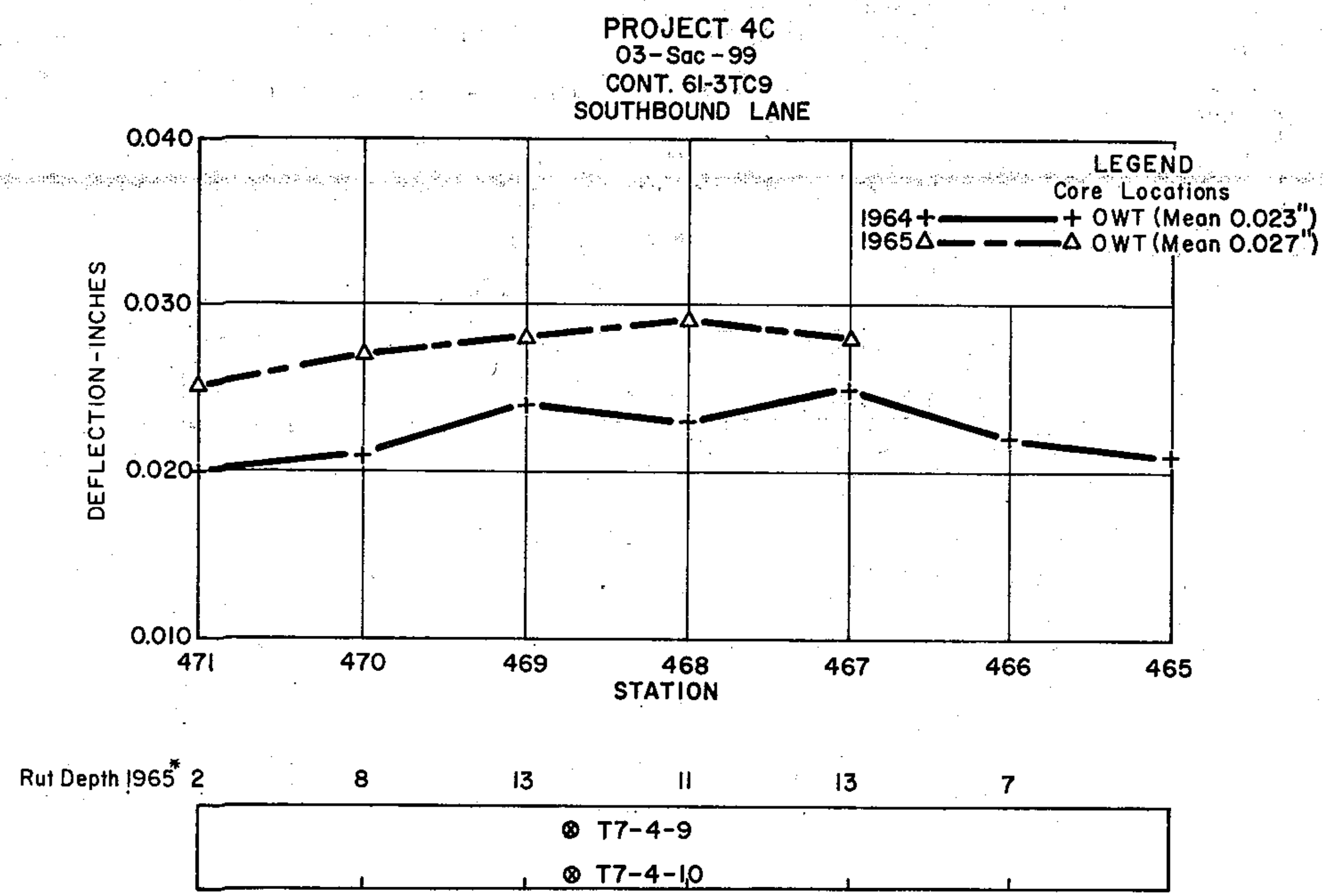
	T7-4-7	T7-4-8 Surf.	T7-4-8 Base
% Asphalt	5.7	5.5	5.0
Pen. at 77°F	33	47	
S.P. (F°)	138	127	
Duct. at 77°F (Cm)	100+	100+	

STRUCTURAL SECTION



* Measured to nearest 0.001' in outer wheel track.

FIGURE 5



TEST DATA

	T7-4-9	T7-4-10
% Asphalt	4.2	5.4
Pen. at 77°F	23	31
S.P. (F°)	148	142
Duct. at 77°F (Cm)	58	100+

* Measured to nearest 0.001' in outer wheel track.

STRUCTURAL SECTION

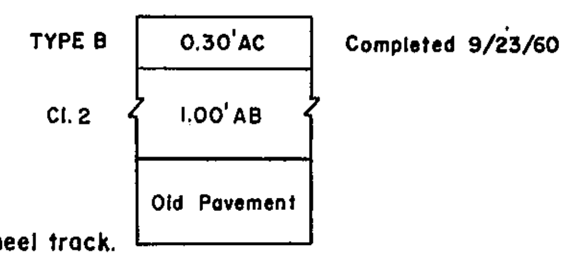
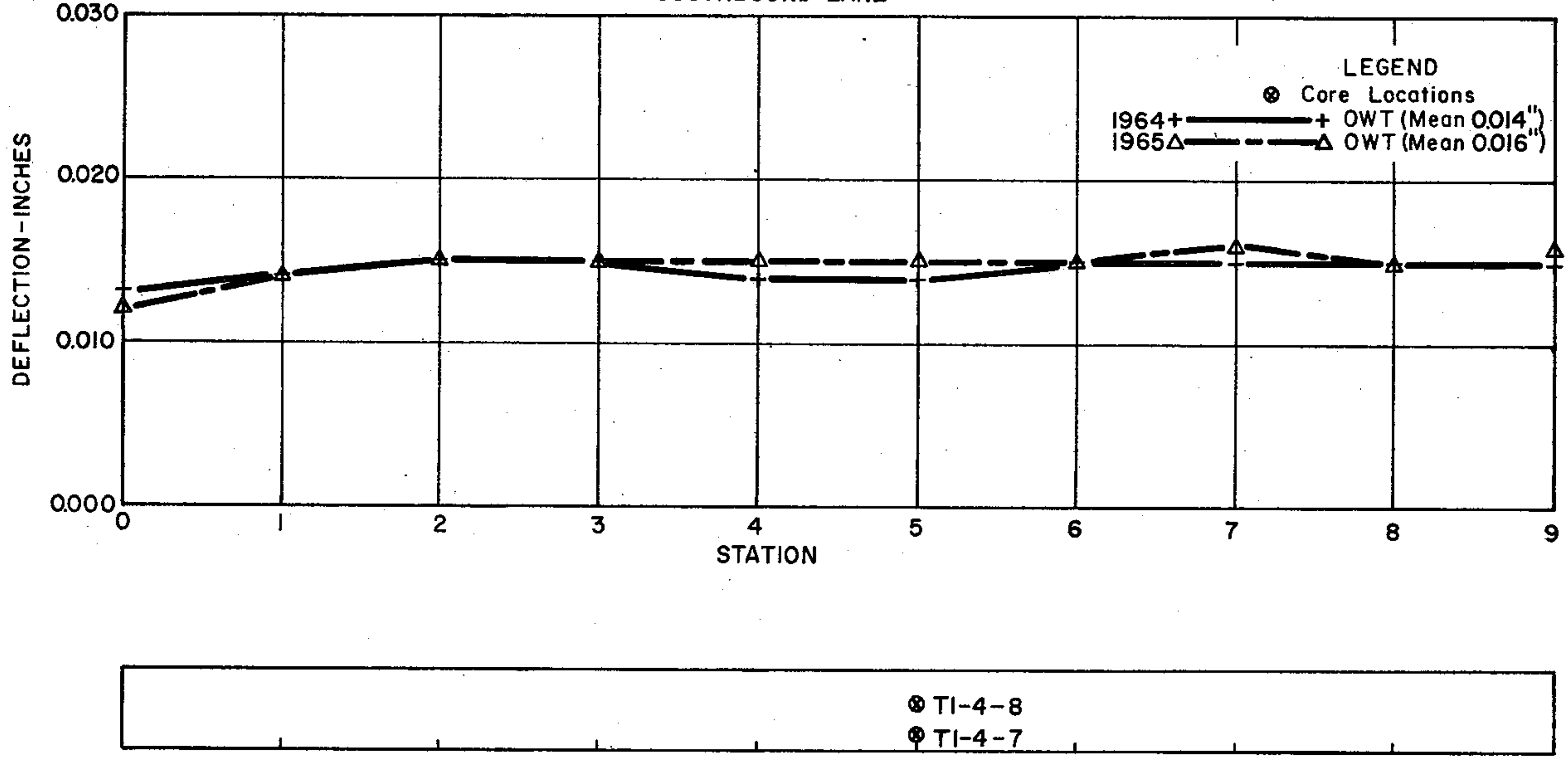


FIGURE 6

PROJECT 5
03 – Yol – 99
CONT. 61-3T13C31
SOUTHBOUND LANE



TEST DATA

	TI-4-7	TI-4-8
% Asphalt	5.1	5.3
Pen. at 77°F	31	33
S.P. (F°)	142.5	141
Duct. at 77°F (Cm)	100+	100+

STRUCTURAL SECTION

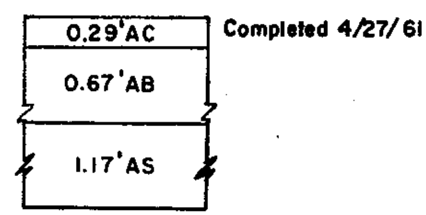


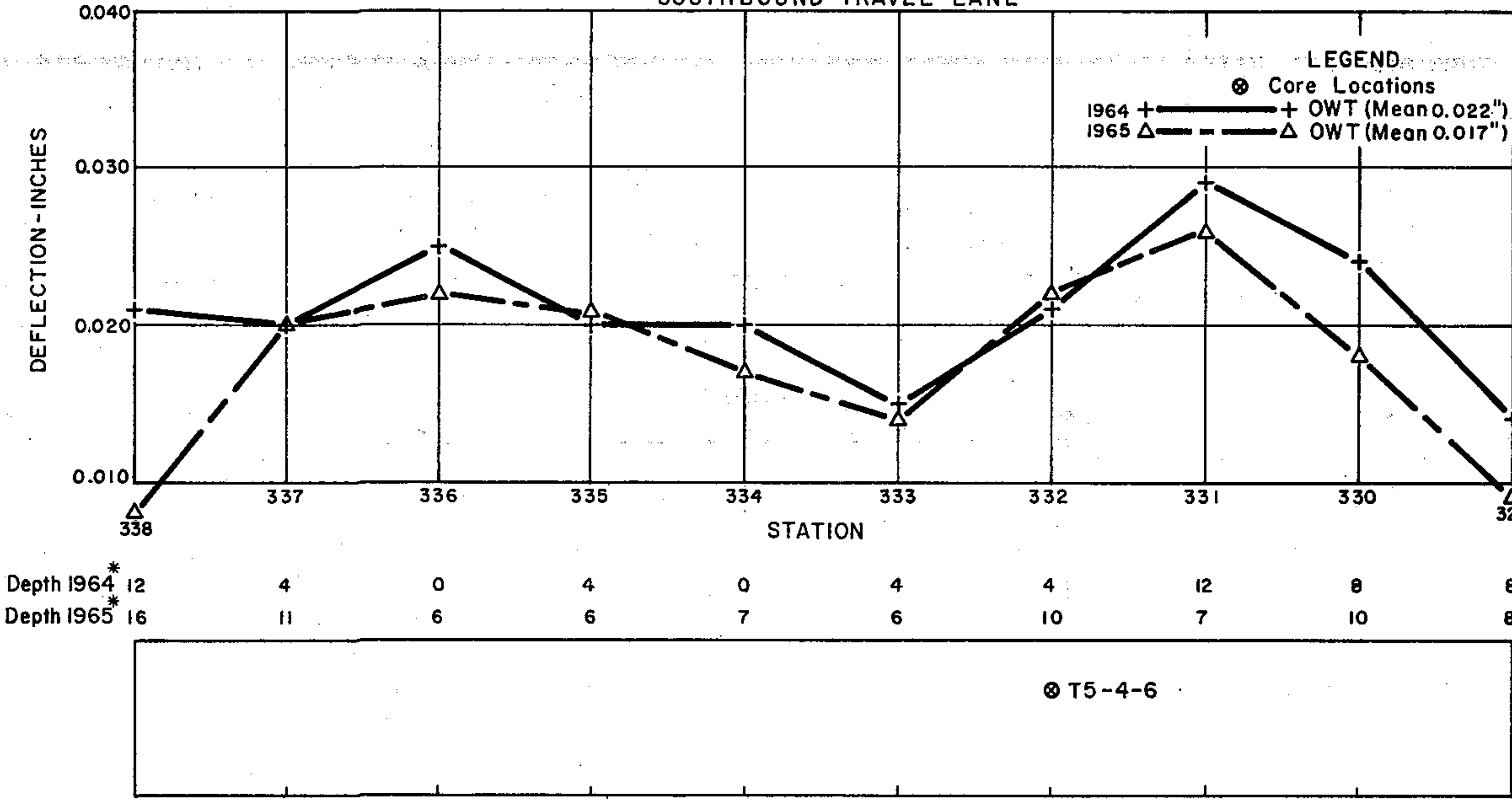
FIGURE 7

PROJECT 6

04-Nap-121,29

CONT. 62-4T13C5-E

SOUTHBOUND TRAVEL LANE



TEST DATA

	T5-4-6
% Asphalt	4.8
Pen. at 77°F	60
S.P. (F°)	137
Duct. at 77°F (Cm)	100+

* Measured to nearest 0.001' in outer wheel track.

STRUCTURAL SECTION

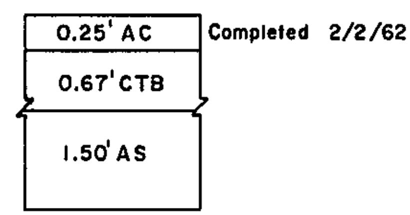
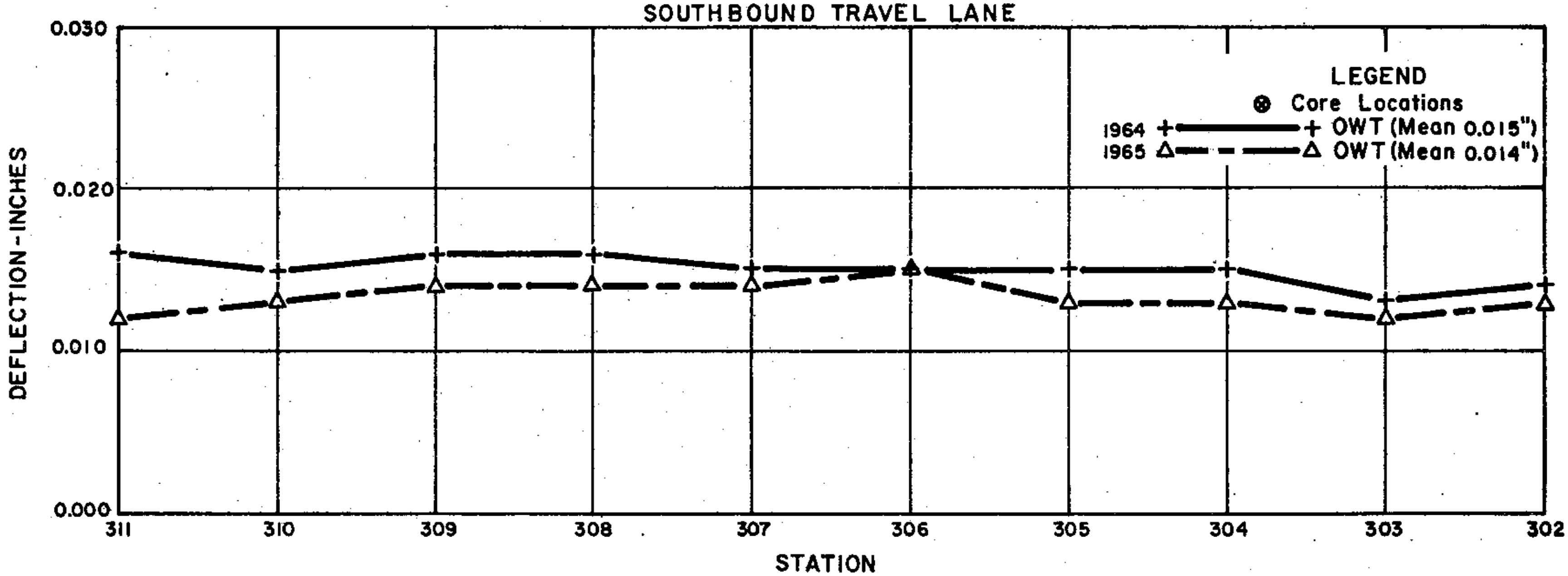
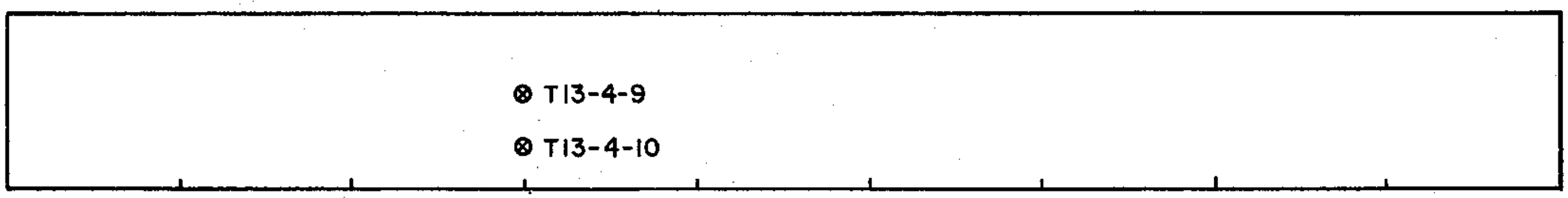


FIGURE 8

PROJECT 7
05-Mon-101
CONT. 62-5T13C3-F
SOUTHBOUND TRAVEL LANE



	311	310	309	308	307	306	305	304	303	302
Rut Depth 1964*	0	0	0	0	0	0	0	4	0	0
Rut Depth 1965*	5	8	6	13	9	7	8	4	.8	9



TEST DATA

	T13-4-10 Surf.	T13-4-10 Base	T13-4-9 Surf.	T13-4-9 Base
% Asphalt	5.8	4.0	5.7	4.3
Pen. at 77°F	48	34	55	36
S.P. (F°)	129.5	140	131	127.5
Duct. at 77°F (Cm)	100+		100+	100+
Mod. of Rupture (PSI)	124.3		118.9	

* Measured to nearest 0.001' in outer wheel track.

STRUCTURAL SECTION

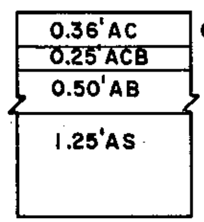


FIGURE 9

PROJECT 8
05 - Mon - 101
CONT. 60 - 14TC1-F
SOUTHBOUND TRAVEL LANE

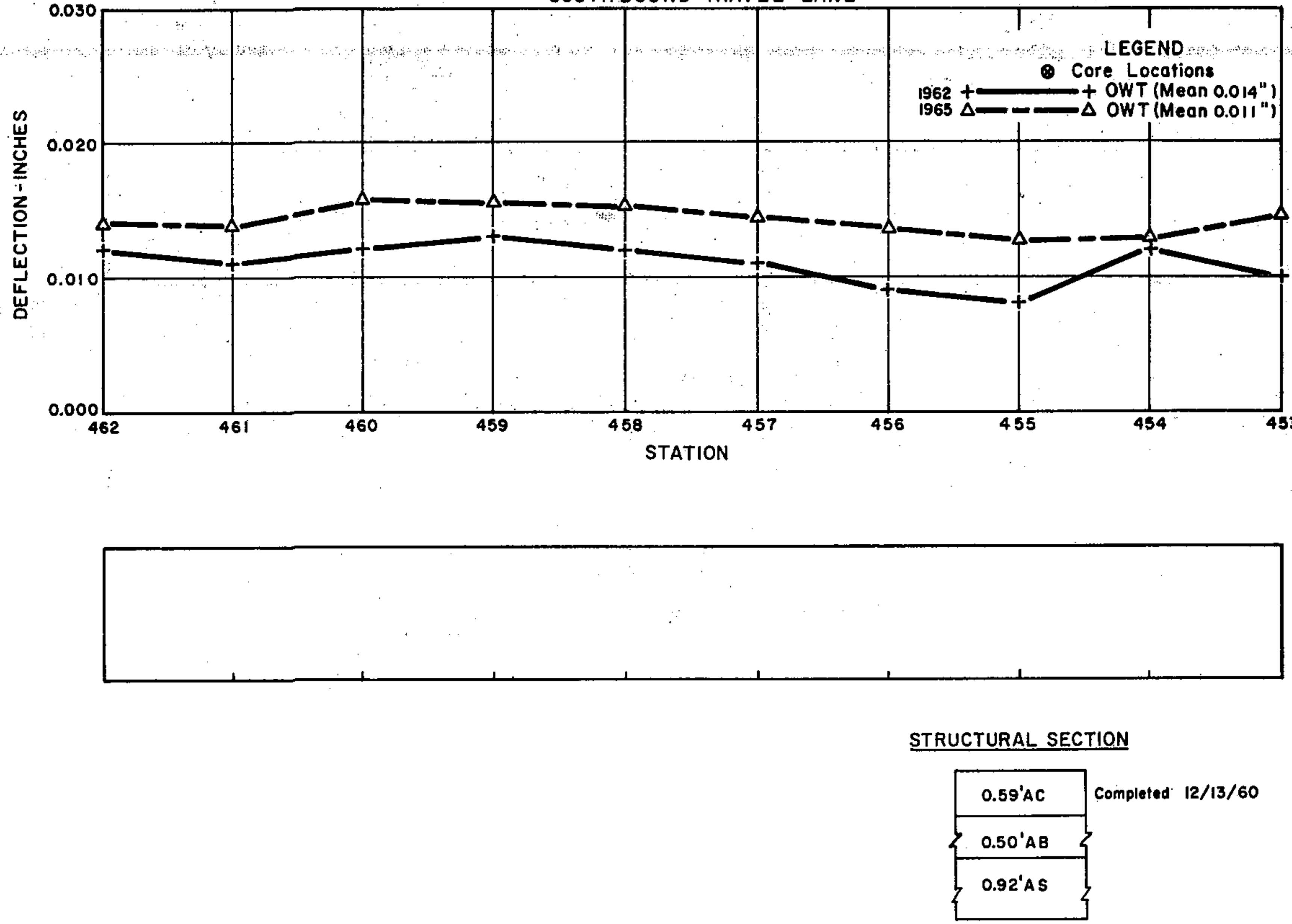


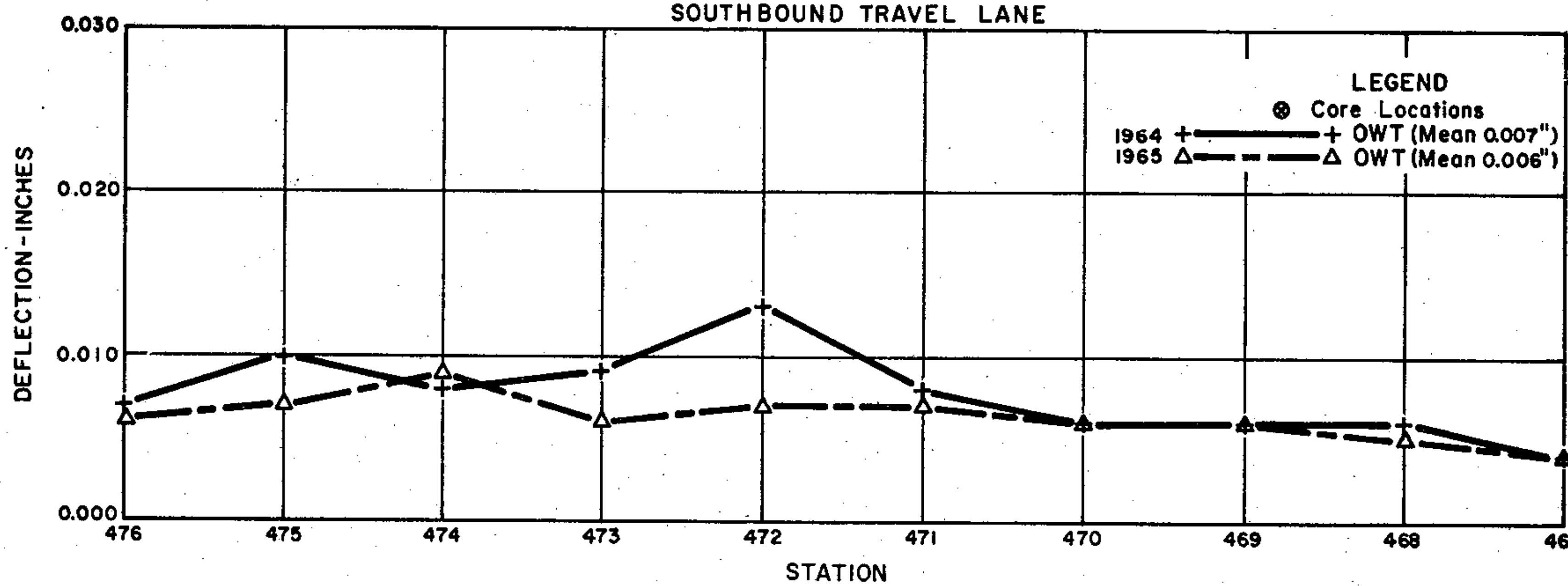
FIGURE 10

PROJECT 9

05-Mon-101

CONT. 62-5T13C4

SOUTHBOUND TRAVEL LANE



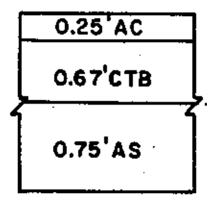
	476	475	474	473	472	471	470	469	468	467
Rut Depth 1964*	0	0	0	0	0	0	0	0	4	4
Rut Depth 1965*	3	3	3	2	8	3	3	3	7	1

⊗ T12-4-1
⊗ T12-4-2

TEST DATA

	T12-4-1	T12-4-2
% Asphalt	5.0	5.0
Pen. at 77°F	38	40
S.P. (F°)	142	139
Duct. at 77°F (Cm)	100+	100+

STRUCTURAL SECTION

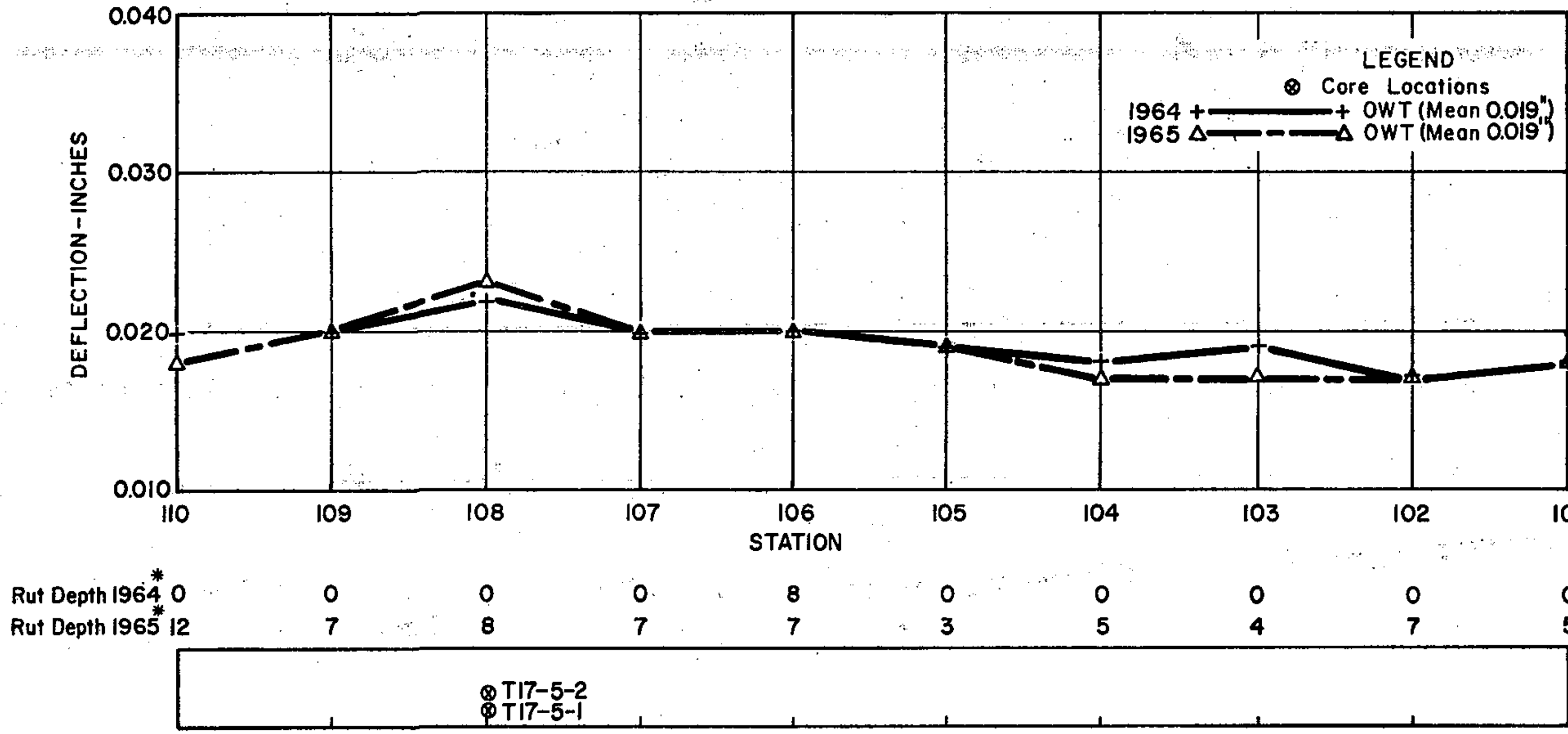


Completed 7/26/62

* Measured to nearest 0.001' in outer wheel track.

FIGURE 11

PROJECT 10
05 – SB – 246
CONT. 61-5V13C9
WESTBOUND LANE



TEST DATA

	T17-5-1	T17-5-2
% Asphalt		
Pen. at 77°F	21	14
S.P. (F°)	154	185
Duct. at 77°F (Cm)	18	3

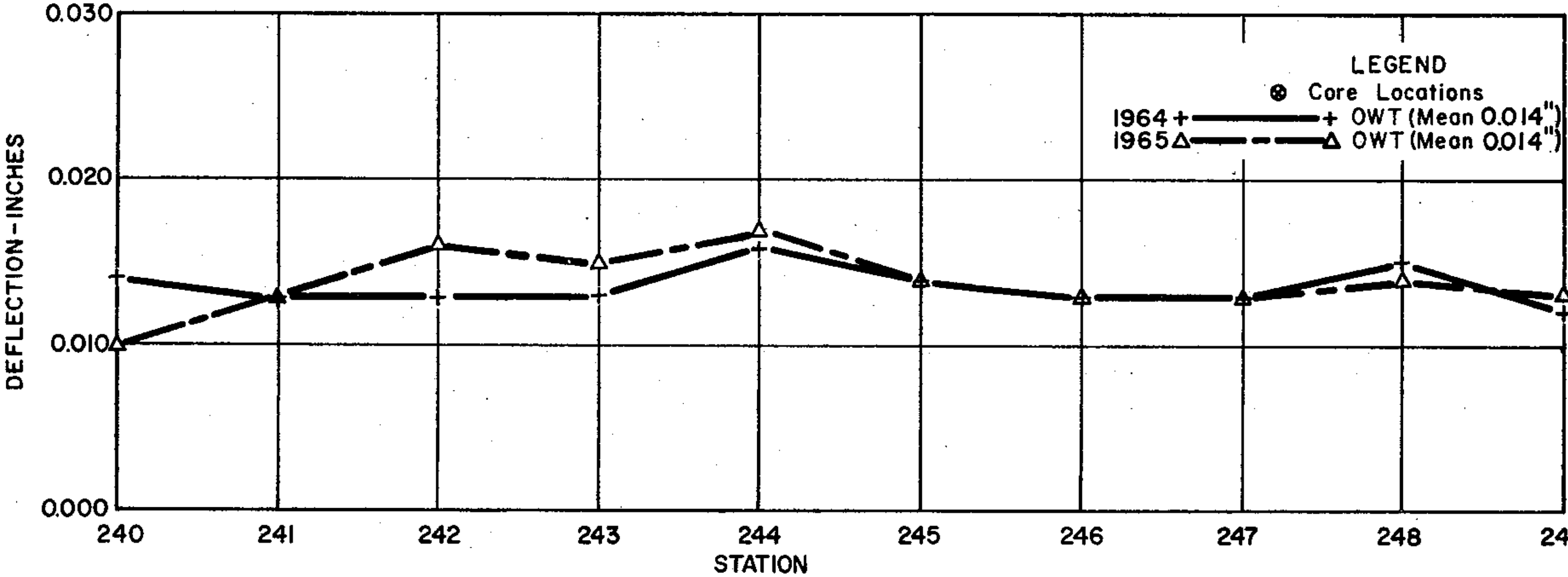
STRUCTURAL SECTION

0.31' AC	Completed 4/17/61
0.50' AB	
Old Pavement	

* Measured to nearest 0.001' in outer wheel track.

FIGURE 12

PROJECT 11
05- SBt-156
CONT. 62-5T13C2
EASTBOUND LANE

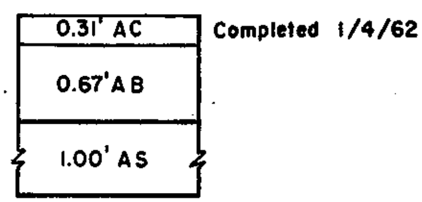


	240	241	242	243	244	245	246	247	248	249
Rut Depth 1964*	0	4	4	0	4	0	8	0	0	0
Rut Depth 1965*	8	9	6	8	5	9	5	11	8	6

TEST DATA

	T10-4-4	T10-4-5
% Asphalt	5.0	5.7
Pen. at 77°F	28	32
S.P. (F°)	138	135
Duct. at 77°F (Cm)	100+	100+

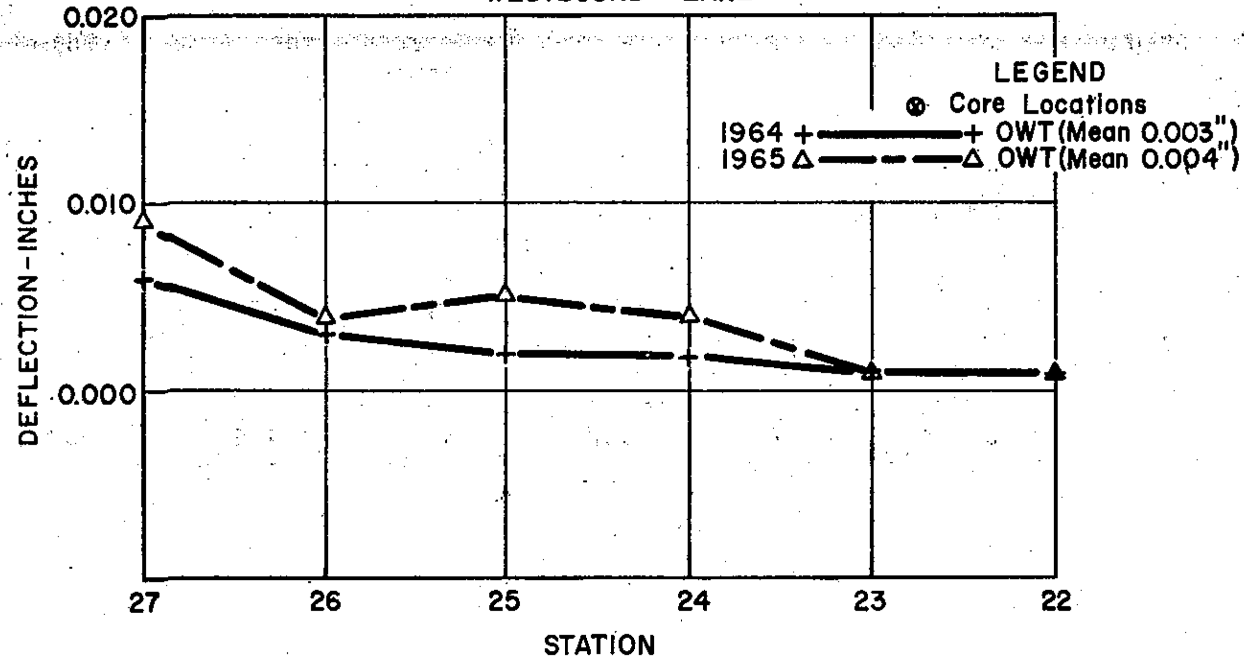
STRUCTURAL SECTION



* Measured to nearest 0.001' in outer wheel track.

FIGURE 13

PROJECT 12
05-SBt-156
CONT. 61-5TC3
WESTBOUND LANE



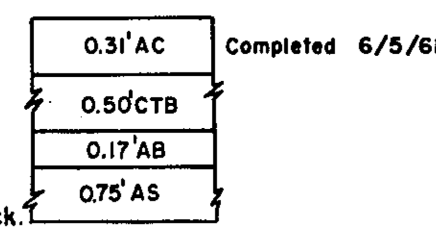
Rut Depth 1964*	8	4	4	4	4	4
Rut Depth 1965*	13	8	6	6	7	7

⊗ T11-4-8
⊗ T11-4-7

TEST DATA

	T11-4-7	T11-4-8
% Asphalt	5.0	4.9
Pen. at 77°F	23	31
S.P. (F°)	152.5	145
Duct. at 77°F (Cm)	29	100+

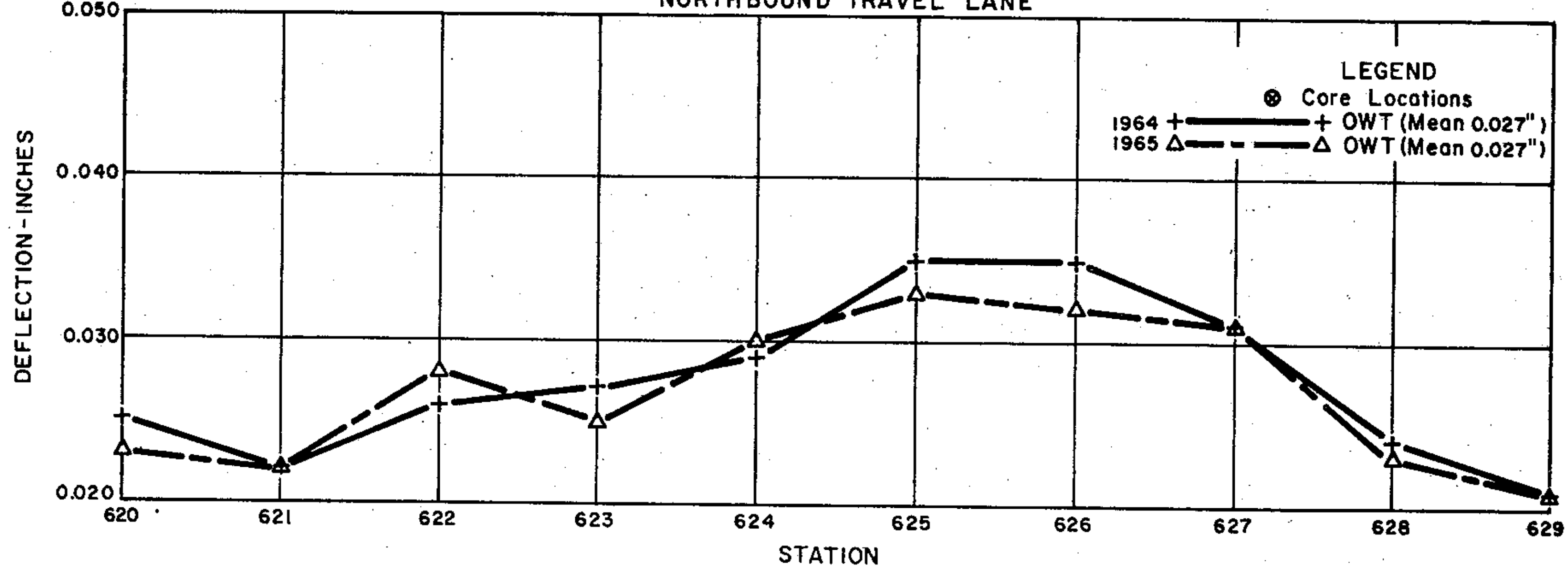
STRUCTURAL SECTION



* Measured to nearest 0.001' in outer wheel track.

FIGURE 14

PROJECT 13
05-SLO-1
CONT. 61 - 5V13 C12
NORTHBOUND TRAVEL LANE



Rut Depth 1964*	0	0	0	0	0	4	0	4	8	0
Rut Depth 1965*	8	6	12	9	5	9	7	4	12	8

STRUCTURAL SECTION

0.27'AC
0.67'AB
1.00 AS

Completed 8/15/63

* Measured to nearest 0.001' in outer wheel track.

FIGURE 15

PROJECT 14

06-Ker-204

CONT. 64-6V13C2-F
WESTBOUND TRAVEL LANE

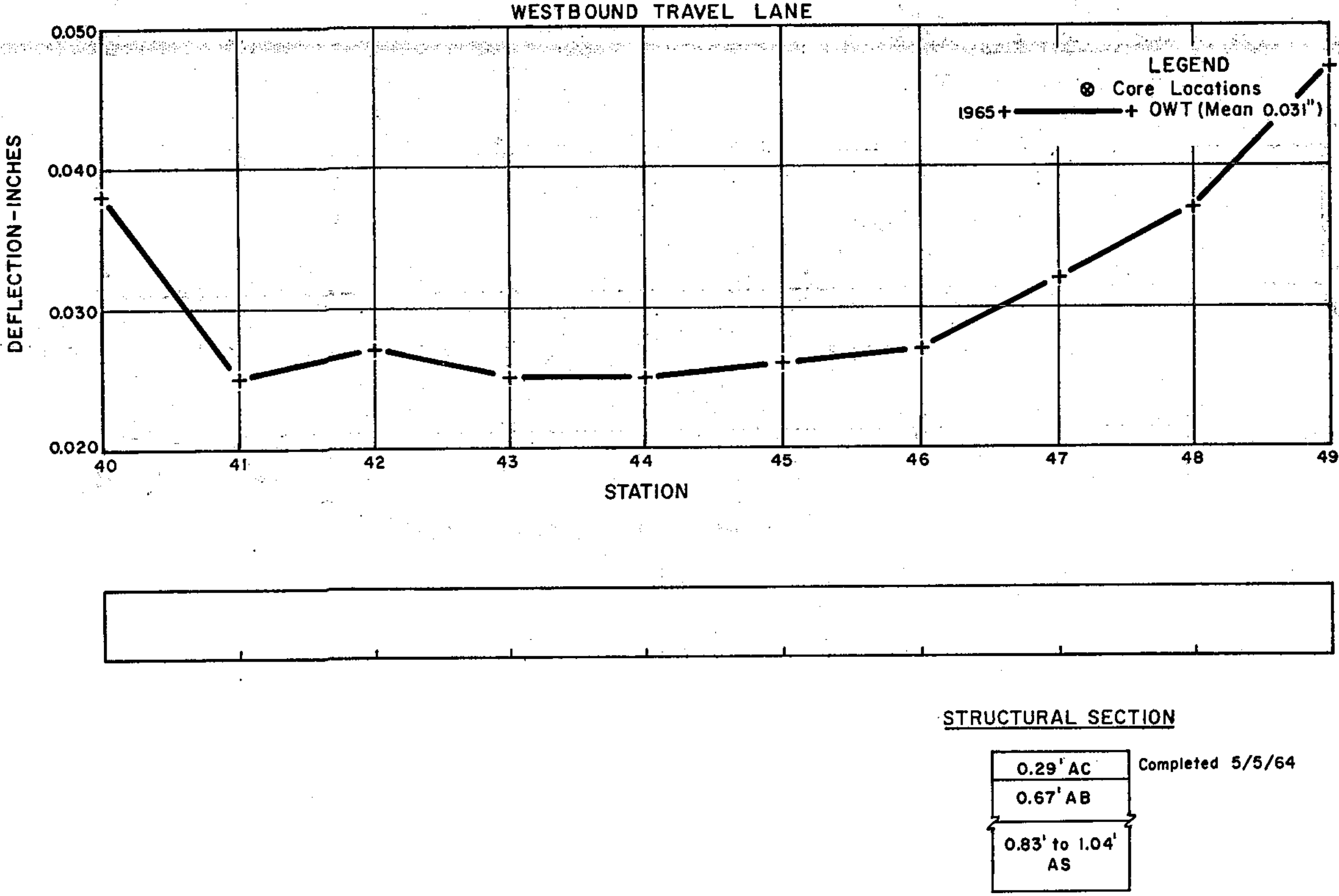
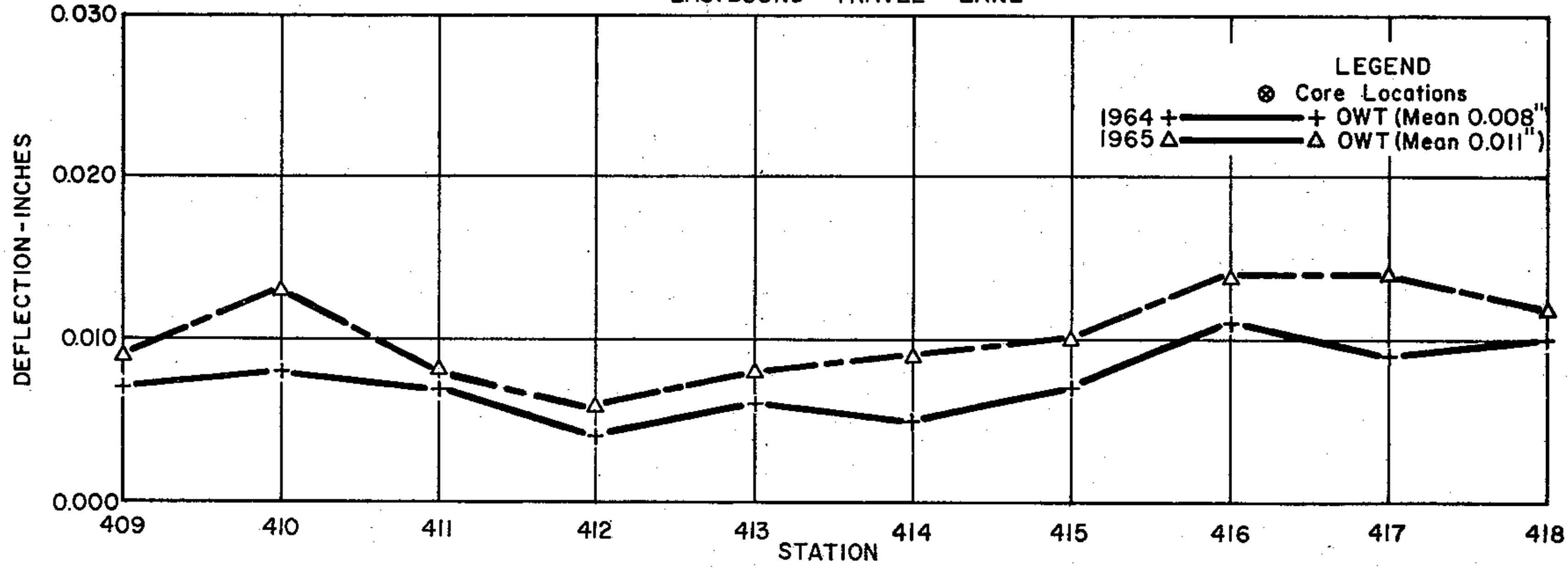


FIGURE 16

PROJECT 15
06 – Kin – 198
CONT. 62-6T13C4
EASTBOUND TRAVEL LANE



	409	410	411	412	413	414	415	416	417	418
Rut Depth 1964*	0	0	0	0	0	0	0	0	0	0
Rut Depth 1965*	0	5	0	4	5	3	6	12	3	9

TEST DATA

	T9-5**	T9-4**
% Asphalt	5.2	4.9
Pen. at 77°F	26	20
S.P. (F°)	145.5	153
Duct. at 77°F (Cm)	69	22.5

STRUCTURAL SECTION

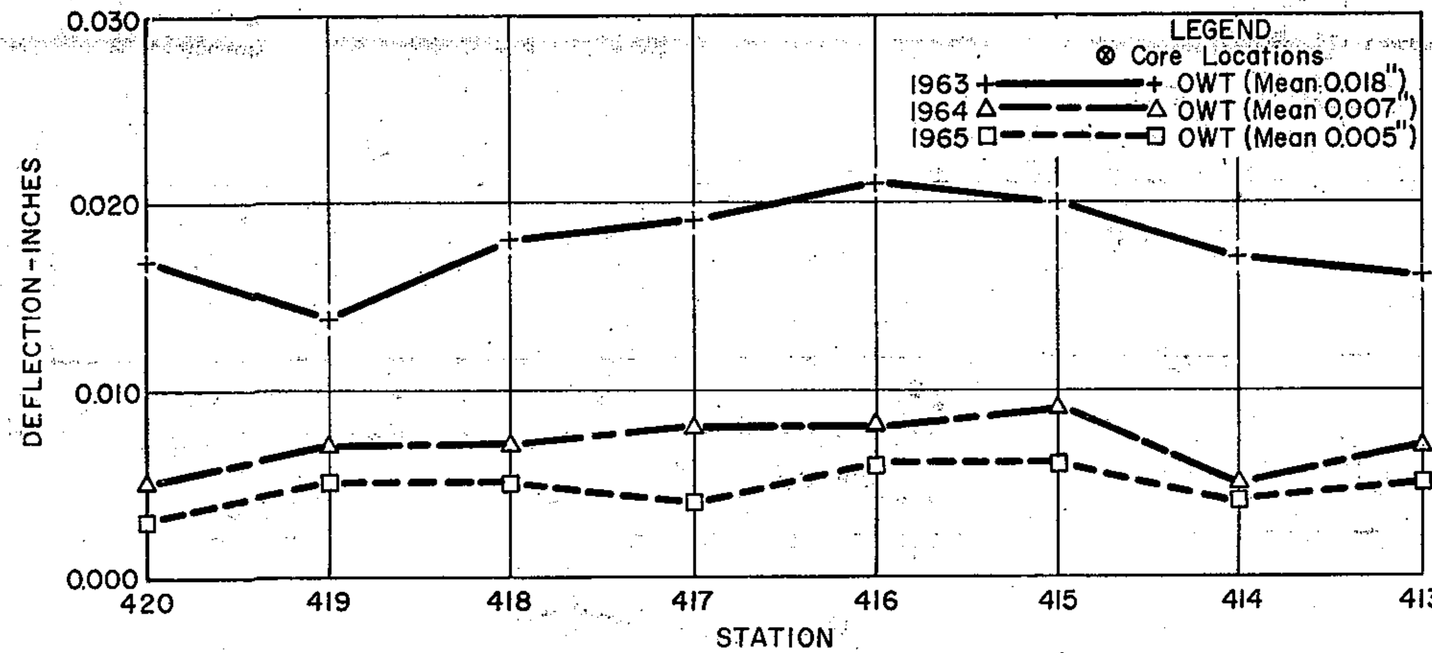
Completed 6/26/63

0.25'AC
0.50'CTB
0.67'AS
0.33'IB

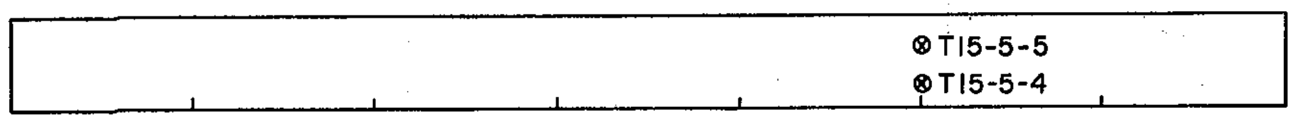
* Measured to nearest 0.001' in outer wheel track.
** Cores taken at Sta. 419

FIGURE 17

PROJECT 16
06-Kin, Tul-43
CONT. 63-6T13C2-P
NORTHBOUND LANE



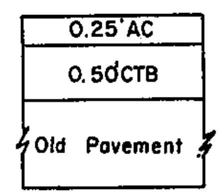
Rut Depth 1964* 10 4 0 12 18 10 6 12



TEST DATA

	T15-5-4	T15-5-5
% Asphalt	5.1	5.0
Pen. at 77° F	22	24
S.P. (F°)	139.5	138
Duct. at 77° F (Cm)	100+	100+

STRUCTURAL SECTION

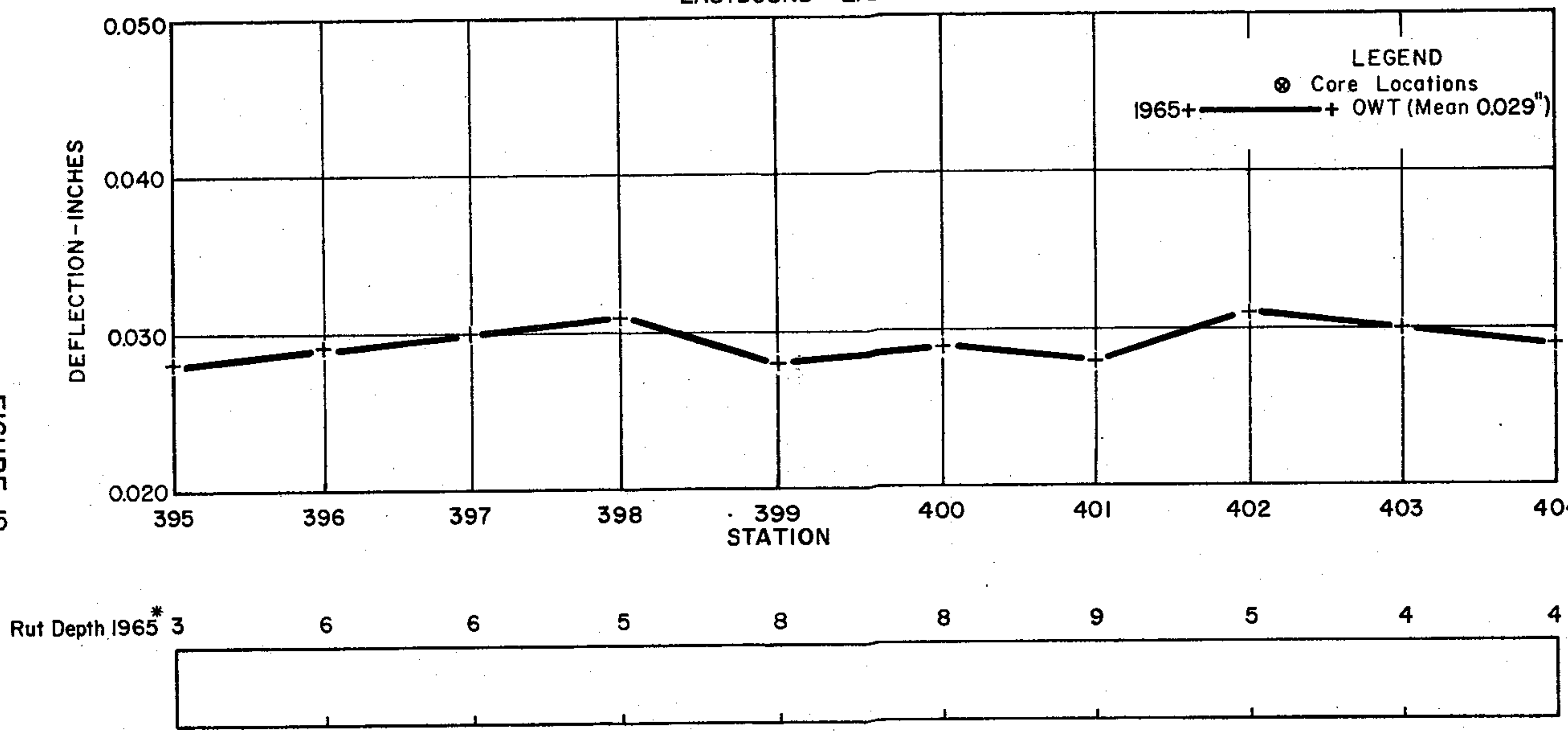


Completed 2/4/63

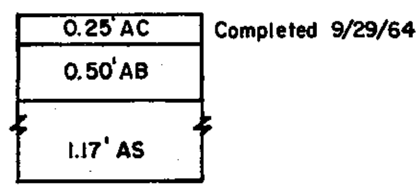
* Measured to nearest 0.001' in outer wheel track.

FIGURE 18

PROJECT 17
06-Fre-811-FAS
CONT. 64-6Y24C19-P
EASTBOUND LANE



STRUCTURAL SECTION



* Measured to nearest 0.001' in outer wheel track.

FIGURE 19

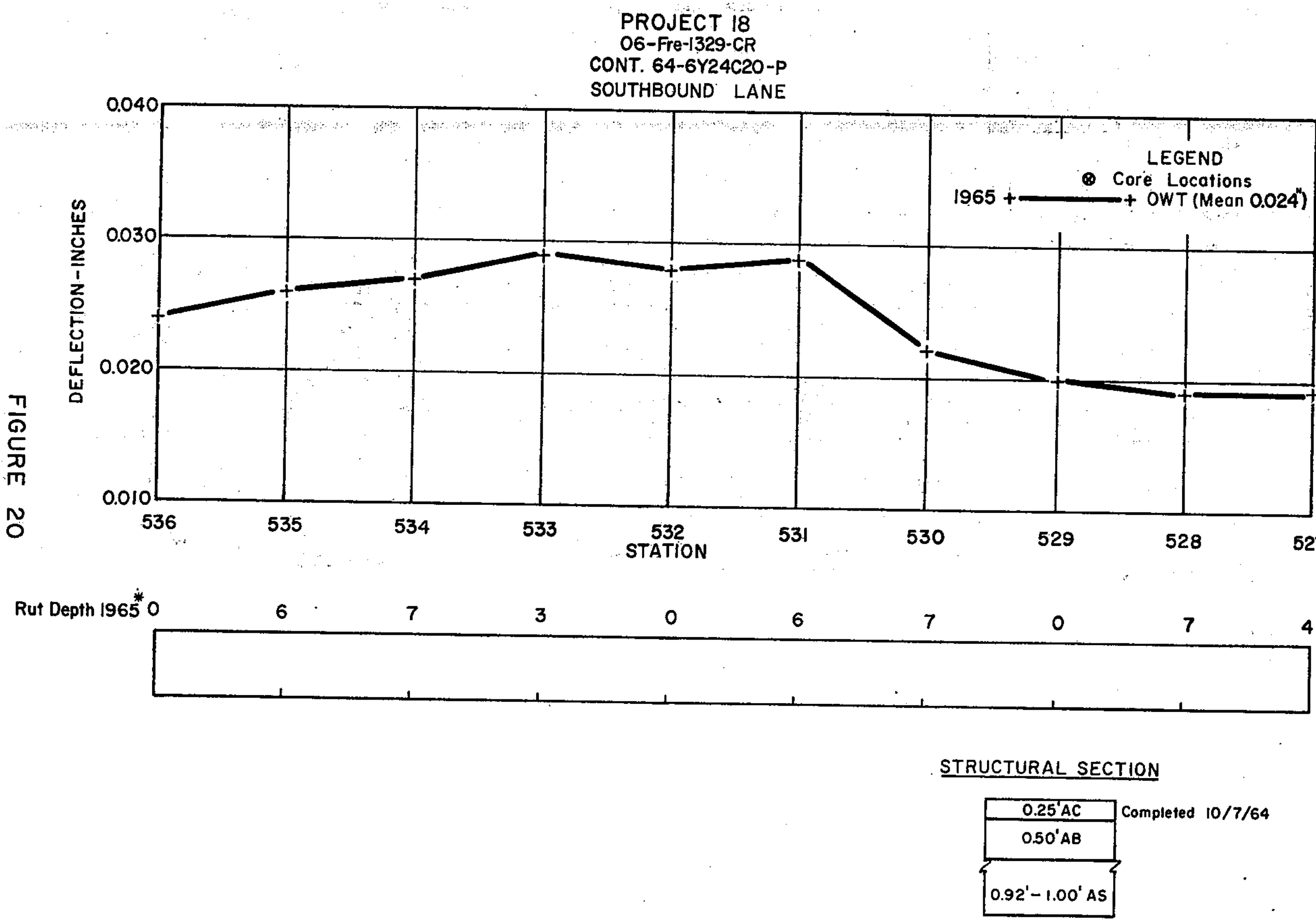
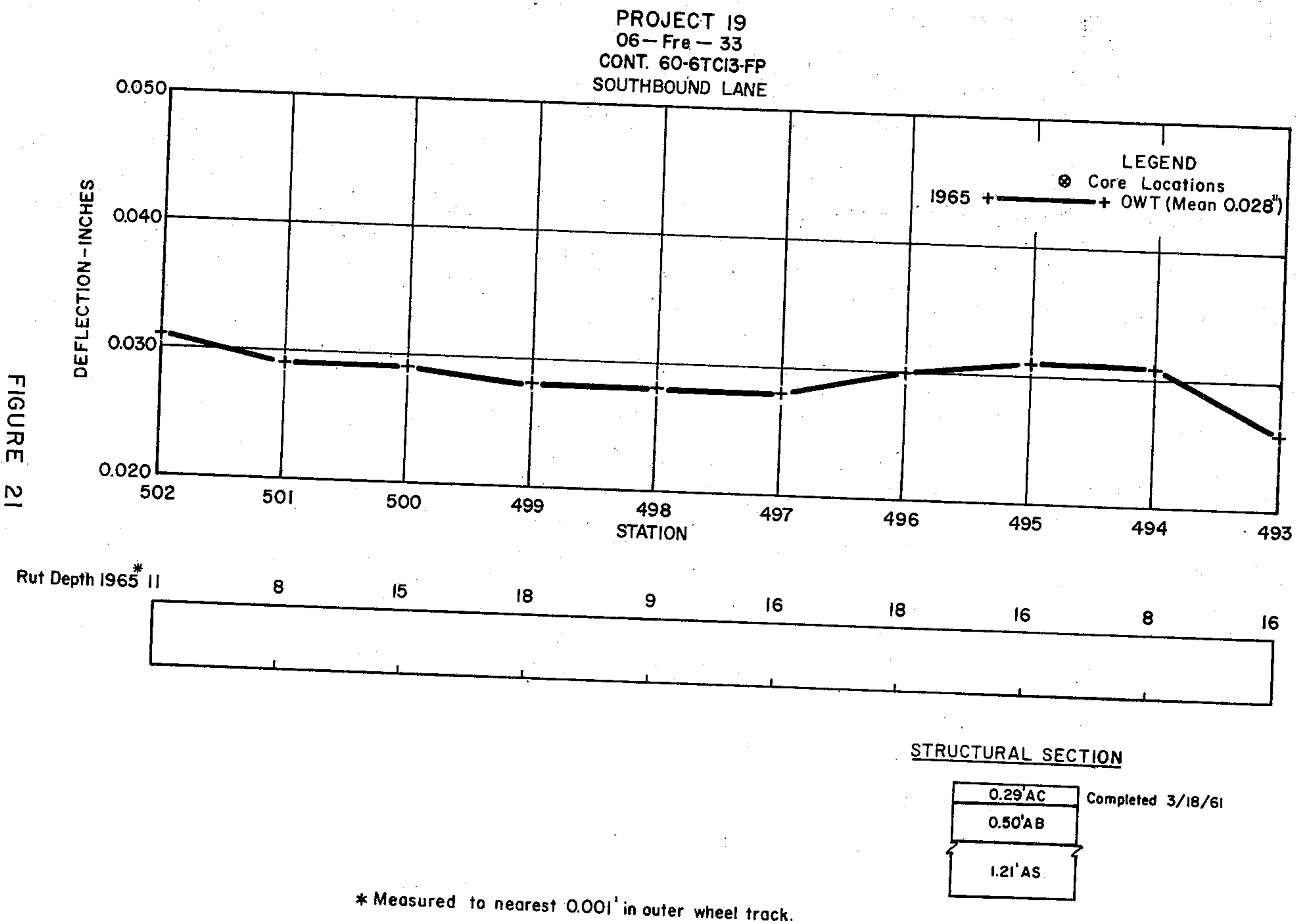


FIGURE 20

* Measured to nearest 0.001' in outer wheel track.



PROJECT 19
06 — Fre — 33
CONT. 60-6TC13-FP
SOUTHBOUND LANE
LEGEND
⊗ Core Locations
1965 + —— + OWT (Mean 0.028")
DEFLECTION - INCHES
0.050
0.040
0.030
0.020
502
501
500
499
498
497
496
495
494
493
STATION
Rut Depth 1965* 11
8
15
18
9
16
18
16
8
16
STRUCTURAL SECTION
0.29' AC
0.50' AB
1.21' AS
Completed 3/18/61
* Measured to nearest 0.001' in outer wheel track.

FIGURE 21

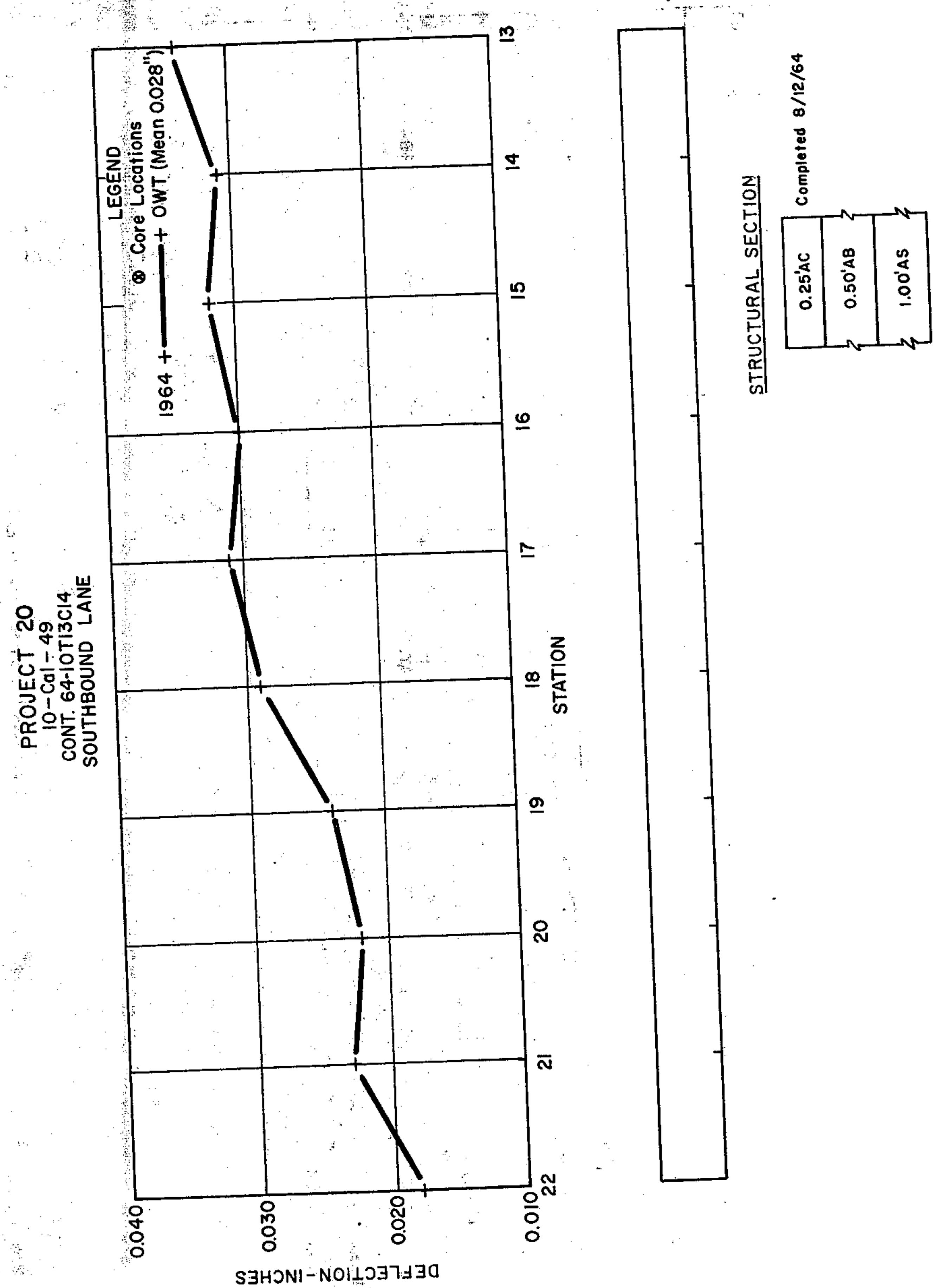

PROJECT 20
10-Cal-49
CONT. 64-10T13C14
SOUTHBOUND LANE
LEGEND
⊗ Core Locations
1964 +——+ OWT (Mean 0.028")
DEFLECTION - INCHES
0.040
0.030
0.020
0.010
STATION
13
14
15
16
17
18
19
20
21
22
STRUCTURAL SECTION
Completed 8/12/64
0.25'AC
0.50'AB
1.00'AS

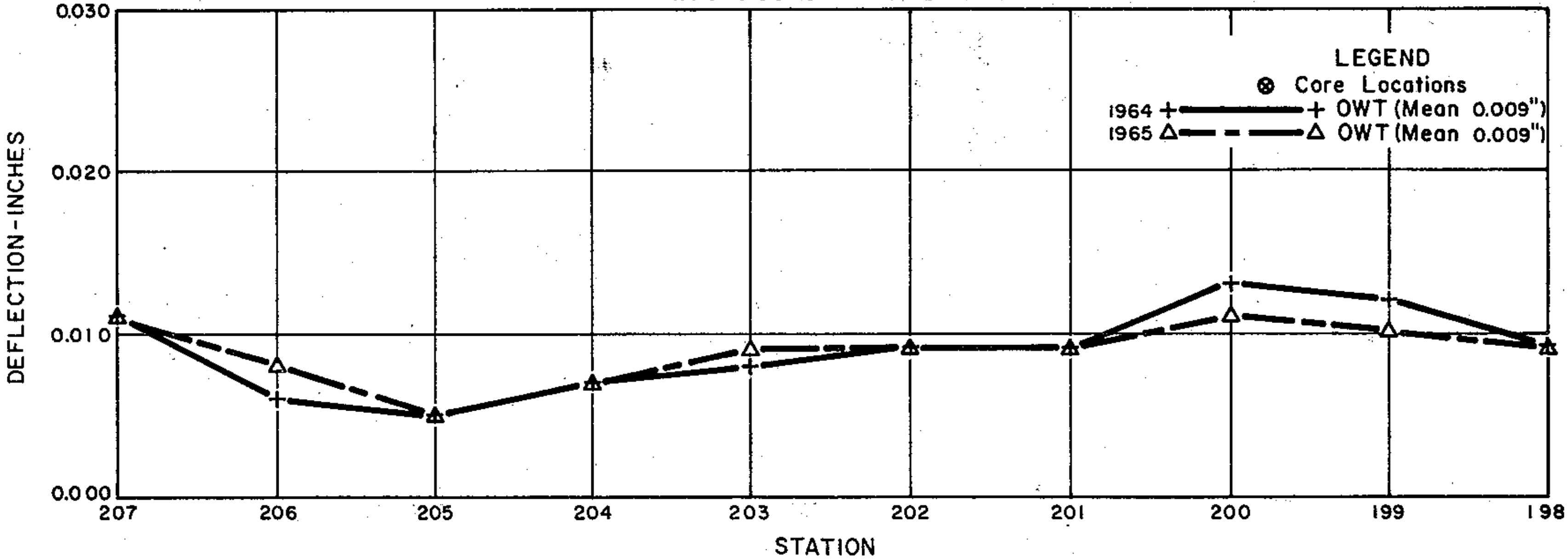
FIGURE 22

PROJECT 21

10 - Sol - 21

CONT. 60 - 10T C18-FI

WESTBOUND TRAVEL LANE



Station	207	206	205	204	203	202	201	200	199	198
Rut Depth 1964*	0	0	8	12	16	0	0	0	8	0
Rut Depth 1965*	7	19	10	7	18	5	6	5	6	2

TEST DATA

	T6-4-11	T6-4-12
% Asphalt	5.5	5.3
Pen. at 77°F	20	30
S.P. (F°)	149	142
Duct. at 77°F (Cm)	35	100+

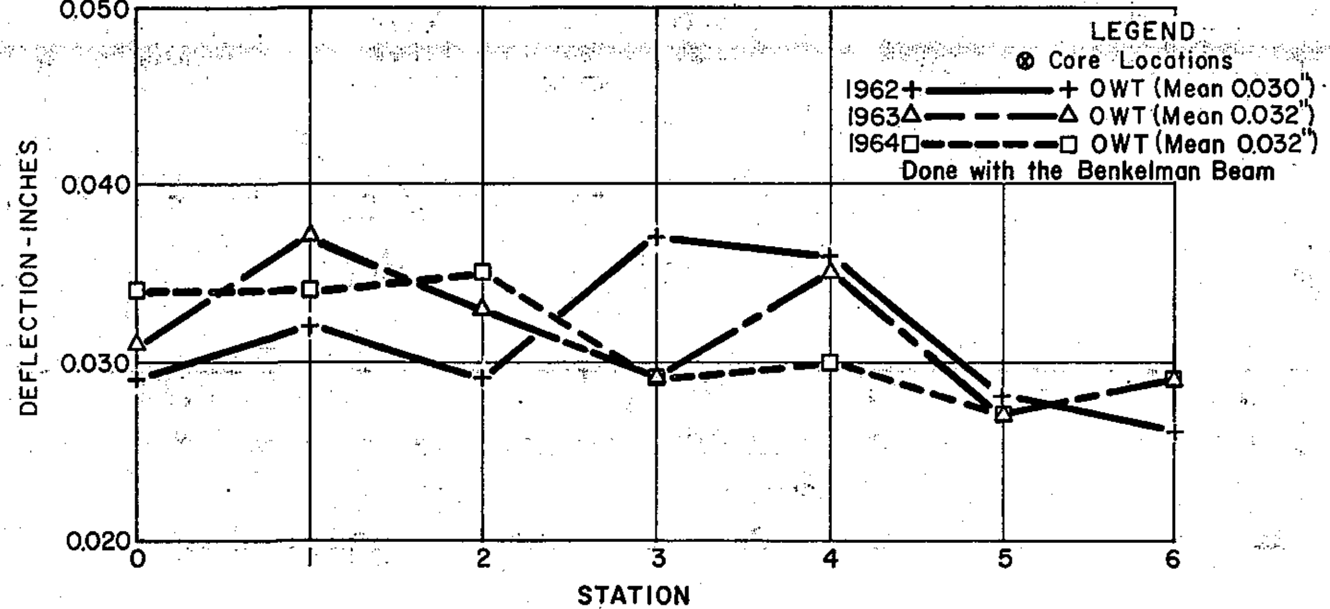
STRUCTURAL SECTION

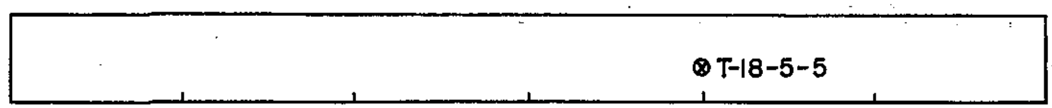
0.39' AC	Completed 6/14/61
0.67' CTB	
1.00' ISM	
1.00' Perm. Matl.	

* Measured to nearest 0.001' in outer wheel track.

FIGURE 23

PROJECT 22A & 22B
City of Woodland - (03)
Cross Street Between
Elm And Cleveland





TEST DATA

	T-18-5-5
% Asphalt	4.3
Pen. at 77°F	27
S.P. (F°)	141
Duct. at 77°F (Cm)	100+

STRUCTURAL SECTION

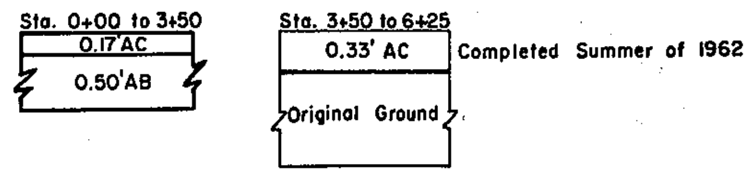


FIGURE 24

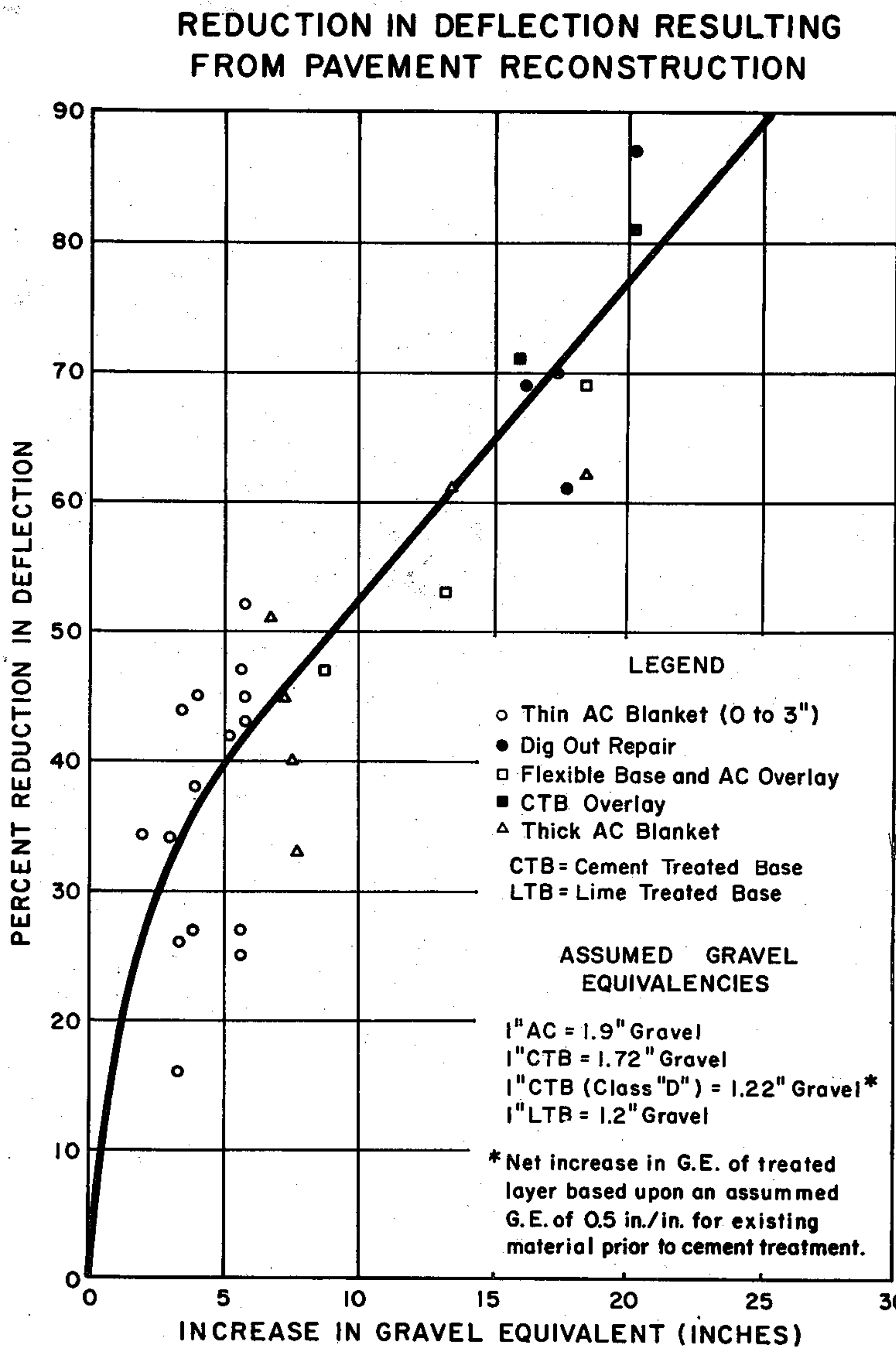
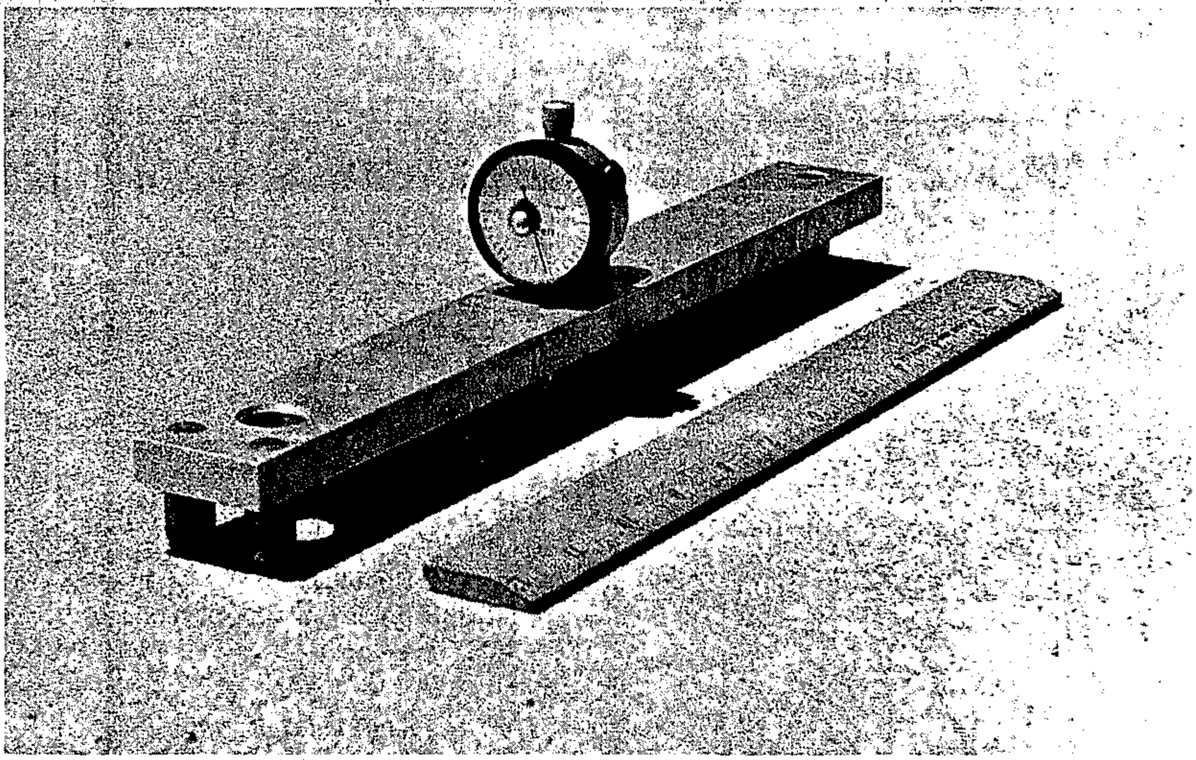

REDUCTION IN DEFLECTION RESULTING
FROM PAVEMENT RECONSTRUCTION
PERCENT REDUCTION IN DEFLECTION
INCREASE IN GRAVEL EQUIVALENT (INCHES)
0
10
20
30
40
50
60
70
80
90
5
15
25
LEGEND
Thin AC Blanket (0 to 3")
Dig Out Repair
Flexible Base and AC Overlay
CTB Overlay
Thick AC Blanket
CTB = Cement Treated Base
LTB = Lime Treated Base
ASSUMED GRAVEL EQUIVALENCIES
1" AC = 1.9" Gravel
1" CTB = 1.72" Gravel
1" CTB (Class "D") = 1.22" Gravel*
1" LTB = 1.2" Gravel
*Net increase in G.E. of treated layer based upon an assummed G.E. of 0.5 in./in. for existing material prior to cement treatment.

FIGURE 25



Dehlen "Curvature Meter"

FIGURE 26

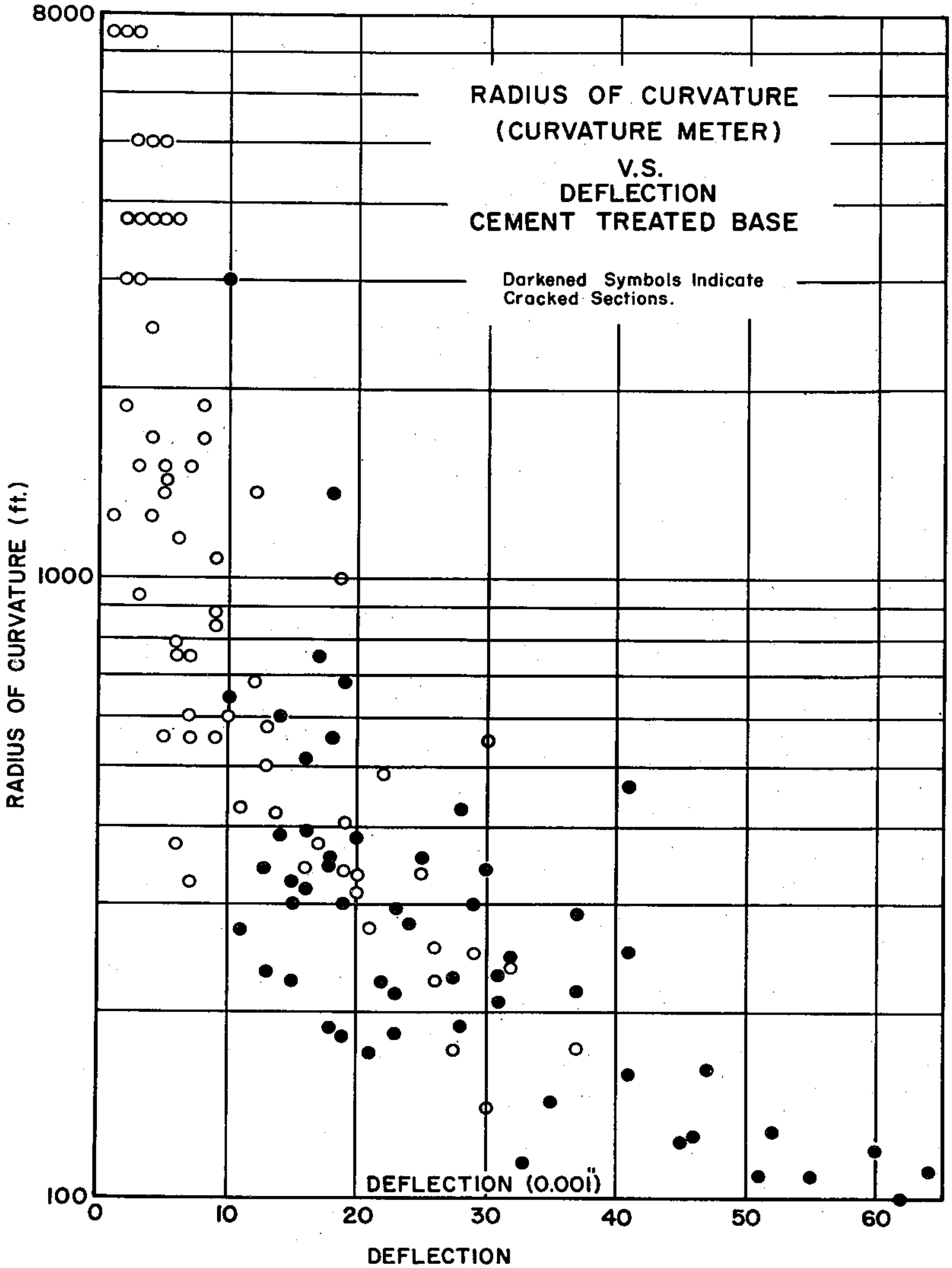
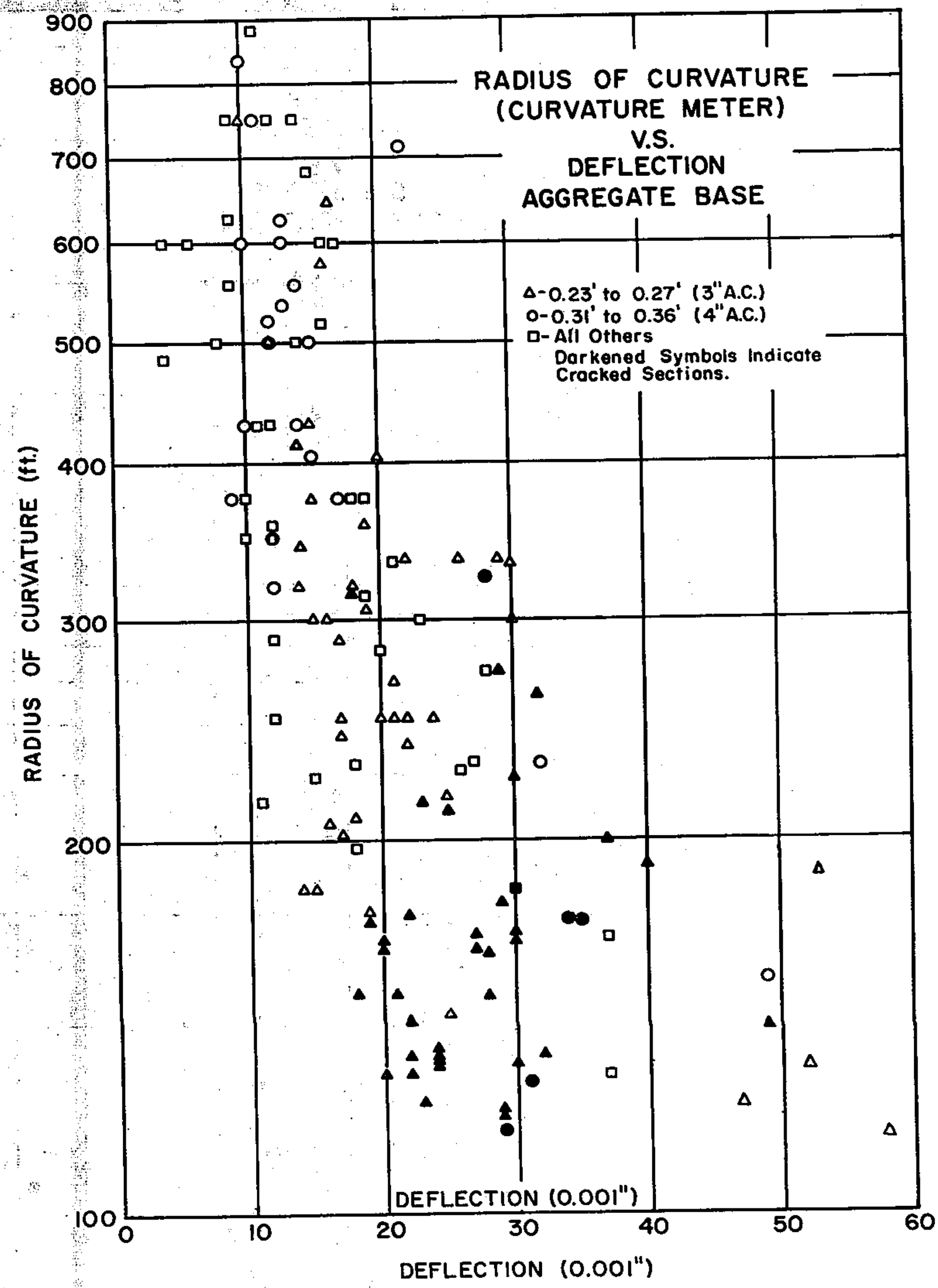

RADIUS OF CURVATURE
(CURVATURE METER)
V.S.
DEFLECTION
CEMENT TREATED BASE
Darkened Symbols Indicate Cracked Sections.
RADIUS OF CURVATURE (ft.)
8000
1000
100
DEFLECTION (0.001")
0
10
20
30
40
50
60
DEFLECTION

FIGURE 27



RADIUS OF CURVATURE
(CURVATURE METER)
V.S.
DEFLECTION
AGGREGATE BASE
Δ-0.23' to 0.27' (3" A.C.)
o-0.31' to 0.36' (4" A.C.)
□- All Others
Darkened Symbols Indicate
Cracked Sections.
RADIUS OF CURVATURE (ft.)
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60
DEFLECTION (0.001")
DEFLECTION (0.001")

FIGURE 28