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The performances of three structural sections constructed over highly resilient soils are evaluated by Benkelman bean deflection measurements and by visual observations of surface fatigue. The structural sections were designed to reduce deflections to tolerable levels. Deflection measurements were made at various stages of construction and annually over a ten year period after construction. All three structural sections resisted surface fatigue satisfactorily even though deflection measurements were higher than the design maximum deflections. The effections of moisture content and temperature conditions on deflection measurements are also discussed.

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RONALD REAGAN, Governor

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Interim Report
M&R 643450
June, 1970

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

DEFLECTION STUDIES PERFORMED ON

EL CENTRO ROAD (03-SAC-99)

TEN YEAR REPORT

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Very truly yours,

JOHN L. BEATON
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REFERENCE: Sherman, G. B., Gates, C. G., Durr, D. L., and Hatano, M., "Deflection Studies Performed on El Centro Road," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 643450, June, 1970.

ABSTRACT: The performances of three structural sections constructed over highly resilient soils are evaluated by Benkelman beam deflection measurements and by visual observations of surface fatigue. The structural sections were designed to reduce deflections to tolerable levels. Deflection measurements were made at various stages of construction and annually over a ten year period after construction. All three structural sections resisted surface fatigue satisfactorily even though deflection measurements were higher than the design maximum deflections. The effects of moisture content and temperature conditions on deflection measurements are also discussed.

KEY WORDS: Pavement deflection, Benkelman beam, temperature, moisture content, bases, cement treated bases, bituminous aggregate bases.

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INTRODUCTION

In 1949 the Materials and Research Department published a report by F. N. Hveem and R. M. Carmany[1] which presented the basis for our present flexible pavement design procedures. This report recognized the importance of plastic deformation and finding a solution to the problem of fatigue action caused by the flexing of more or less rigid slabs over resilient foundations. This study is concerned with the latter problem. A later report by F. N. Hveem[2] offered the following three solutions for preventing fatigue failures: Provide a pavement that is sufficiently flexible to accommodate repeated substantial vertical deflections without serious cracking; decrease the magnitude of the vertical deflections to a tolerable amount by providing greater stiffness with greater depths of granular bases and subbases under the pavement; or provide a pavement with a slab strength sufficient to sustain the forces induced by traffic which cause cracking.

In order to evaluate the capability of various structural sections to reduce surface deflections, a local road, constructed with three different structural sections over highly resilient soils, was used as a test road.

The primary objectives of this study were:

1. To determine the reduction in deflection achieved by adding layers of various materials to the structural section.

2. To determine the range of deflections that could be expected on the existing roadway at various times during the year.

3. To determine the time required for a cement treated base section to cure sufficiently to reduce deflection.

4. To investigate the adequacy of our present criteria for maximum permissible deflections of various structural sections.

Other objectives were formed after the project was underway. These objectives were:

1. To determine the effect of temperature on deflection measurements.

2. To compare the performance of high quality and low quality CTB.

CONCLUSIONS

The performance of each of the test sections was observed and deflection measurements were made annually from 1959 to 1969. It was estimated that by 1968 the traffic had reached the 10,000,000 EWL's for which the road was designed. Based on this information, the following conclusions are made:

1. The deflections were reduced as each layer of structural section was added. The average percent reductions for each additional layer of material based on the last reading on the immediate underlying layer are shown in Table XIII. The actual deflection reductions agree reasonably well with the expected reductions.

2. The average deflections of individual test sections on the original road varied from 0.037" to 0.087". There was also a seasonal variation in the deflections. The largest deflections occurred during the spring and apparently resulted from high moisture contents in the base and underlying soil.

3. The cement treated base layer gained most of its resistance to deflection within four days after being placed.

4. The performance of the test sections is exceeding the performance predicted by current California deflection design criteria. These criteria, however, were established from many projects on a Statewide basis. Many of these projects had poorer performance than El Centro Road. It appears that other factors need to be considered, along with deflection, to accurately predict pavement performance.

5. Temperature directly affected deflection readings. The deflections on the ACB sections changed about 0.0005" for each 1°F of change in 5 day average mean temperature. The temperature had less influence on the deflections of the cement treated base and aggregate base sections than it did on the deflections of the asphalt concrete base sections.

6. Sufficient traffic has not been carried by El Centro Road to induce failures in any of the sections. Therefore, no comparison can be made, at this time, between the performance of high strength and low strength cement treated base.

7. In order to fully meet the objectives of this study, the performance of this test road needs to be evaluated yearly until failures occur.

GENERAL PROJECT DESCRIPTION

The portion of State Route 99, which is located in Sacramento County between the Garden Highway and the Sutter County line, was selected for this study for several reasons. Convenient accessibility from the Materials and Research Department, high deflections on the existing roadway, and the need for major reconstruction because of the poor condition of the road and the rapidly increasing volume of traffic made this road ideally suited.

This portion of Route 99, known locally as El Centro Road, served as a direct connection between Sacramento and Marysville until 1968. With the completion of Interstate 5 between Sacramento and the Sacramento Metropolitan Airport, portions of the test road were no longer subjected to heavy traffic.

The road traverses low farmland which has an average annual rainfall of about 18 inches. Much of the area is flood irrigated and there are deep drainage ditches parallel to the road on both sides throughout much of its length. Photographs of the reconstructed road are shown in Figure 1.

At the time El Centro Road was adopted into the state highway system, the structural section consisted of approximately 3/4" armor coat surfacing, 6" of aggregate base material (sand and gravel) and 9" of imported subbase material (sand). Native soils in the area are poor quality clay having R-values as low as 3. El Centro Road was constructed by Sacramento County between 1949 and 1953 and no major improvements had been made prior to the time of the reconstruction in 1959 and 1960. Sampling and testing of the in-place materials indicated that the R-values and resilience characteristics of the native soils, imported subbase and aggregate base were reasonably uniform throughout the length of the test sections. Test results for each existing material are summarized in Tables I, II and III.

Prior to reconstruction, this road was in poor condition due to insufficient cover over the low quality basement soil. The traveled way was cracked, deformed and costly to maintain. Many deflection measurements, taken on the existing road, were quite large.

As plans were being made to reconstruct El Centro Road to meet the increasing traffic demands, it was decided to try three different structural designs to determine which type would be the most effective in reducing high deflections. The basic difference in the sections was the type of base used.

Based on the 1957 California design method, a traffic volume of 10,000,000 EWL was estimated for the 1960 to 1970 design life of the new construction. Projections of truck counts made in 1959 and 1963 indicate that the design EWL was reached in 1968.

STRUCTURAL SECTIONS AND MATERIALS

The test sections discussed in this report were constructed under two separate contracts. The limits of each structural section and the location of each test section are shown in Figure 2. Each of the three structural sections are also shown and identified according to the type of base used. Throughout the remainder of this report the designations CTB, ACB and AB will be used to identify the structural section containing cement treated base, asphalt concrete base and aggregate base, respectively.

Samples taken during construction indicate that the materials placed in the roadway generally conformed to the specifications and the project was constructed substantially as planned. A summary of test results of materials sampled by construction personnel during construction are given in Tables IV through VIII.

Cement Treated Base Section

The structural section consisting of 1/2" of open graded AC, 3" of AC, and 8" of Class "A" CTB was constructed in 1959 under contract 60-3TC20. The limits of this contract are between Stations 7+40 and 315+00.

Mineral aggregate for the CTB was obtained from Cache Creek near Woodland and conformed to the 1954 California Standard Specifications for one inch maximum Class "A" CTB.

Four percent cement and seven percent mixing water were used. This mixture was designed to meet the laboratory compressive strength requirement of 650 psi at seven days.

The mineral aggregate for CTB was deposited on the roadway with dump trucks and a motor grader was used to blade the material into windrows. Cement was then distributed on the windrow by truck and the material was mixed by two Pettibone-Wood traveling pug mixers. The mixed material was spread by a motor grader over the existing roadway in one eight inch lift and compacted with a three wheel steel roller and a pneumatic roller. Public traffic was allowed on the CTB as soon as a curing seal and sand cover could be placed on the compacted material.

Forty compressive strength specimens were fabricated during construction. Almost one third of these specimens failed to attain the seven day compressive strength requirement of 650 psi. Generally, however, the strengths were only slightly below the 650 psi requirement and none of these low strengths were within the planned test sections. The four specimens taken between Stations 209+50 and 212+80 (see Table IV) represent an area where it was necessary to mix the cement and aggregate with a motor grader. A wet grade after a heavy rainfall made it impossiblè to use the road mix machine in this area. The compressive strengths of all four of these specimens were far below the required strength. A summary of the compressive strength tests is given in Table IV.

The two lifts of Type "B" AC and the 1/2" of open graded AC were placed with a Barber Greene paving machine and compacted with a two wheel steel roller. The AC mix generally conformed to the 1954 California Standard Specifications for Type "B", 3/4" maximum, with the exception that the material was slightly finer than specified in the sand sizes. All of the samples tested met the 35 minimum stability requirement. The material was mixed with 5.5 percent of 85-100 penetration paving asphalt. See Table V for a summary of tests. Out of 57 samples of asphalt tested, three were slightly out of specifications on the flash test and one was slightly out on penetration.

Asphalt Concrete Base Section

The structural section consisting of 1/2" open graded AC, 3" AC, 3" ACB and 6" AB was constructed in 1960 under contract 61-3TC9. The limits of this structural section are between Stations 360+00 and 444+00 (see Figure 2).

The aggregate base material was obtained from Cache Creek near Woodland. Only three samples of the base material from this section were tested during construction. Each sample met the grading requirements, but one failed to meet the R-value requirement and all three sand equivalents were below the specification requirements. These data and the aggregate base data for the AB section are summarized in Table VI. The AB material was deposited on the existing grade with dump trucks and spread to approximate grade by a tractor with a blade attachment. Compaction was accomplished with a three wheel steel roller and trimming to finished grade was done with a motor grader.

The three inch asphalt concrete base course was spread and compacted in one lift. The aggregate conformed to the 1960 California Standard Specification requirements for 1-1/2 inch maximum base course. Five and one half percent of 85-100 penetration asphalt was used. Although five of six samples taken during construction showed the grading to be slightly out of specifications, all of the stabilometer values were well above the 35 minimum. See Table VII.

The asphalt concrete surface was placed in two 1-1/2 inch lifts with a Cedar Rapids paving machine and compacted with a two wheel steel roller. Five and one half percent of 85-100 penetration asphalt was used in the mix. The gradings on four of the six samples tested were slightly out of specifications but the stabilometer values were at or above the 35 minimum required. These data are included in Table VIII. Tests on 42 asphalt samples showed eleven to be slightly out of specifications for penetration and two out of specifications for the flash test.

Tests on the open graded asphalt showed one sample to be slightly out of the grading specifications.

Aggregate Base Section

This section was also constructed in 1960 under contract 61-3TC9. The structural section consisted of 1/2" open graded AC, 3" AC and 12" AB. The limits of this section are between Stations 315+00 and 360+00 and between Stations 444+00 and 484+09.

The aggregate base material was the same as was used in the ACB section and the manner of spreading and compacting was similar except that it was placed in two lifts. Tests on 11 samples taken during construction indicated that three were out of grading and R-values were low on two. Three of the samples were also low on the sand equivalent test. These data are included in the summary in Table VI.

The asphalt concrete was the same as that used in the surface course of the ACB section. Tests on samples taken within this section also showed all of the stabilometer values to be well above the minimum required, but again the gradings were slightly out of specifications on three of the four samples tested. These data are included in Table VIII.

TEST SECTIONS

A total of twelve test sections were selected within the limits of the described structural sections and the limits are listed below. Test Section 2 was not incorporated into the study until after the CTB was placed. This was the previously described area where the cement and aggregate were mixed with a motor grader. It was felt that this test section would provide a comparison between good and low quality CTB.

Test Section	Base Type	Station Limits	Lane
1	CTB	101+17 to 106+17	NB
2	"	209+00 to 217+00	SB
3	"	235+00 to 240+00	NB
4	"	278+00 to 283+00	NB
5	"	303+00 to 308+00	SB
6	ACB	369+00 to 374+00	NB
7	"	395+00 to 400+00	NB
8	"	409+25 to 414+25	SB
9	"	435+00 to 440+00	NB
10	AB	321+00 to 326+00	NB
11	"	342+30 to 352+30	SB
12	"	466+00 to 471+00	SB

TESTING PROGRAM

To evaluate the capability of each of the three structural sections to reduce surface deflections over highly resilient soils and also to determine the effect of each layer of material within the structural section, the following testing program was adopted:

1. Test sections were laid out and referenced so that each subsequent series of deflection tests would be made at the same locations.

2. Deflection measurements were made on the existing roadway at various times during the year prior to reconstruction.

3. Deflections measurements were made as each layer of the new structural section was completed.

4. Deflection measurements were made on the CTB layer at periodic intervals prior to adding the AC surface.

5. Deflection measurements were made periodically on the completed roadway.

Weather conditions, availability of equipment and personnel, the contractors operations, and weekend delays hindered the proposed testing program in some instances, but for the most part the preceding schedule was followed.

The deflection measurements taken from 1959 to 1967 inclusive were made with the Benkelman beam. This instrument consists of an eight foot long probe which is inserted between the dual tires (11.00 x 22.5, 12-ply and 70 psi pressure) of a truck which carries a 15,000 pound single axle test load.

The deflection measurements taken during 1968 and 1969 were made with a traveling deflectometer. This instrument is an automatic deflection measuring device with a single axle load of 15,000 pounds and dual tires (11.0 x 22.5, 12-ply and 70 psi pressure) between which a probe is inserted. The traveling deflectometer readings were converted to Benkelman beam values since there is a difference in the tire configuration and location of reference to the deflection basin for the two test vehicles.

A third deflection measuring device, a Dehlen "curvature meter", was used on this road although not in this particular research project. This device consists of a 1/2" thick aluminum bar which is 1-1/2" wide and 13" long. The bar has supporting feet at 12" centers and a dial gage at its center. After placing this device between the wheels of the truck described for use with the Benkelman beam, a radius of curvature can be calculated by treating the dial reading as the distance between the centers of an arc and a chord.

ANALYSIS OF DATA

In order to simplify the analysis and presentation of data in this study, only deflection measurements of the outer wheel track are reported. Deflection readings were generally higher in the outer wheel track than in the inner wheel track of the existing road before reconstruction; however, the deflections were about equal on the completed new road. Table IX is included to show typical examples of inner and outer wheel track deflections.

Deflections versus Season of the Year

Three series of deflection readings, at different times of the year, were made on test sections 6 through 12 before the road was reconstructed. These data, presented in graph form in Figure 3, indicate a definite trend of deflection variations at the different times of the year. All of the sections tested show a substantial increase in deflection during the spring of the year. No spring measurements were made in Section 11.

Moisture samples were taken from each layer of material within the test sections in an effort to correlate the variations in deflection with differences in the percent of moisture. A direct correlation was not possible for two reasons. First, no deflection readings were taken at the exact location of the moisture samples and secondly, the moisture content was found to vary not only from location to location but within the layer of material at any one location. It was possible, however, to establish a trend. By averaging all of the moisture values within each layer, it was established that the moisture content of each layer was highest during the spring when the deflection readings were highest. The average moisture contents of each material are shown in Figure 4.

Deflection Reduction

As each subsequent layer of the new structural section was added, deflection measurements were made. These readings are plotted in Figures 5 through 14 to show the decreases in deflections brought about by each layer. Because of the wide variations in deflection on the existing road, only the deflections taken immediately before reconstruction are shown.

Each individual reading is plotted in Figures 5 through 14 to show the effects of the subsequent layers on areas of varying deflections. Local high deflections in the finished roadway correspond with high deflection areas through each phase of construction and reflect the areas of higher deflection in the existing road prior to reconstruction. The average deflections are also shown.

Test Sections 4, 6, and 11, plotted respectively in Figures 6, 8 and 13, will be discussed in detail. Each of these three sections is representative of one of the structural sections and each was placed over areas of approximately equal deflections.

CTB Section:

The average deflection readings for Test Section 4 (Figure 6) are substantially reduced by the completed structural section. It should be noted, however, that the average deflection of the completed roadway just meets the design maximum pavement deflection[7] for cement treated base surfaced with AC. Two of the five CTB sections exceeded this .012 maximum deflection criteria.

Deflection readings were taken on the untreated CTB aggregate after it had been spread and compacted to approximately 90% relative compaction. The average deflection value of this layer of material compares with similar layers of aggregate base material in the other sections.

Deflection readings were made on the CTB in Section 4 approximately three hours and 18 hours after the material was mixed. The wet, freshly mixed and compacted CTB showed very high deflections but by the time the mix was 18 hours old, the average deflection dropped to .023 inch.

Deflection readings were made on the CTB after various curing periods. Data from several test sections are compiled in Figure 15. The average deflections plotted against the curing time prior to testing indicate that the CTB develops most of its resistance to deflection within approximately four days after being placed.

The subsequent layers of asphalt concrete each resulted in significant reductions in the average deflection, but the eight inches of cement treated base was responsible for most of the total decrease.

Four days after deflection measurements were first taken on 1-1/2" of AC overlying 8" of CTB in Test Section 4, a second set of deflection measurements were taken. The average deflection of the second set was .004" less than the average deflection of the first set. The additional compaction of the AC by public traffic is apparently responsible for this reduction in deflections.

ACB Section:

The average deflection readings for these sections are substantially reduced by the completion of the structural section. Each subsequent layer of base, asphalt concrete base and asphalt surfacing resulted in decreases in deflection.

If the asphalt concrete base material were assumed to be asphalt surfacing, a maximum allowable deflection of 0.011" is obtained from our design criteria. Deflections of 0.019" to 0.026" were observed on the four ACB test sections which had no apparent failures.

AB Section:

The average deflection of Test Section 11 (Figure 13) was reduced from .062" before reconstruction to .021" when the new structural section was completed. This .021" deflection does not meet the design maximum deflection of .017". The other two AB test sections 10 and 12, had average deflection readings of .015" and .019" respectively.

The second six inch layer of aggregate base in Section 11 did not reduce the average deflections by any great amount, but it did result in some decrease and, possibly of greater importance, it apparently reduced the variation between individual readings within the section. This is also shown in Test Section 10.

All Sections:

Table XIII lists the average deflection reduction caused by the addition of each layer of material for each type of structural section. They compare favorably with the expected deflection reduction[7] in most cases. Generally, the actual reductions are less than the expected reductions but are within the range usually experienced when establishing field correlations. The expected deflection reductions are based on statewide experience on many projects and the El Centro Road reconstruction gave results on one side of the spectrum of results from all the projects.

Maximum Tolerable Deflections

The maximum tolerable deflections are compared with the first, latest and highest deflection readings on the completed roadway. The lack of distress in the test sections and the fact that most of the measured deflections exceed the tolerable limits would indicate that the deflection limits may be conservative. However, there are several reasons why these sections are performing better than would be expected from the deflection measurements alone.

Interim reports[5,6] on another research project conducted to evaluate our present deflection criteria have included data obtained from this test road. Tests performed on asphalt recovered from cores taken from several of the test sections in 1968 showed that the ductility was greater than 100 centimeters at 77°F. This suggests that the asphalt binder has not yet reached a critical state. Fatigue cracking of the AC surfacing may not occur until the ductility of the asphalt binder decreases significantly.

Water permeability tests were performed on the AC surfacing overlying the CTB sections four days after completion. The water permeability of the AC averaged 96 milliliters per minute and ranged from 30 to 205 with only 2 out of 36 results greater than 150. These results are well within the tentative limit of 150 milliliters per minute established[9] to indicate a well compacted AC with a low void content. This low void content, which minimizes the entrance of air and water into the AC, may explain why the asphalt binder has retained a relatively high ductility.

Statewide experience indicates that during the first year of service an additional deflection reduction of about 25% will be realized due to traffic densification of the pavement and age hardening of the asphalt binder. However, on 10 out of 12 test sections on this project the deflections increased slightly after 6 months under traffic. This may be explained by the fact that public traffic was carried through this project during construction and most of the densification due to traffic had already taken place by the time the pavement was completed. Also, the age hardening of the asphalt binder has not progressed at the normally experienced rate.

Radius of curvature measurements were obtained with a Dehlen "curvature meter" on these test sections. Large radii of curvature which averaged 3825 feet for CTB, 457 feet for AB and 667 feet with two anomalous readings of 15,000 feet for ACB sections. These radii are not considered critical for any of the three types of structural sections.

From the above discussion, it is concluded that deflection level alone is not a good predictor of pavement performance for this test road. The tolerable deflection levels may be too conservative, particularly for thick asphalt concrete layers. Research is underway[5,6] to reevaluate our present deflection criteria.

Effects of Temperature Variation

Deflection readings were taken on an annual basis after completion of the reconstruction work. The average deflections for each series of tests through January 1969 are shown in Figures 16 through 27.

It is obvious that there is a significant variation in the average deflection readings from year to year. The first assumption was that the varying moisture content of the base, subbase and underlying soils was possibly responsible. Since moisture contents had not been measured, an attempt was made to correlate deflection variations with rainfall. A study was made of the total season rainfall to the time of the deflection measurements and the total rainfall during the one month and three month periods immediately prior to deflection measurements, but no correlation could be found. This could, in part, have resulted from the influence which crop irrigation had on moisture content. A summary of monthly rainfall totals from January 1959 through December 1968 is shown in Table X.

A closer look at the deflection data showed that there was considerably more variation in the ACB sections than in either the CTB or AB sections. This greater variation could have resulted from softening of the AC base and surfacing as the temperature increased and stiffening of the AC as the temperature decreased. A shortage of data regarding pavement temperature resulted in an investigation which compared air temperature to deflection measurements. In a report by Southgate and Deen[8], it is suggested that the average mean daily temperatures for a five day period are related to pavement temperature on the day following that period, and furthermore, that the pavement temperature is related to deflection measurements. The implication is therein established that the mean daily temperature alone might be related to deflection measurements.

Monthly weather records for Sacramento, published by the U.S. Weather Bureau, were consulted for mean daily temperatures on the days of deflection measurements and for five days immediately preceding. An abbreviated summary of daily mean temperatures is shown in Table XI. A comparison of the average mean daily temperatures for the indicated five day periods with deflection measurements demonstrates a definite correlation. This correlation for the ACB test sections has a confidence level above 99% as indicated in Table XII which shows the F-ratio of the correlation being greater than that of the 99% confidence level. The F-ratio is the ratio between the variation in deflection due to temperature and variation from other sources. The CTB and AB sections confidence levels are not that high; temperature had less influence on deflection measurements of these sections. The deflection measurements for the ACB sections are plotted against the corresponding five day average mean temperature in Figure 28.

<u>Low Quality Cement Treated Base</u>

The low quality CTB provided weaker compressive strength specimens and less resistance to deflection. Surface cracking, which is sometimes an indicator of pavement performance, was less severe on the section with poor quality CTB than on the other CTB sections. Weak CTB sometimes has a tendency to develop smaller cracks in greater quantity than strong CTB. These smaller cracks are less likely to appear on the surface of the AC than large cracks. Because neither the good nor the poor quality CTB failed, a meaningful comparison is difficult.

IMPLEMENTATION

The first objective of this study, as stated in the introduction, was to determine the reduction in deflection achieved by adding layers of various materials to the structural section. The systematic deflection measurements taken during the reconstruction of El Centro Road proved to be of much value in establishing deflection attenuation values for various materials.[4,5] Based on findings in the above referenced reports, a test method was developed to determine overlay and maintenance requirements by pavement deflection measurements.[7]

Another objective was to investigate the adequacy of the present criteria for maximum permissible deflections of various structural sections for design purposes. This was to be done by correlating pavement deflections with visible cracking or distress. Even though most of the average deflection values of the test sections were slightly above the maximum limits, no distress developed. The lack of distress in these test sections indicates that the deflection limits may be conservative; however, the deflection limits were established from data on many projects which indicate otherwise. The current research project "Statewide Flexible Pavement Performance and Deflection Study", HPR Item D-5-5, is in progress to evaluate California's present deflection criteria.

The five day average of mean temperatures correlates well with the deflection measurements on the sixth day. Based on these data, it appears that further research should be conducted to determine the effects of temperature on deflection.

The performance of this roadway will be evaluated yearly until failures occur. This will provide much valuable information and should enable us to fully meet the objectives of this study.

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2. Hveem, F. N., "Pavement Deflections and Fatigue Failures," Highway Research Board Bulletin 114, pp. 43-87, 1955.

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5. Zube, E., Forsyth, R. A and Hannon, J., "Interim Report on Statewide Follow-up Deflection Study of Overlays and Roadway Reconstruction," State of California, Department of Public Works, Division of Highways, Materials and Research Department, August, 1966.

6. Zube, E., Forsyth, R. A, Tueller, D., and Hannon, J., "Interim Report on Statewide Flexible Pavement Performance and Deflection Study," State of California, Department of Public Works, Division of Highways, Materials and Research Department, December, 1968.

7. State of California, Department of Public Works, Division of Highways, Materials Manual, Vol. I, Test Method No. Calif. 356-A.

8. Southgate, H. F., and Deen, R. C., "Temperature Distribution Within Asphalt Pavements and its Relationship to Pavement Deflections," Commonwealth of Kentucky, Department of Highways, Division of Research, June, 1968.

9. Zube, E., "Compaction Studies of Asphalt Concrete Pavements as Related to the Water Permeability Test," Highway Research Board Bulletin 358, pp. 12-37, 1962.

TABLE I

Summary of Test Results on the Existing Basement Soil

Station	Grading #4	Grading #30	Grading #200	SE	PI	R-value	Resilience*
323+10	99	99	75	6	19	6	High
342+00	99	92	33	3	25	8	High
350+30	100	99	85	5	38	3	High
351+80	100	99	92	5	34	7	High
373+30	100	99	86	4	21	6	High
397+35	100	97	78	6	19	9	High
411+90	82	76	62	6	18	8	High
437+70	100	95	62	9	12	15	High
438+70	100	96	72	5	19	13	High
467+60	100	96	61	8	17	3	High

* A criteria developed in the Pavement Section of the Materials and Research Department to classify the rebound characteristics of different materials.

TABLE II

Summary of Test Results on the Existing Imported Subbase Material

Station	Grading				SE	R-value	Resilience
	3/4"	#4	#30	#200			
323+10		100	96	14	47	72	Low
342+00	100	98	23	3	44	71	Low
350+30	99	98	94	16	33	72	Low
351+80		100	97	16	39	75	Low
373+30		100	98	18	29	71	Low
392+35		100	96	17	32	74	Low
411+90		100	68	20	26	74	Low
438+70	99	97	73	27	56	77	Low
467+60		100	67	15	40	72	Low

TABLE III

Summary of Test Results on the Existing Aggregate Base Material

Station	Grading 1-1/2"	3/4"	#4	#200	SE	R-value	Resilience
323+10	100	83	46	7	54	79	Low
350+30	100	71	35	6	44	79	Low
373+30	100	71	37	6	54	79	Low
411+90	100	77	47	13	23	77	Low
436+70	100	80	50	13	23	72	Low
467+60	100	86	67	14	30	77	Low
Unknown	100	67	34	4	43	78	Low
"	100	68	32	2	45	77	Low
"	100	70	39	8	27	78	Low
"	100	73	46	4	56	78	Low

TABLE IV

Summary of Test Results on the
Cement Treated Base (Class "A")
Planned Cement Content of 4%

Contract 60-3TC20

Station	Compr. Str. psi at 7 days (Spec. 650 psi at 7 days)	Remarks	Station	Compr. Str. psi at 7 days (Spec. 650 psi at 7 days)	Remarks
32	640		195	832	
"	528		"	704	
52	1168		"	512	
"	960		"	400	
40	1232	8 day break	209+50	496	Blade
"	1040	"	210+60	304	Mixed
60	544	"	211+70	256	Section
"	448	"	212+80	224	"
98	640		220	1216	
"	656		224	2000	
105	816	10 day break	258	1040	
"	656	"	259	944	
129+75	784	"	268	1552	
"	656	"	"	1409	
158	608		288	1040	
"	480		"	1008	
186	752		262	1040	
188	688		"	944	
208	800		297	848	
209	1072		"	720	

TABLE V

Summary of Test Results on the
Asphaltic Concrete Surfacing
Type B 3/4" Maximum, Medium Grading

Contract 60-3TC20

Sta. \ Specs.	Grading 1" 100	3/4" 95-100	3/8" 65-80	#4 45-60	#8 30-45	#30 15-25	#200 3-7	% Asphalt Extracted 5.5% Planned	Stability 35 Min.
54+25	100	91	70	57	47	28	5	*	35
93		100	71	61	46	29	6	4.7	44
120		100	85	70	53	30	6	6.2	41
140		100	76	68	51	29	6	6.0	38
142	100	97	72	57	43	30	6	4.8	38
152		100	73	56	43	29	5	5.6	43
155	100	97	68	55	42	24	4	5.7	41
203	100	98	66	52	42	35	5	4.9	42
207+20		100	74	58	45	28	6	5.2	43
288	100	99	75	60	47	33	6	5.1	36
289		100	80	63	47	28	7	5.5	44
302	100	98	78	61	49	34	7	5.0	45
303		100	78	58	45	29	5	5.5	44
305		100	76	56	46	31	6	5.2	42
Truck		100	81	65	50	32	6	5.3	43

* No test result

TABLE VI

Summary of Test Results on the Aggregate Base

Class 2 1-1/2" Maximum Grading

Contract 61-3TC9

	Grading							
	2"	1-1/2"	3/4"	#4	#30	#200	R-value	SE
Specs. / Sta.	100	90-100	50-85	25-45	10-25	2-9	78 Min.	30 Min.
326+00 Rt	100	96	79	42	20	6	78	25
329+00 Rt	100	96	85	46	21	6	81	30
330+00 Lt	100	98	84	47	22	6	81	31
331+00 Rt	100	97	83	39	16	6	78	38
333+00 Rt	100	96	80	45	22	5	79	33
334+00 Lt	100	93	76	42	22	6	75	27
342+00 Rt	100	97	82	39	15	7	78	30
346+00 Lt	100	98	81	45	23	5	76	*
349+00 Rt	100	97	84	37	16	6	78	27
350+00	100	98	88	50	24	7	78	31
372+00 Lt	100	97	81	44	22	7	71	28
401+00	100	99	84	45	20	6	79	25
430+00	100	97	83	43	18	6	79	25
446+20	100	95	83	47	20	6	78	33

* No test result

TABLE VII

Summary of Test Results on the
Asphalt Concrete Base

Type "B" AC Base Course 1-1/2" Maximum Grading

Contract 61-3TC9

	Grading							% Asphalt Extracted	Stability
	1-1/2"	1"	3/4"	3/8"	#4	#30	#200		
Specs. / Sta.	90-100	75-90	65-85	45-65	30-45	12-25	2-7	5.5% Planned	35 Min.
422+30	100	84	58	44	30	14	3	4.3	40
423	100	91	78	63	38	15	5	5.0	39
Truck	100	85	75	60	26	13	5	5.7	48
Truck	100	86	79	61	37	15	4	6.0	43
Truck		100	79	63	45	15	3	5.6	43
Truck	100	95	84	75	42	21	11	5.0	45

TABLE VIII

Summary of Test Results on the Asphalt Concrete Level and Surface Course

Type "B" 3/4" Maximum Medium Grading

Contract 61-3TC9

	Grading							% Asphalt Extracted	Stability
	1"	3/4"	3/8"	#4	#8	#30	#200		
Specs. / Sta.	100	90-100	65-80	45-60	30-45	15-25	3-7	5.5% Planned	35 Min.
(ACB Section)									
362+00 Rt	100	96	69	42	27	20	5	4.2	43
364+00 Rt		100	80	51	40	24	6	5.5	40
404+50 ¢	100	99	83	64	44	20	5	5.2	36
438+00 Rt		100	81	54	39	22	5	5.6	44
439+00 Rt	100	99	82	59	40	22	5	5.6	44
440+00 Rt		100	75	53	35	21	5	5.2	46
(AB Section)									
355+00 Lt		100	84	59	42	28	8	6.0	44
356+00 Lt		100	83	54	42	24	7	5.5	49
452+00	100	97	73	49	38	23	6	5.3	45
453+00		100	81	59	43	28	6	5.7	40

TABLE IX

Average Deflection Readings for Inner and Outer Wheel Tracks

Test Section 4		CTB			
	Exist. Rdwy.	8" Comp. Grav.	8" CTB 1 day old	1-1/2" AC+CTB 2 hours old	1-½" AC+CTB 6 days old
Date	9/3/59	9/21/59	10/1/59	10/2/59	10/6/59
IWT	0.064	0.033	0.021	0.017	0.015
OWT	0.067	0.036	0.023	0.017	0.013

Test Section 6		ACB			
	Exist. Rdwy.	6" AB	3" AC +6" AB	4½" AC +6" AB	6" AC +6" AB
Date	7/18/60	8/16/60	8/29/60	9/2/60	9/20/60
IWT	0.046	0.043	0.034	0.030	0.020
OWT	0.069	0.042	0.032	0.030	0.019

Test Section 11		AB		
	Exist. Rdwy..	6" AB	12" AB	3" AC +12" AB
Date	7/19/60	8/16/60	8/30/60	9/20/60
IWT	0.052	0.038	0.030	0.019
OWT	0.062	0.036	0.031	0.020

TABLE X

Summary of Monthly Rainfall for the Sacramento Area (From U. S. Weather Bureau Reports)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1959	4.62	3.64	.46	.30	T	0	T	T	1.54	T	.01	1.28
1960	3.25	2.91	1.62	1.26	.41	0	T	0	T	T	4.38	.70
1961	3.11	1.19	2.02	.49	.13	.02	T	.01	.17	.03	2.96	1.44
1962	.95	7.60	1.84	.19	.06	.01	0	.13	.11	6.85	.40	1.74
1963	3.65	1.75	3.56	3.43	.64	.02	0	T	.35	1.27	3.92	.38
1964	3.35	.19	.83	.16	.18	.41	.01	.06	0	1.55	2.64	5.69
1965	3.66	.48	1.61	2.97	.07	T	0	.59	0	.11	3.25	2.89
1966	2.11	1.58	.22	.59	.24	T	.09	0	.05	0	5.48	3.33
1967	7.94	.40	4.15	3.85	.12	.68	0	0	.04	.26	1.25	1.29
1968	3.34	2.13	2.42	.40	.32	.23	0	.08	0	.68	2.49	2.77

"T" designates a month in which there was only a trace of rainfall.

TABLE XI

Abbreviated Summary of Daily Mean Temperatures Preceding Annual Deflection Measurements

Day of Month	Mar. 1961	Oct. 1961	Apr. 1962	May 1963	Feb. 1964	Mar. 1965	May 1966	Feb. 1967	Apr. 1967	Jan. 1968	Jan. 1969
1											
2											
3	50										
4	52										
5	49										
6	51										
7	49						67				
8	55*						63				
9	49			53			60				
10	52*		64	54			62				
11		61	65	56			65				
12		67	68	56			69*				
13		71	70	57			66*				
14		78	66	62*							
15		77	61	65*				41			
16		77*	61	69*				46			
17			64*					49			
18			65					50			
19			56*			55		52			
20						57		48*			
21						59			49		
22						59			50		48
23						55			51		39
24						51*			54		40
25					51	52*			52		52
26					47				51*		51
27					47				50*	41	46*
28					49					43	43
29					48					48	39*
30					--					42	
31					--					45	
1					46					41*	
2					44*						
3					50*						
4											
5											

* Days on which deflection measurements were made.

TABLE XII

Results from Comparison of
Deflection Readings and 5 Day
Mean Daily Temperatures

Test Section	Type of Base	Coef. of Correlation	F-Ratio of Correlation	F-ratio for 99% Confidence Level	Slope
1	CTB	0.850	18.19	12.25	0.287
2	"	0.723	8.74	11.26	0.355
3	"	0.334	0.50	21.20	0.050
4	"	0.635	4.73	12.25	0.222
5	"	0.479	2.38	11.26	0.164
6	ACB	0.894	27.75	12.25	0.580
7	"	0.851	18.36	12.25	0.473
8	"	0.953	69.35	12.25	0.659
9	"	0.895	28.32	12.25	0.683
10	AB	0.724	7.69	12.25	0.237
11	"	0.635	4.72	12.25	0.261
12	"	0.858	19.54	12.25	0.532

TABLE XIII

Deflection Reduction for each Layer of Material

Layer of Material Added	Immediate Underlying Material	Average % Deflection Reduction	Expected[1] Deflection Reduction
	Aggregate Base Sections		
0.50' AB	Existing road	38%	44%
0.50' AB	0.50' AB	12%	44%
0.25' AC + 0.05' OGAC	1.00' AB	36%	43%
Total Section	Existing road	68%	77%
	Cement Treated Base Sections		
0.67' CTB	Existing road	60%	62%
0.25' AC + 0.05' OGAC	0.67' CTB	48%	43%
Total Section	Existing road	78%	77%
	Asphalt Concrete Base Sections		
0.50' AB	Existing road	23%	44%
0.25' ACB	0.50' AB	29%	41%
0.25' AC + 0.05' OGAC	0.25' ACB	31%	43%
Total Section	Existing road	63%	74%

Note: [1] Expected deflection reduction from Test Method No. Calif. 356-A

TABLE XIV

Comparison of Tolerable and Actual Deflections

Deflections on Completed Roadway

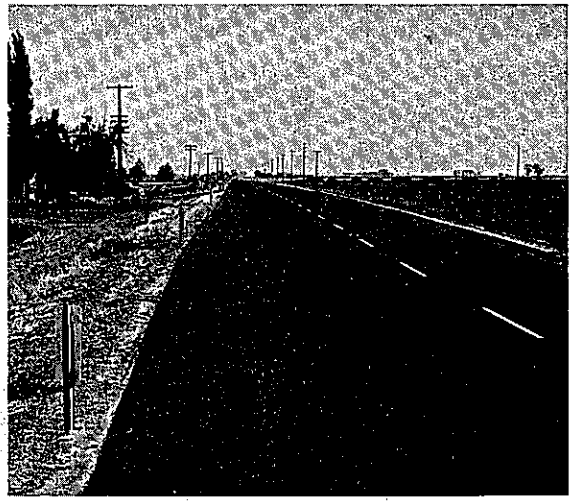
Test Section	Base Type	First	Latest	Highest	Tolerable Deflection[2]
1	CTB	.014(1959)[1]	.009(1969)	.018(1961)	.012
2	"	.015(1959)	.008(1969)	.019(1961)	"
3	"	.011(1959)	.011(1966)	.011(1966)	"
4	"	.012(1959)	.009(1969)	.016(1966)	"
5	"	.009(1959)	.007(1969)	.014(1964)	"
6	ACB	.019(1960)	.019(1969)	.030(1962)	.011
7	"	.020(1960)	.019(1969)	.032(1962)	"
8	"	.022(1960)	.017(1969)	.033(1962)	"
9	"	.026(1960)	.024(1969)	.040(1962)	"
10	AB	.015(1960)	.015(1969)	.024(1962)	.017
11	"	.021(1960)	.021(1969)	.028(1962)	"
12	"	.019(1960)	.015(1969)	.033(1962)	"

Note: All deflections in inches.

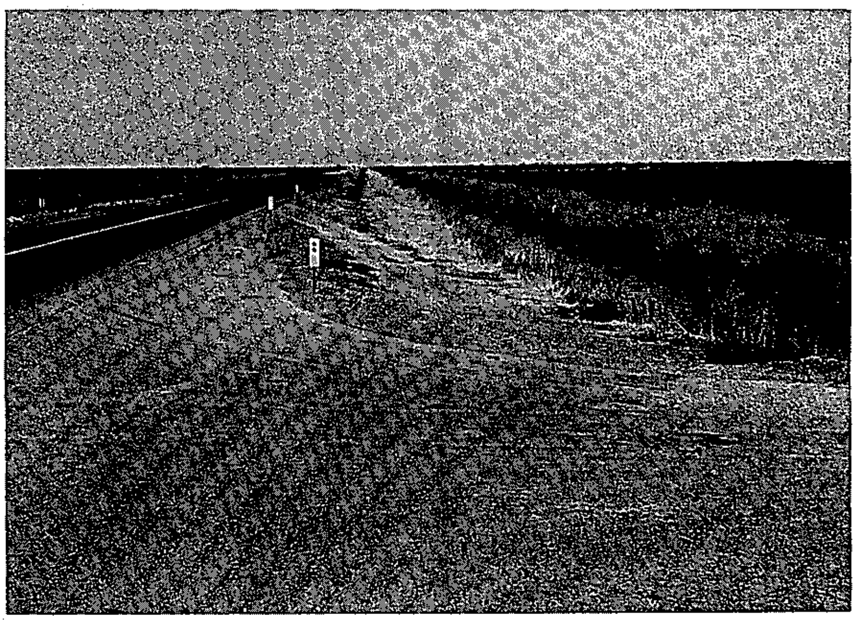
1. Year of deflection reading shown in parentheses
2. Tolerable deflections from Test Method No. Calif. 356-A

Figure 1

Photographs of Completed Roadway

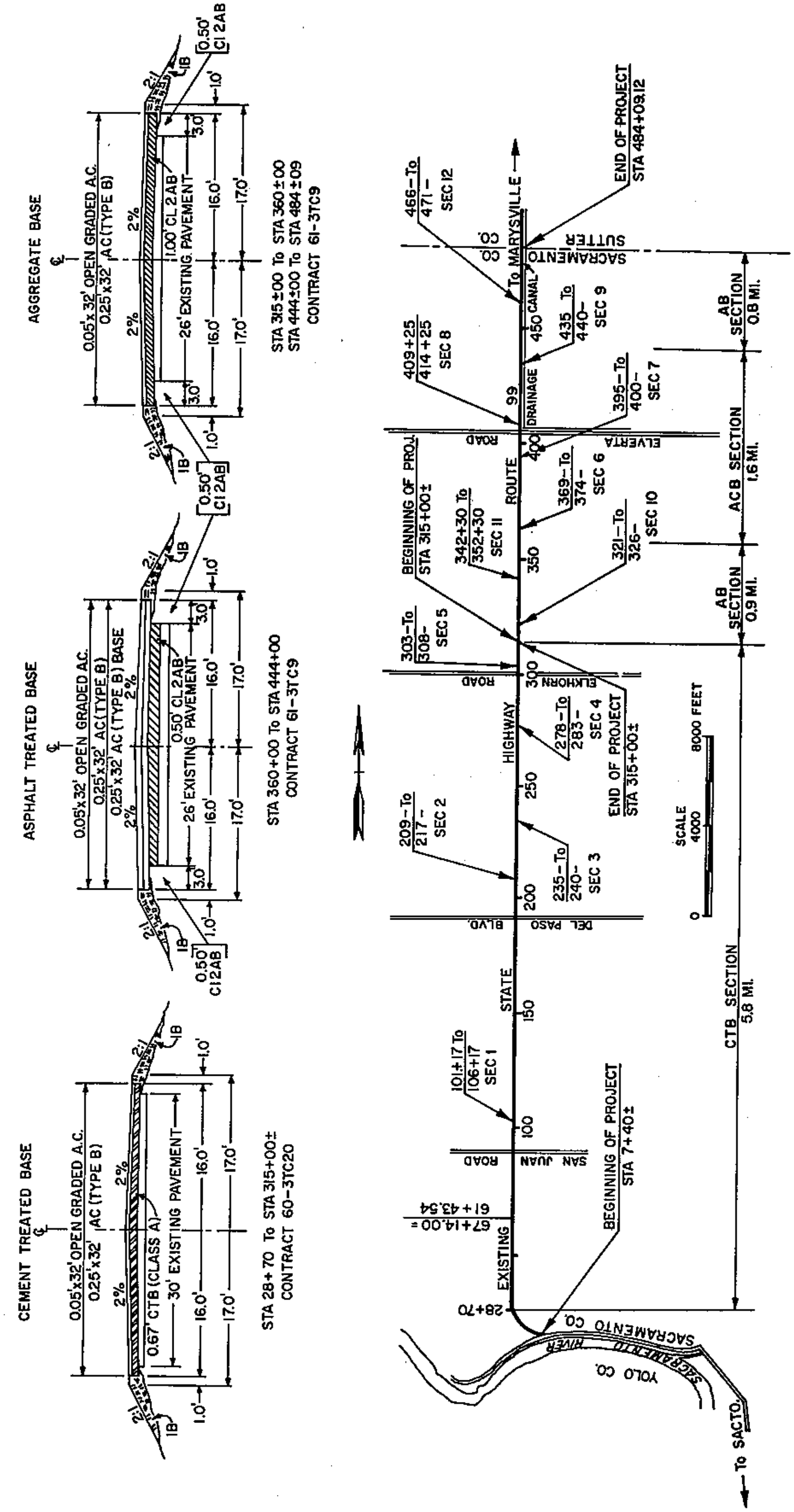


Typical Area Without Drainage Ditch
(Looking North From Station 28+70)



Drainage Canal Parallel to Road
(Looking North From Elverta Road)

Figure 2



CEMENT TREATED BASE
0.05'x32' OPEN GRADED A.C.
0.25'x32' AC (TYPE B)
0.67' CTB (CLASS A)
30' EXISTING PAVEMENT
STA 28+70 To STA 315+00±
CONTRACT 60-3TC20
ASPHALT TREATED BASE
0.25'x32' AC (TYPE B) BASE
0.50' CL 2AB
26' EXISTING PAVEMENT
STA 360+00 To STA 444+00
CONTRACT 61-3TC9
AGGREGATE BASE
1.00' CL 2AB
STA 315±00 To STA 360±00
STA 444±00 To STA 484±09
CONTRACT 61-3TC9
STATE HIGHWAY ROUTE 99
To MARYSVILLE
To SACTO.
SACRAMENTO RIVER
YOLO CO.
SACRAMENTO CO.
SUTTER CO.
SAN JUAN ROAD
DEL PASO BLVD.
ELKHORN ROAD
ELVERTA ROAD
DRAINAGE CANAL
BEGINNING OF PROJECT STA 7+40±
END OF PROJECT STA 315+00±
BEGINNING OF PROJ. STA 315+00±
END OF PROJECT STA 484+09.12
CTB SECTION 5.8 MI.
AB SECTION 0.9 MI.
ACB SECTION 1.6 MI.
AB SECTION 0.8 MI.
SCALE
0
4000
8000 FEET

Figure 3

AVERAGE DEFLECTION READING ON EXISTING ROAD AT VARIOUS SEASONS OF THE YEAR

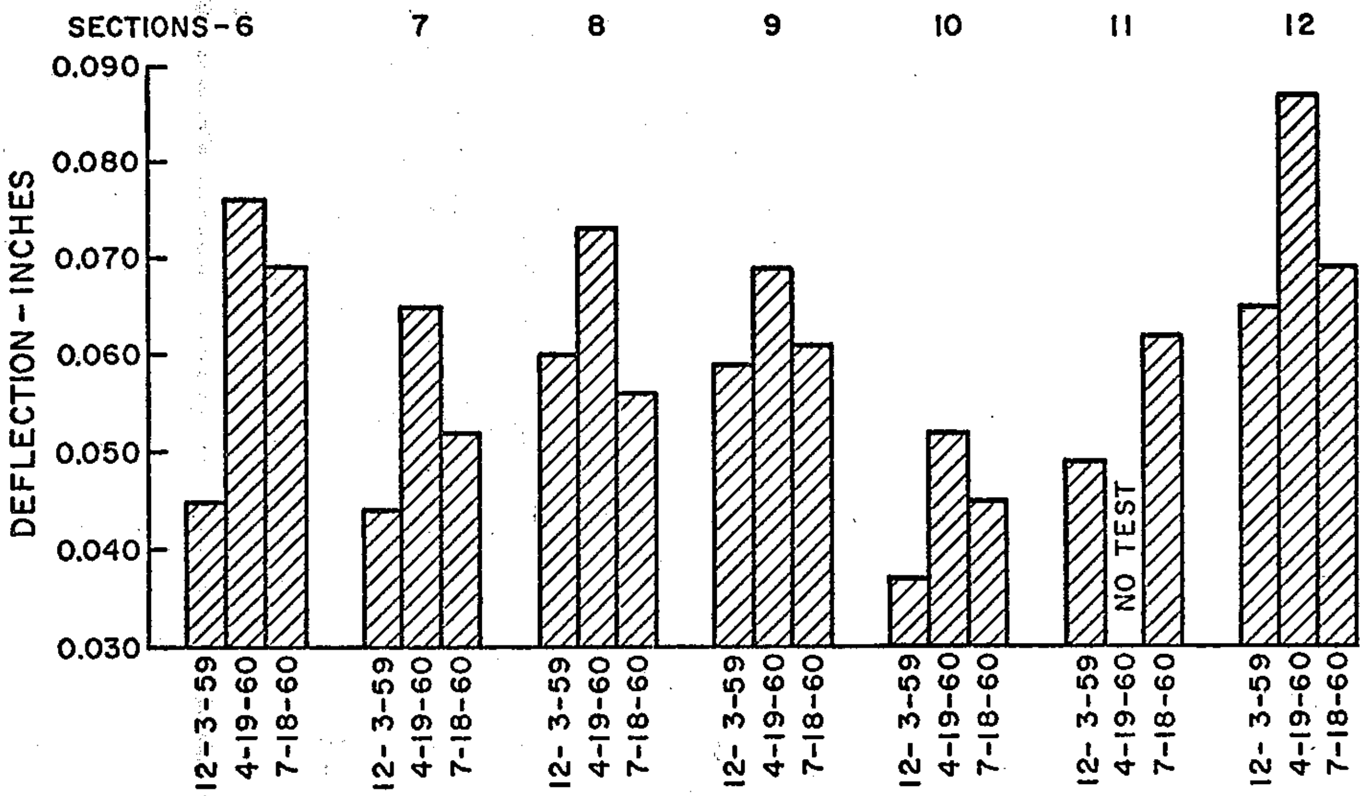


Figure 4

AVERAGE MOISTURE CONTENT OF EXISTING ROAD AT VARIOUS SEASONS OF THE YEAR

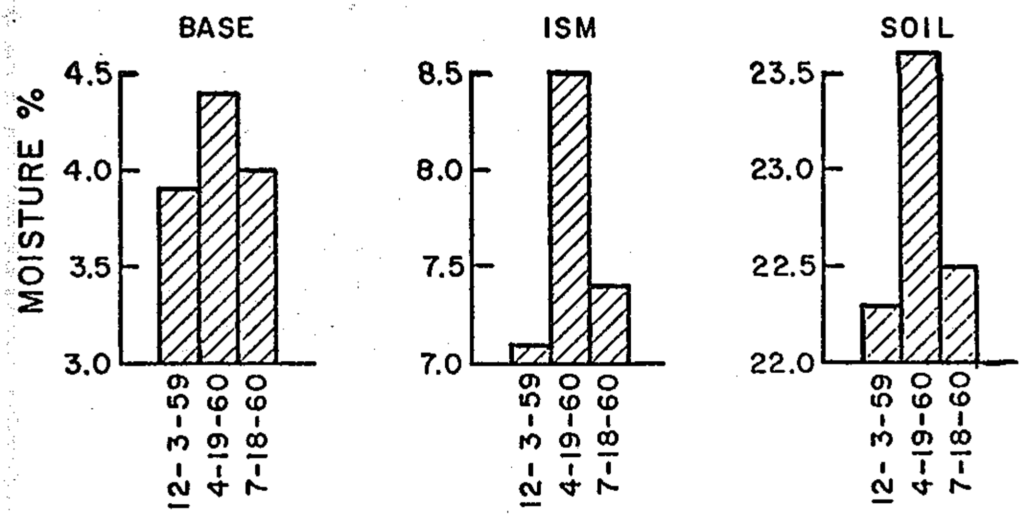


Figure 5

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 3 CTB
STATION 235+00 TO STATION 240+00
Northbound Lane

Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	9-3-59	0.047
—○—	CTB (4 days)	9-21-59	0.015
—+—	CTB (13 days)	9-30-59	0.017
—◇—	1 1/2" AC	10-6-59	0.014
—△—	FINISHED ROAD	10-21-59	0.011

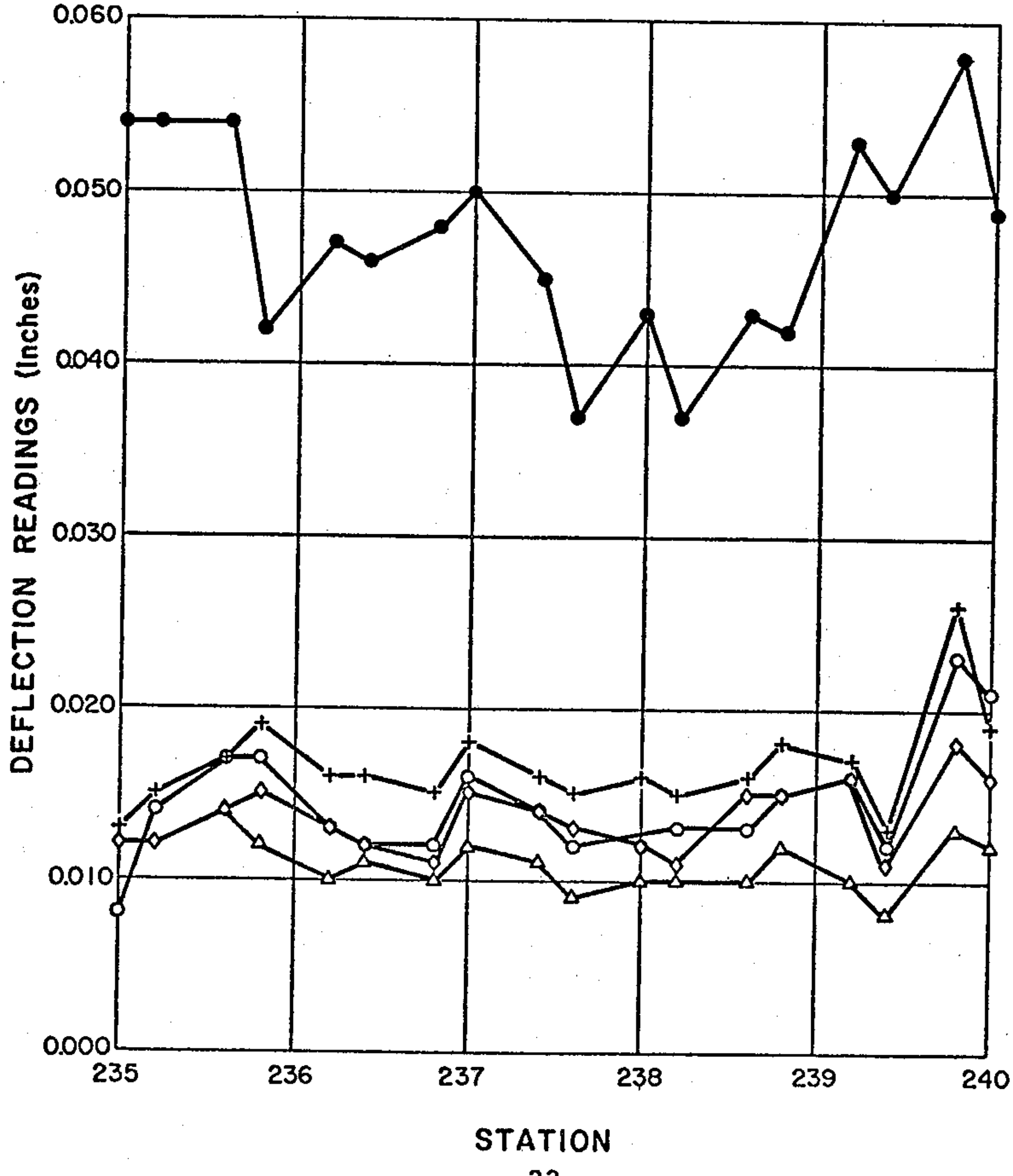


Figure 6

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 4 CTB
STATION 278+00 TO STATION 283+00
Northbound Lane

Symbol	Stage	Date	Avg.	Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	9-3-59	0.067	—□—	1 1/2" AC	10-2-59	0.017
—○—	UNTREATED AGG.	9-21-59	0.036	—▲—	1 1/2" AC	10-6-59	0.013
—+—	CTB (3 hours)	9-30-59	0.048	—△—	FINISHED ROAD	10-21-59	0.012
—◇—	CTB (1 day)	10-1-59	0.023				

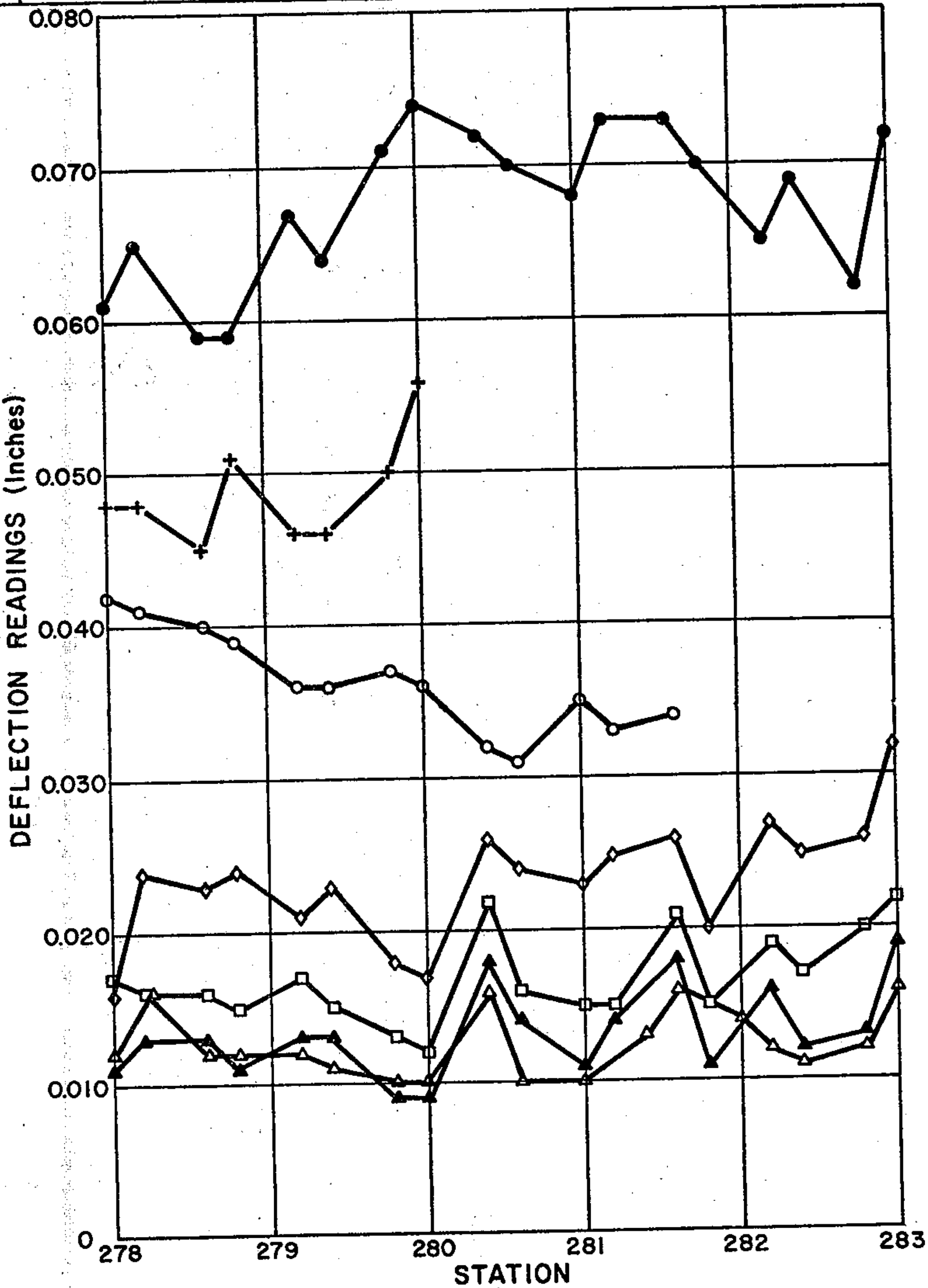


Figure 7

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 5 CTB
STATION 303+00 TO STATION 308+00
Southbound Lane

Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	9 - 3 - 59	0.048
—○—	UNTREATED AGG	9 - 23 - 59	0.032
—+—	CTB (17 Hour)	9 - 30 - 59	0.024
—◇—	1 1/2" A C	10 - 2 - 59	0.015
—△—	FINISHED ROAD	10 - 21 - 59	0.009

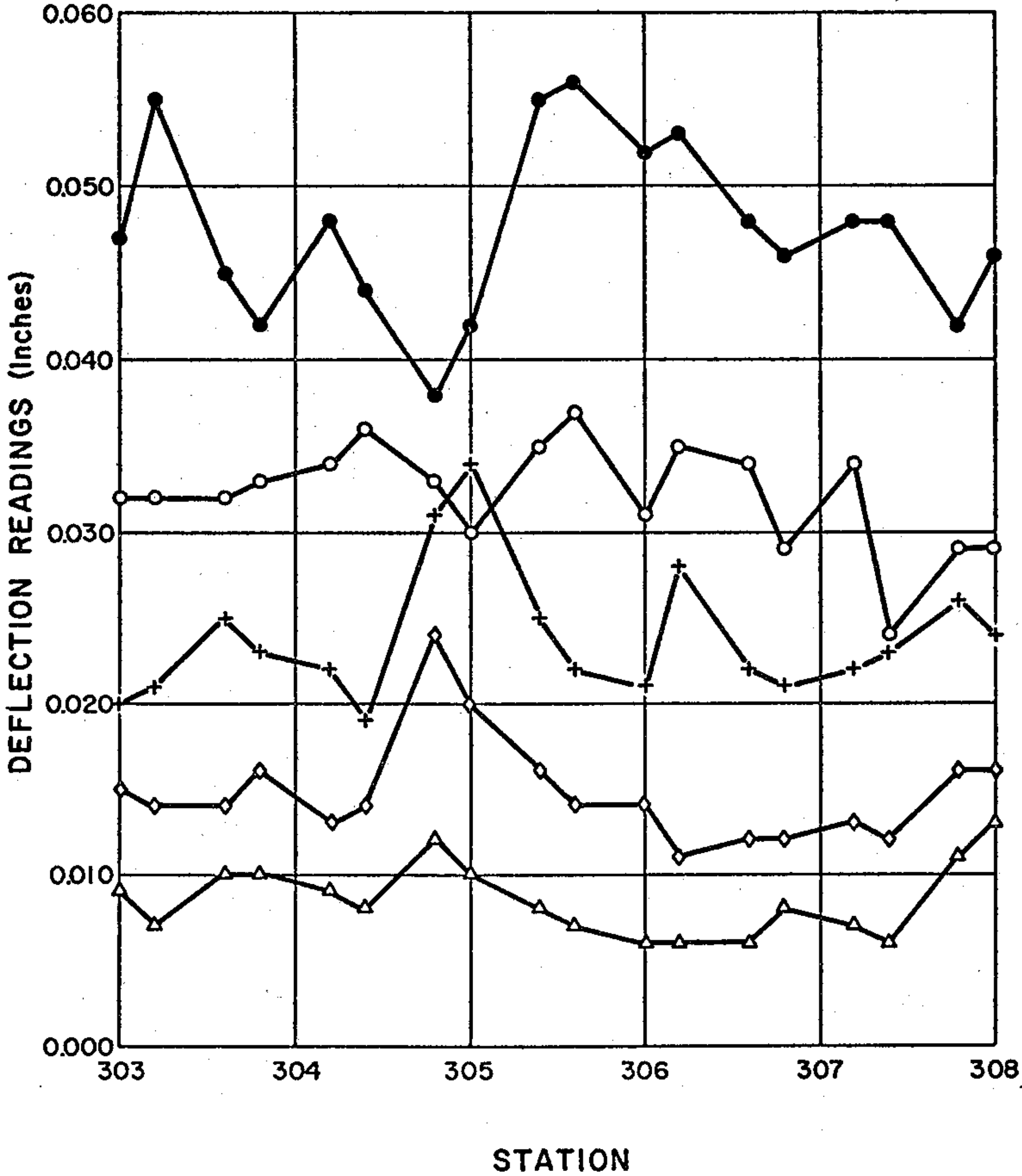


Figure 8

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 6 ACB
STATION 369+00 TO STATION 374+00
Northbound Lane

Symbol	Stage	Date	Avg.	Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	7-18-60	0.069	—△—	FINISHED ROAD	9-20-60	0.019
—○—	6" AB	8-16-60	0.042				
—+—	3" ACB	8-29-60	0.032				
—◇—	1 1/2" AC	9-2-60	0.030				

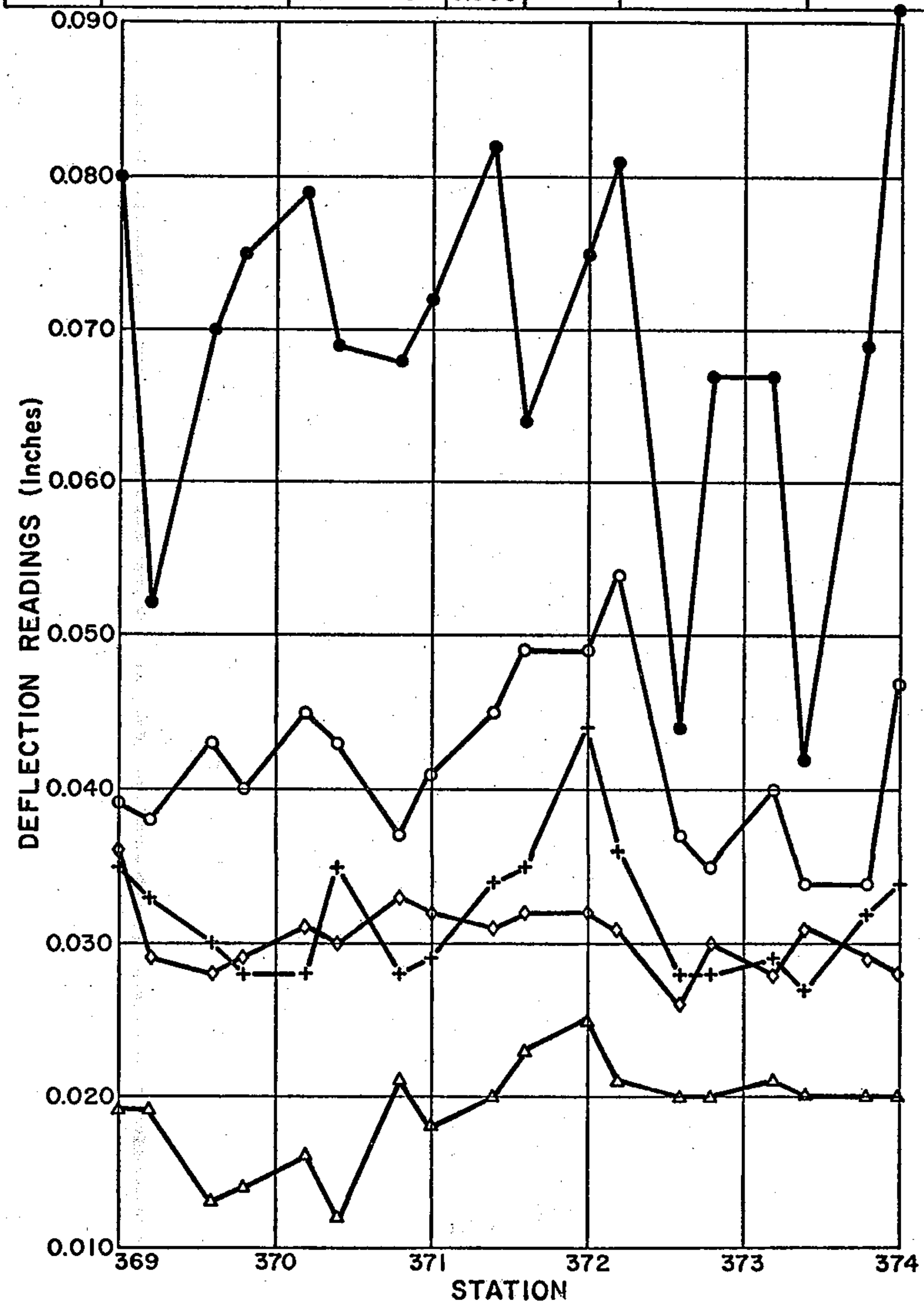


Figure 9

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 7 ACB
STATION 395+00 TO STATION 400+00
Northbound Lane

Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	7-19-60	0.052
—○—	6" AB	8-16-60	0.038
—+—	3" ACB	8-29-60	0.024
—◇—	1 1/2" AC	9- 2-60	0.026
—△—	FINISHED ROAD	9-20-60	0.020

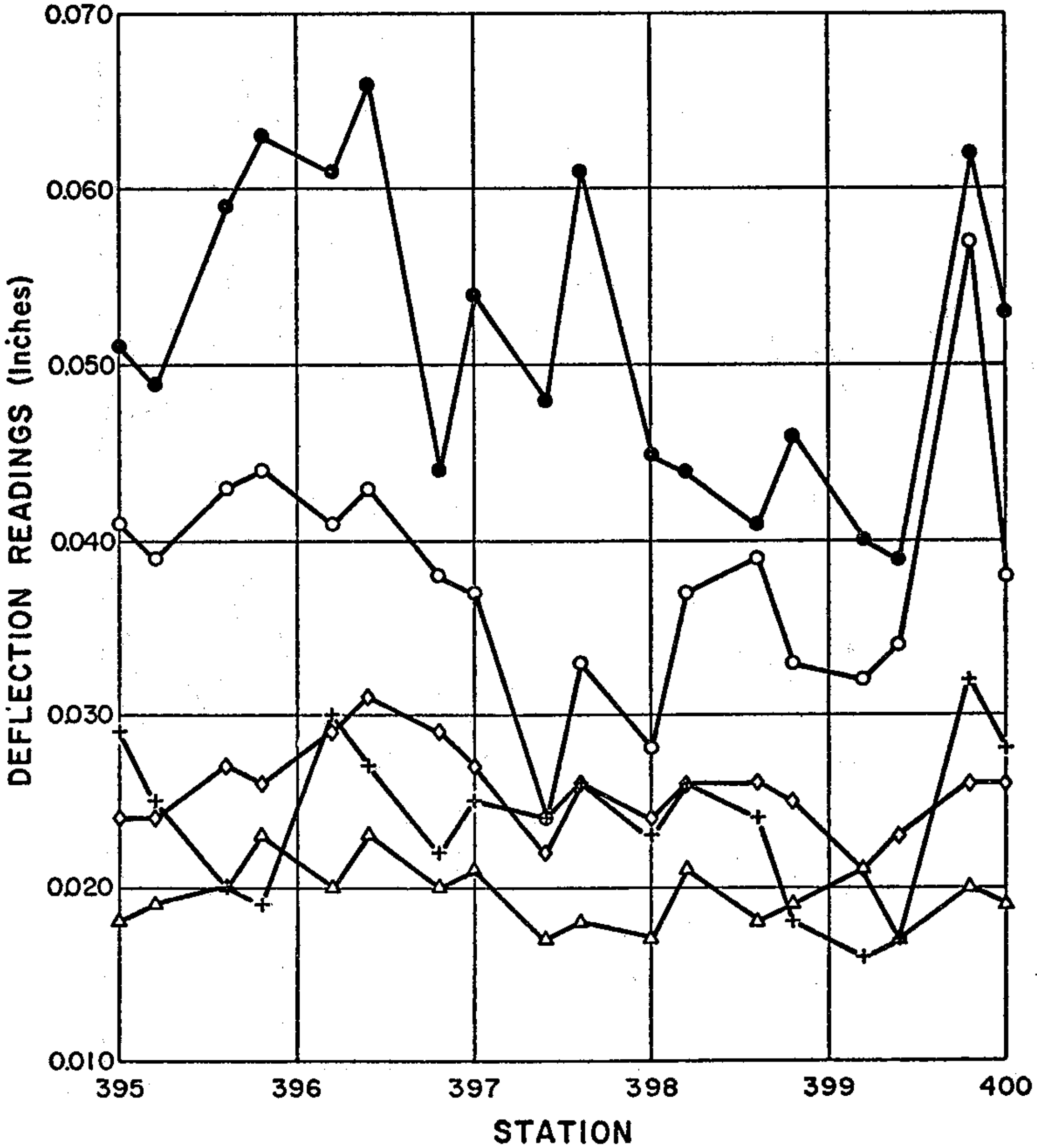


Figure 10

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 8 ACB
STATION 409+25 TO STATION 414+25
Southbound Lane

Symbol	Stage	Date	Avg.	Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	7-18-60	0.056	—△—	3" AC	9-2-60	0.032
—○—	6" AB	8-19-60	0.052	—□—	FINISHED ROAD	9-20-60	0.022
—+—	3" ACB	8-29-60	0.035				
—◇—	1 1/2" AC	8-30-60	0.031				

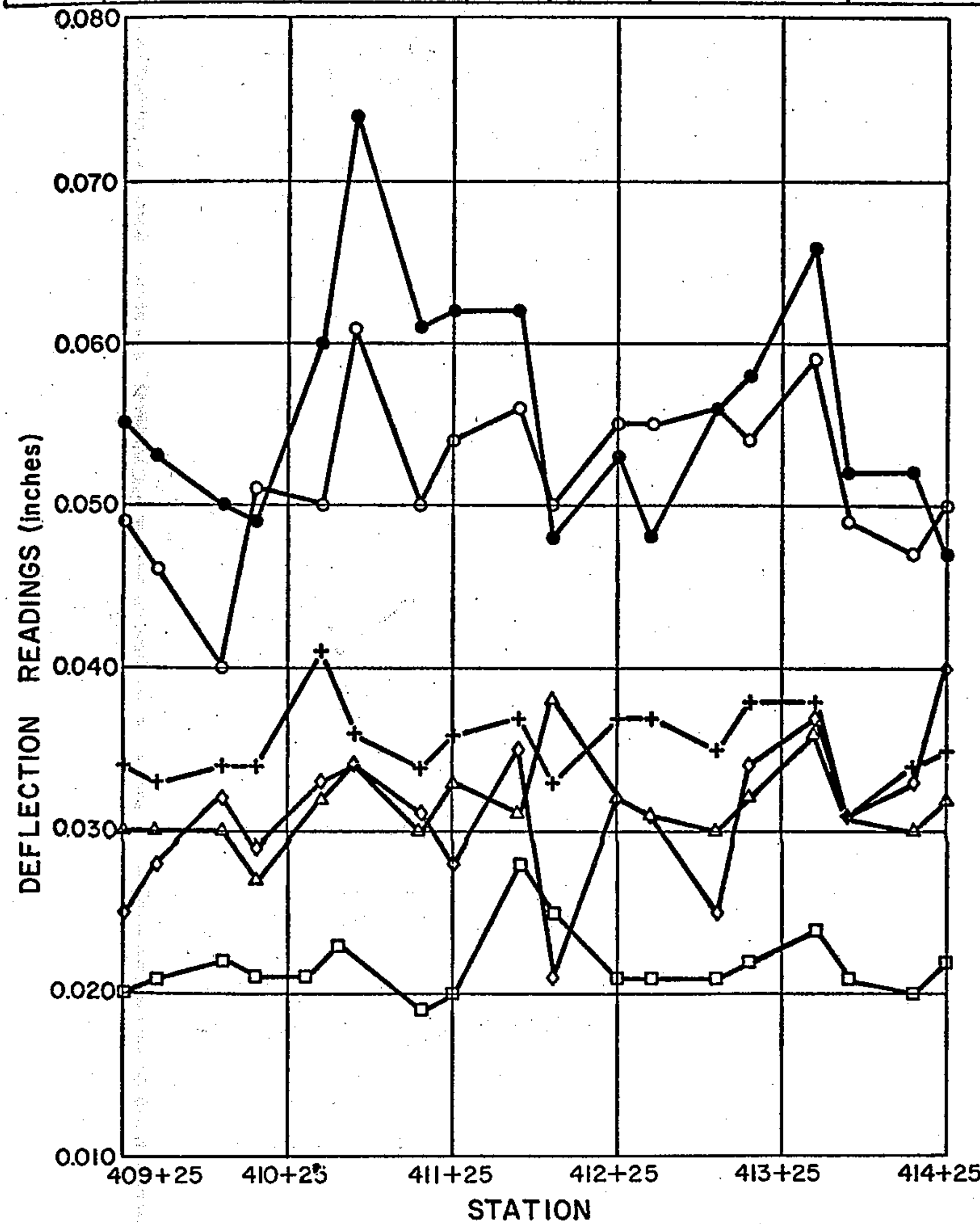


Figure 11

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 9 ACB
STATION 435+00 TO STATION 440+00
Northbound Lane

Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	7-19-60	0.061
—○—	6"AB	8-19-60	0.050
—+—	3"ACB, 1 1/2"AC	8-29-60	0.040
—◇—	3"AC	9- 2-60	0.035
—△—	FINISHED ROAD	9-20-60	0.026

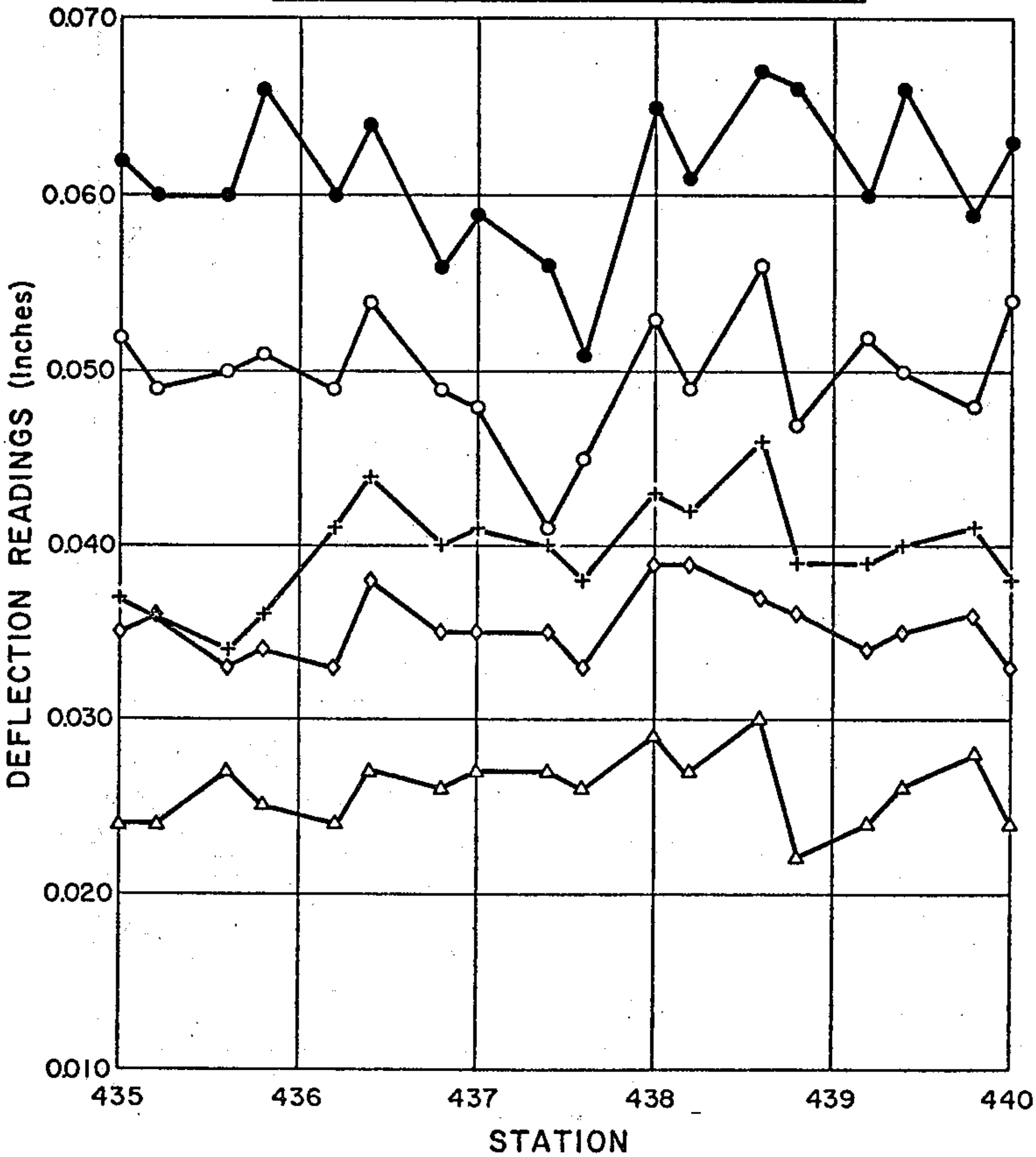


Figure 12

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 10 AB
STATION 321+00 TO STATION 326+00
Northbound Lane

Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	7-18-60	0.045
—○—	6" AB	8-16-60	0.028
—+—	12" AB	8-30-60	0.025
—◇—	1 1/2" AC	9- 9-60	0.020
—△—	FINISHED ROAD	9-20-60	0.015

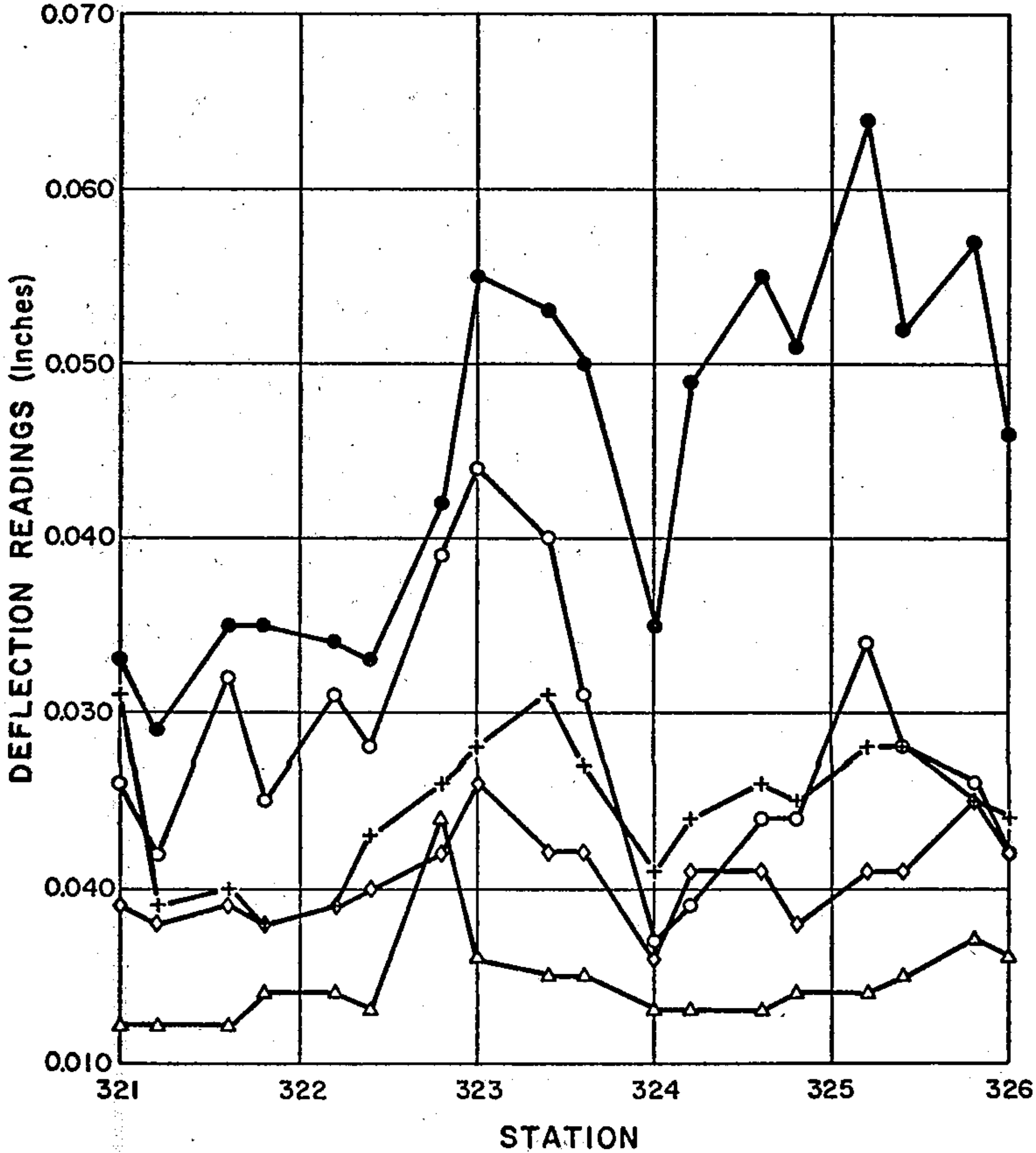


Figure 13

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION II AB
STATION 342+30 TO STATION 352+30
Southbound Lane

Symbol	Stage	Date	Avg.	Symbol	Stage	Date	Avg.
—●—	EXISTING ROAD	7-19-60	0.062				
—○—	6" AB	8-16-60	0.036				
—+—	12" AB	8-30-60	0.031				
—◇—	FINISHED ROAD	9-20-60	0.021				

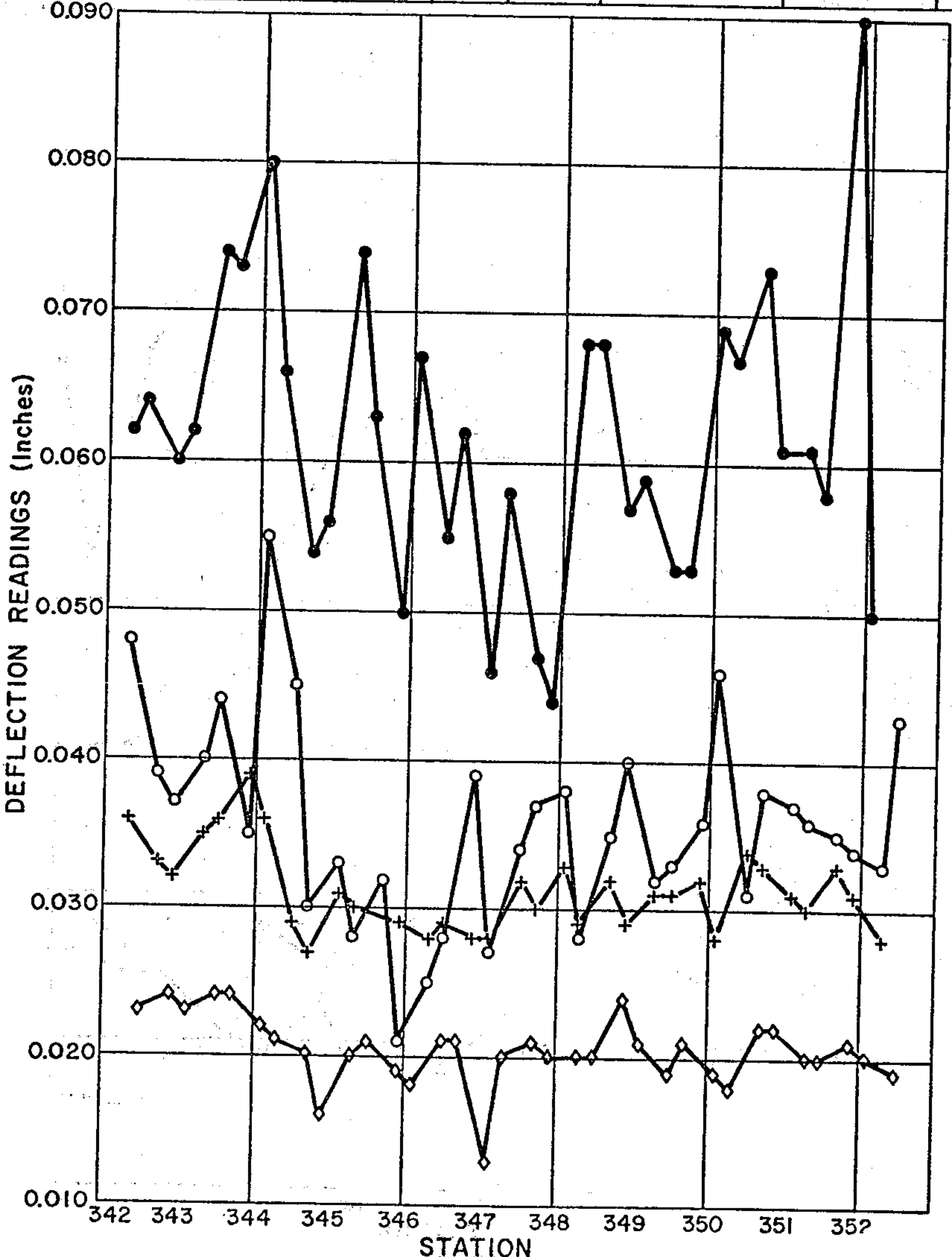


Figure 14

DEFLECTION READINGS DURING STAGES OF CONSTRUCTION
SECTION 12 AB
STATION 466+00 TO STATION 471+00
Southbound Lane

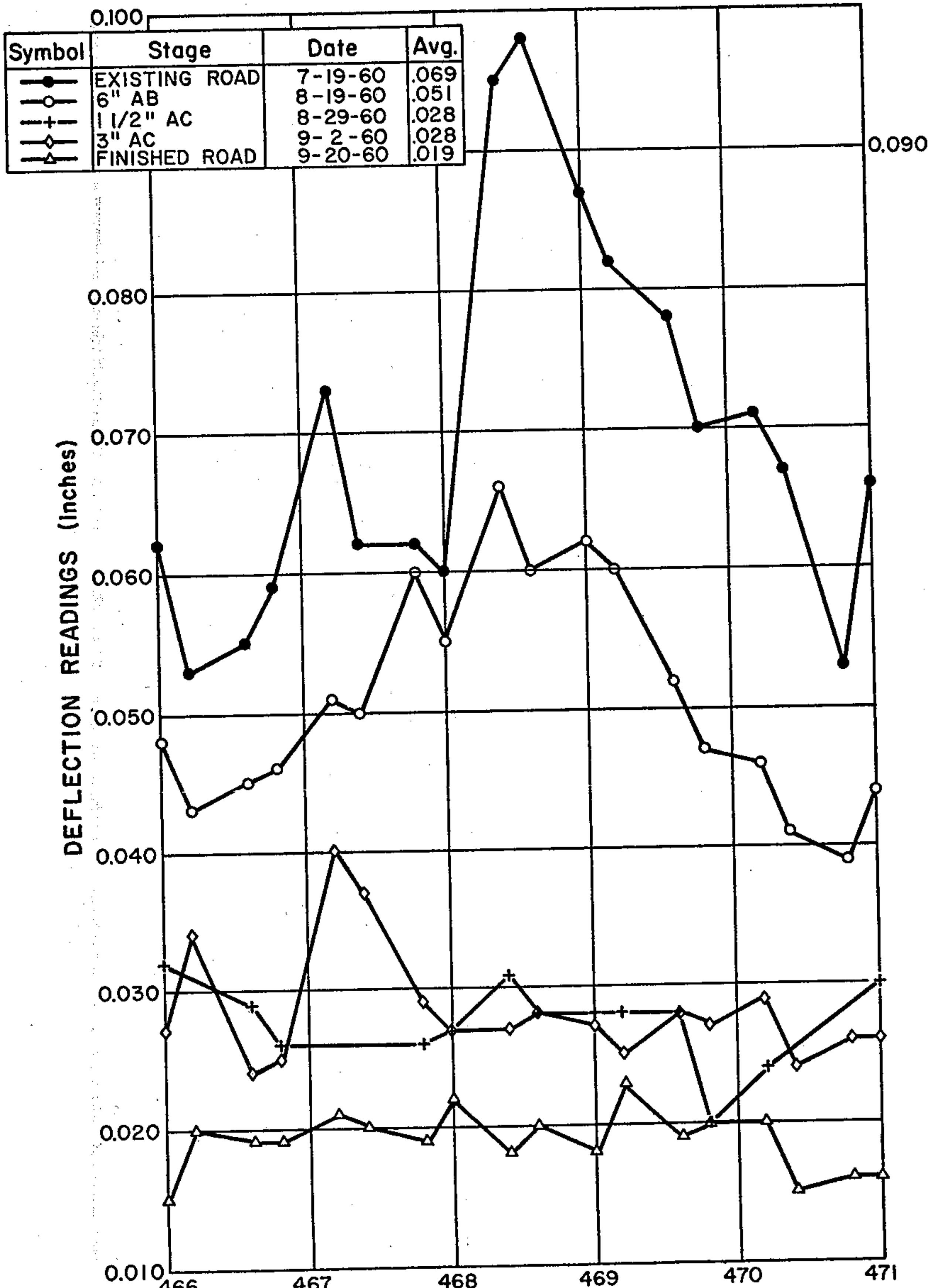


Figure 15

EFFECT OF CTB CURING TIME
ON AVERAGE DEFLECTION READINGS

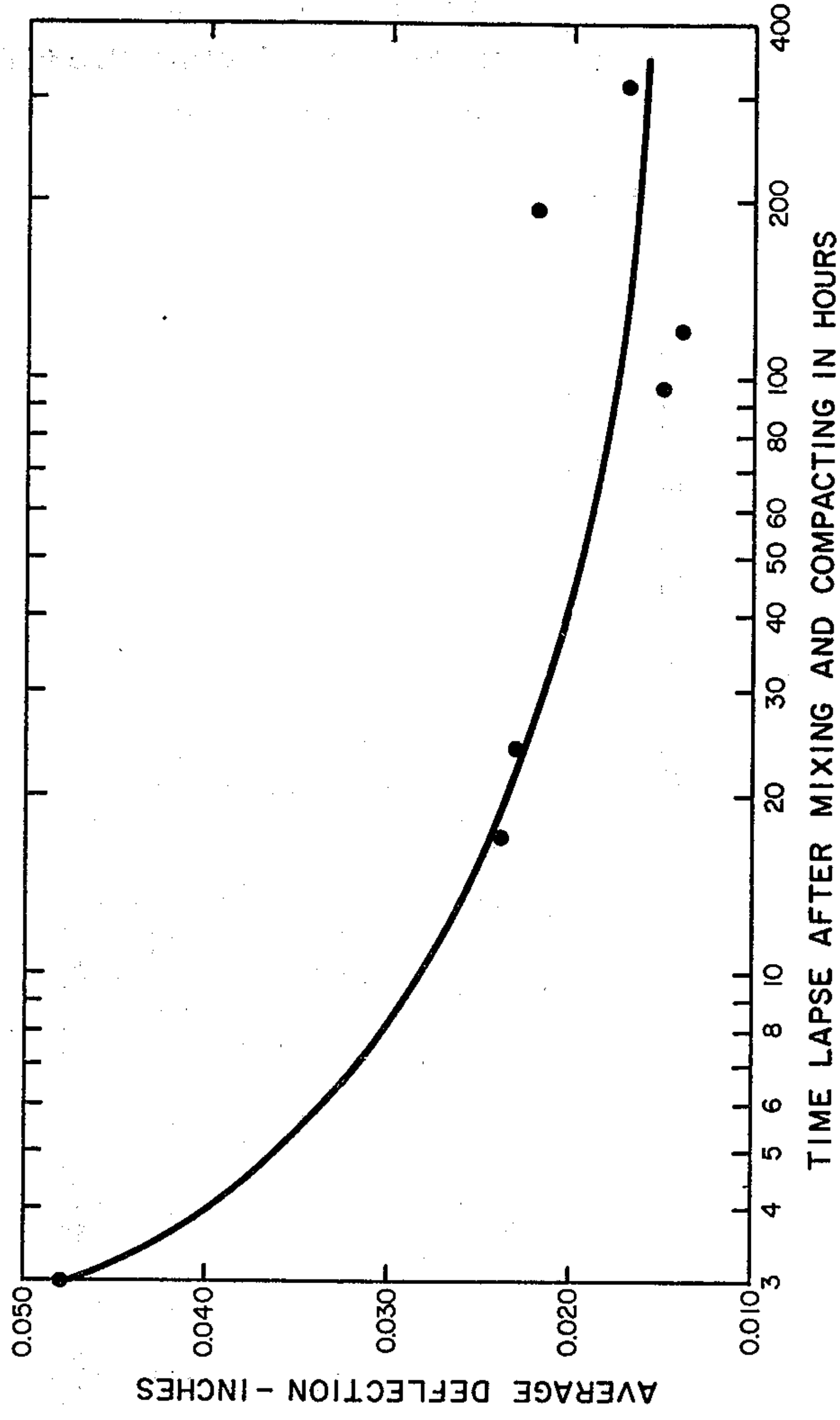


Figure 16

AVERAGE DEFLECTIONS
SECTION I CTB
Station 101+17 to Station 106+17
Northbound Lane

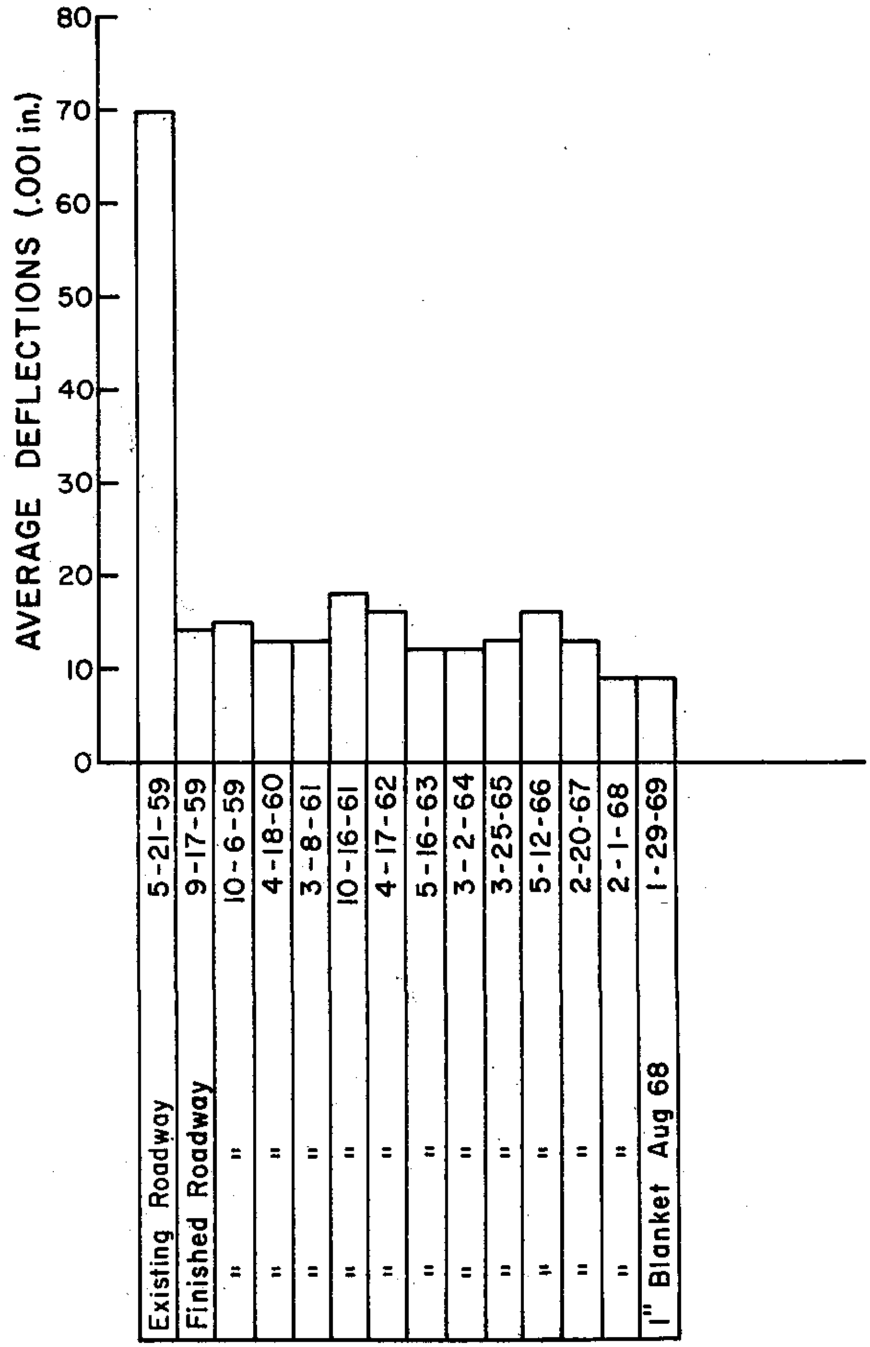


Figure 17

AVERAGE DEFLECTIONS
SECTION 2 CTB
Station 209+00 to Station 217+00
Southbound Lane

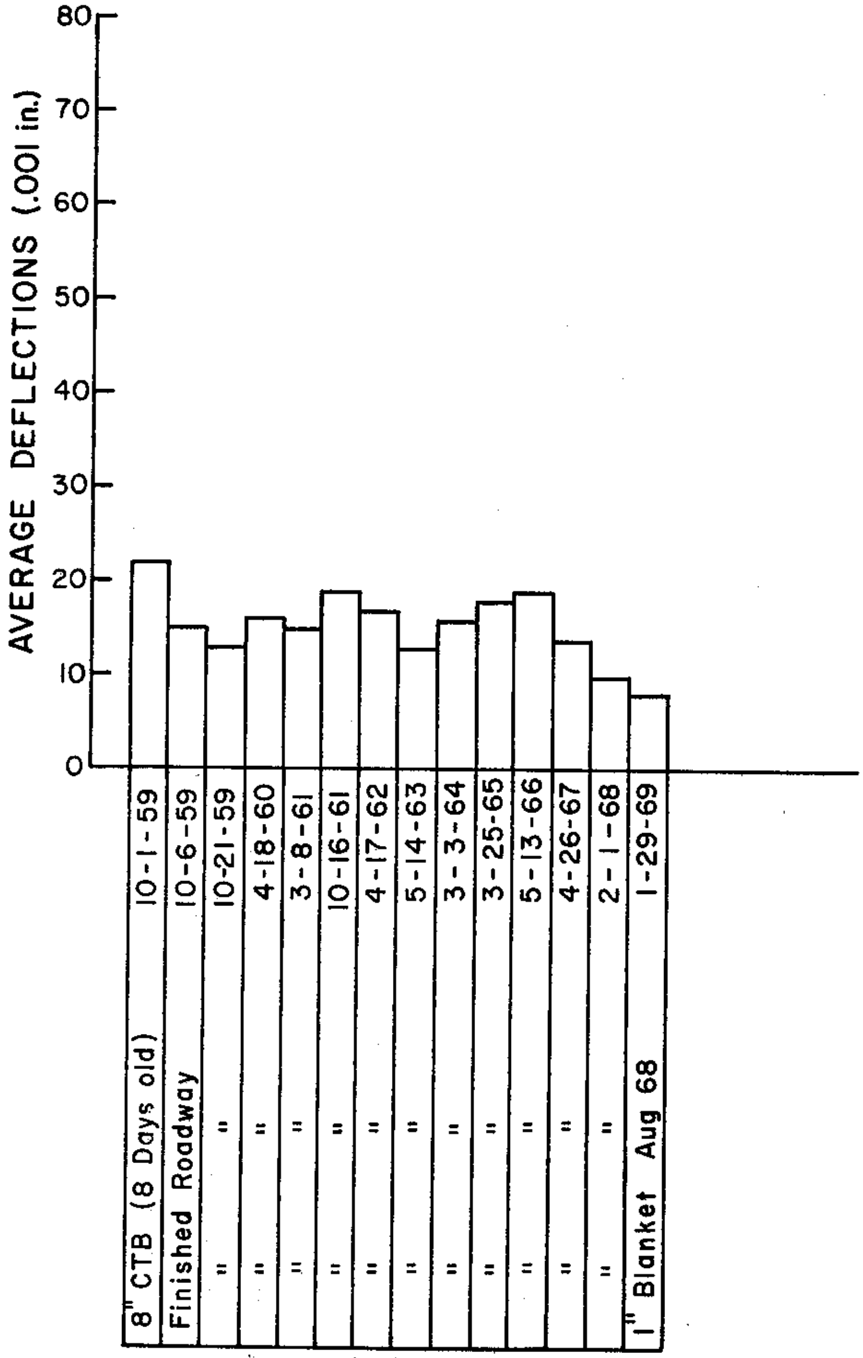


Figure 18

AVERAGE DEFLECTIONS
SECTION 3 CTB
Station 235+00 to Station 240+00
Northbound Lane

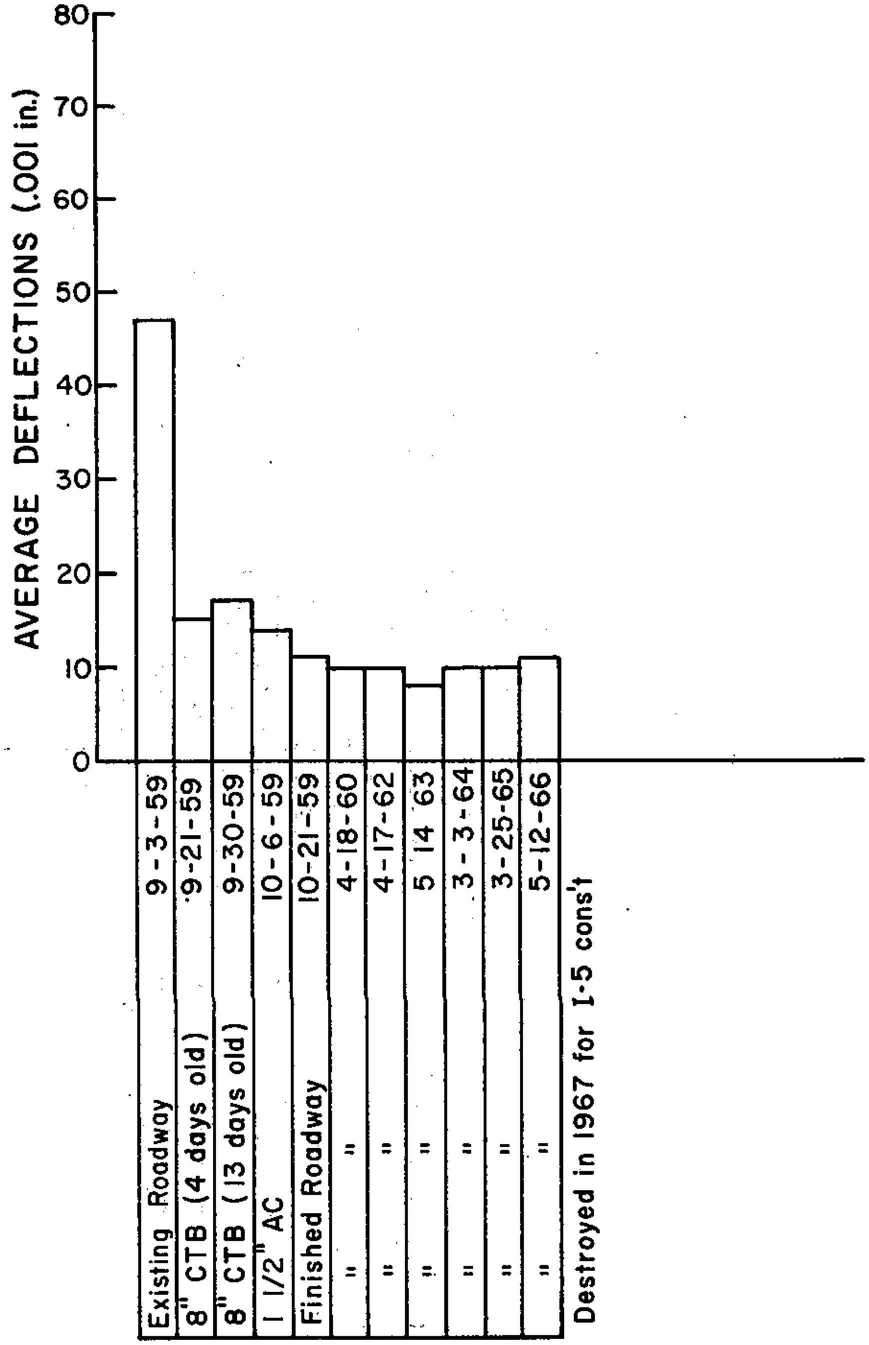
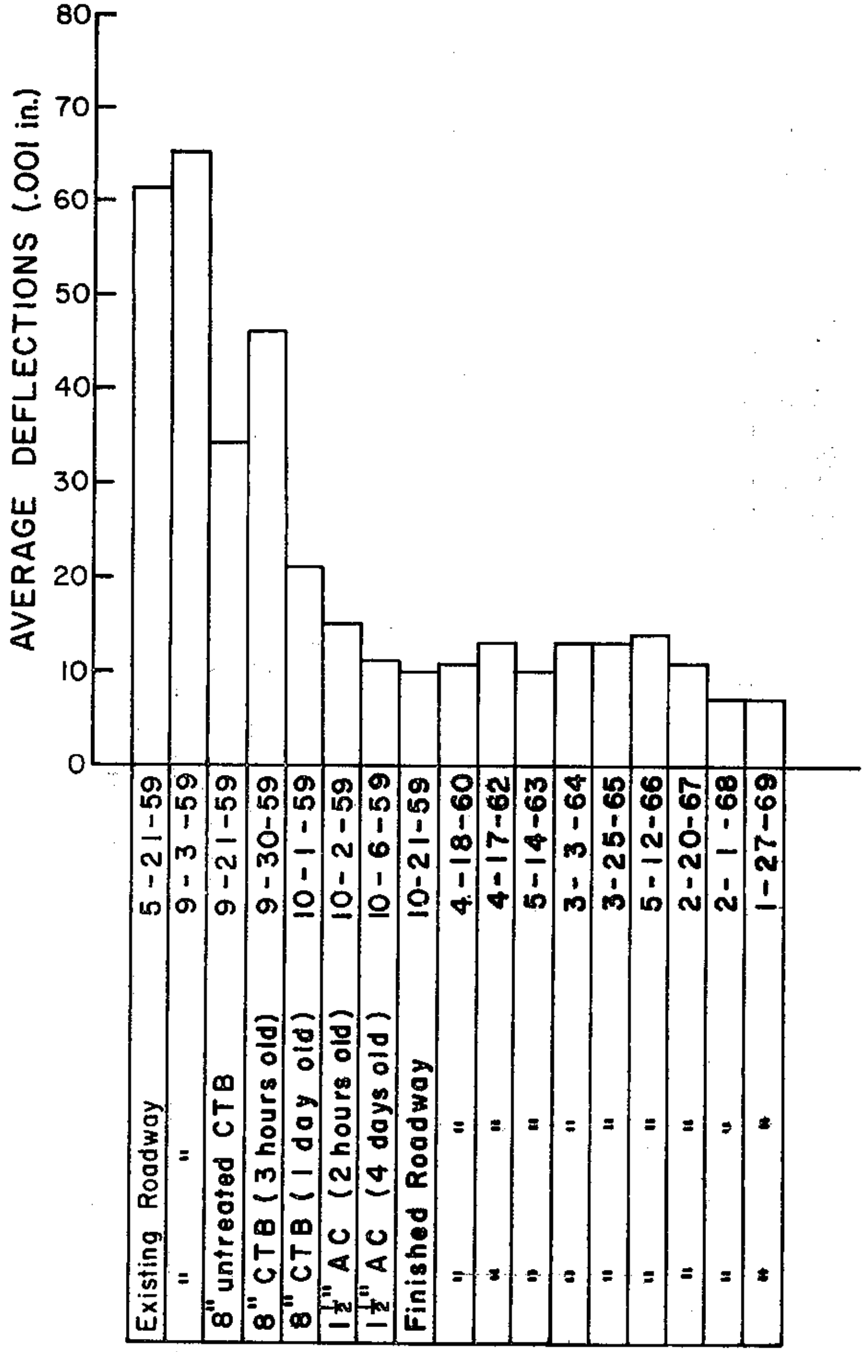


Figure 19

AVERAGE DEFLECTIONS
SECTION 4 CTB
Station 278+00 to Station 283+00
Northbound Lane



AVERAGE DEFLECTIONS
SECTION 5 CTB
Station 303+00 to Station 308+00
Southbound Lane

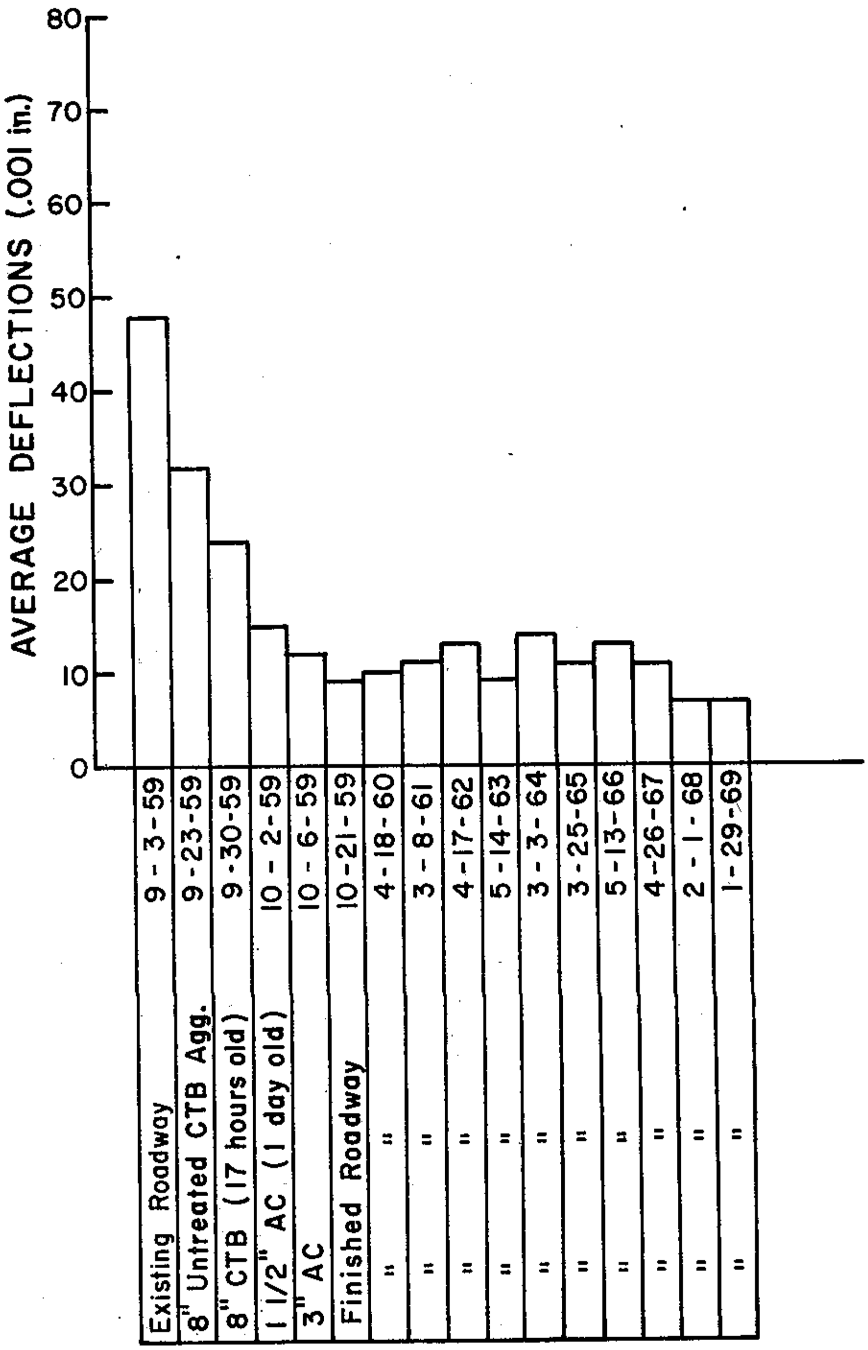


Figure 21

AVERAGE DEFLECTIONS
SECTION 6 ACB
Station 369+00 to Station 374+00
Northbound Lane

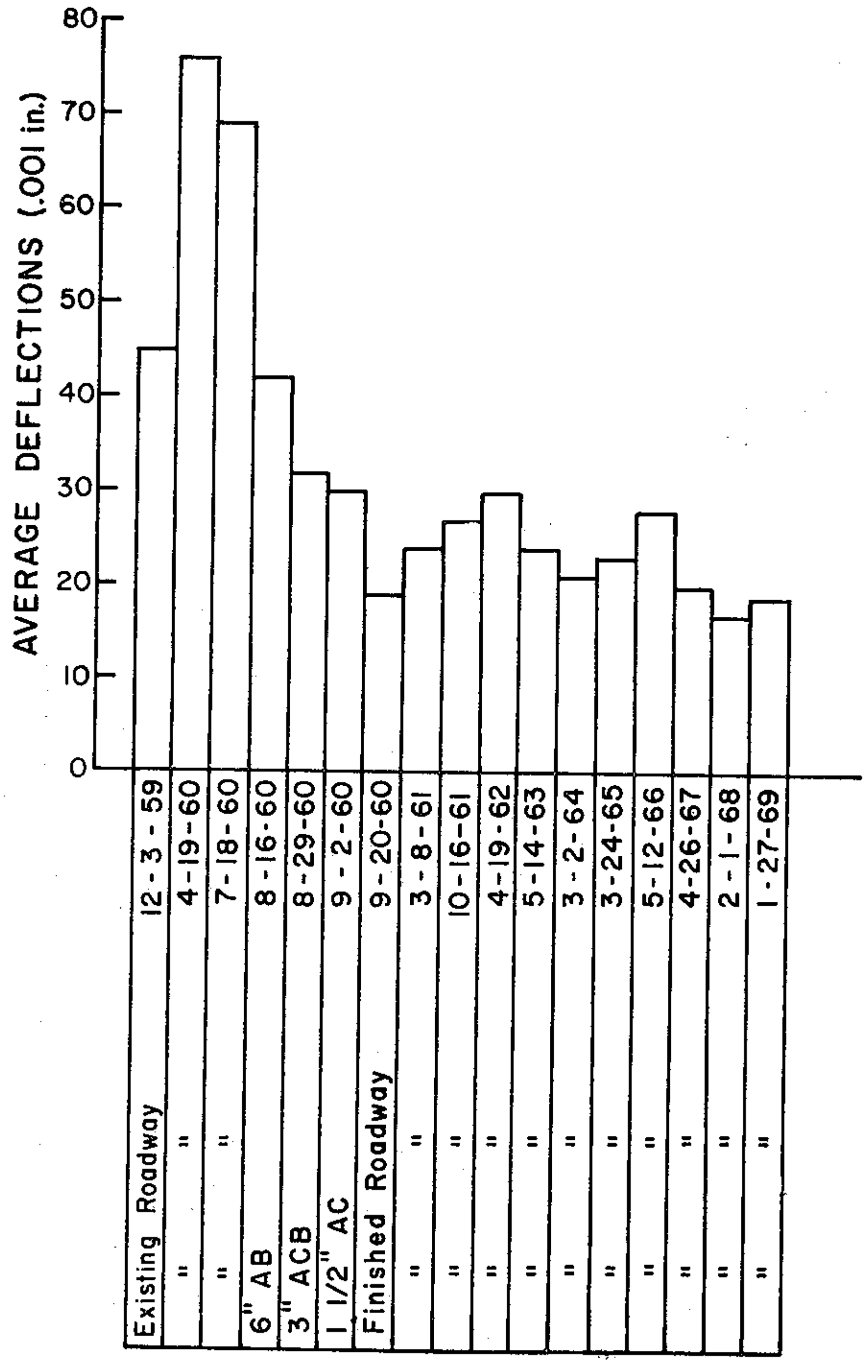


Figure 22

AVERAGE DEFLECTIONS
SECTION 7 ACB
Station 395+00 to Station 400+00
Northbound Lane

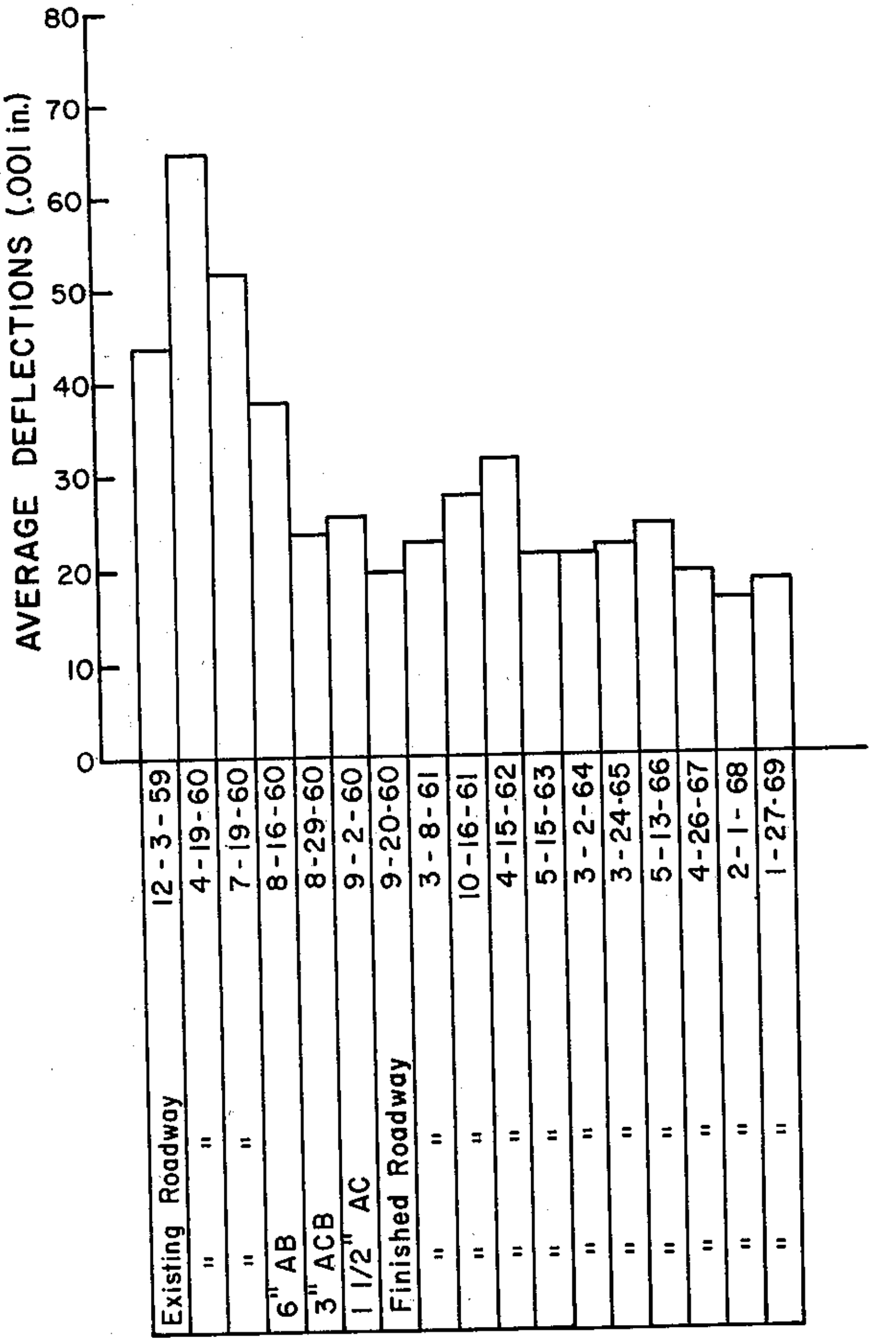


Figure 23

AVERAGE DEFLECTIONS
SECTION 8 ACB
Station 409+25 to Station 414+25
Southbound Lane

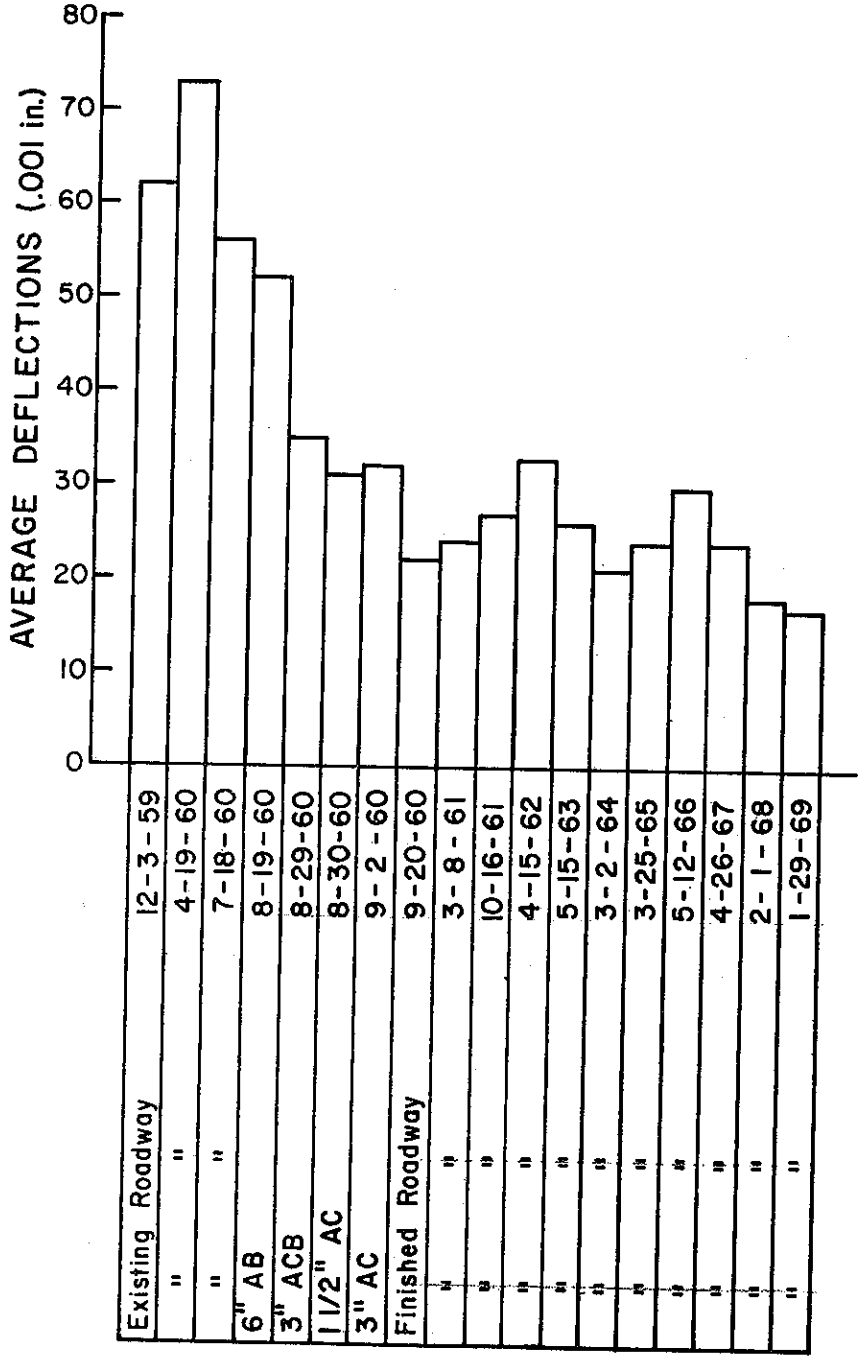


Figure 24

AVERAGE DEFLECTIONS
SECTION 9 ACB
Station 435+00 to Station 440+00
Northbound Lane

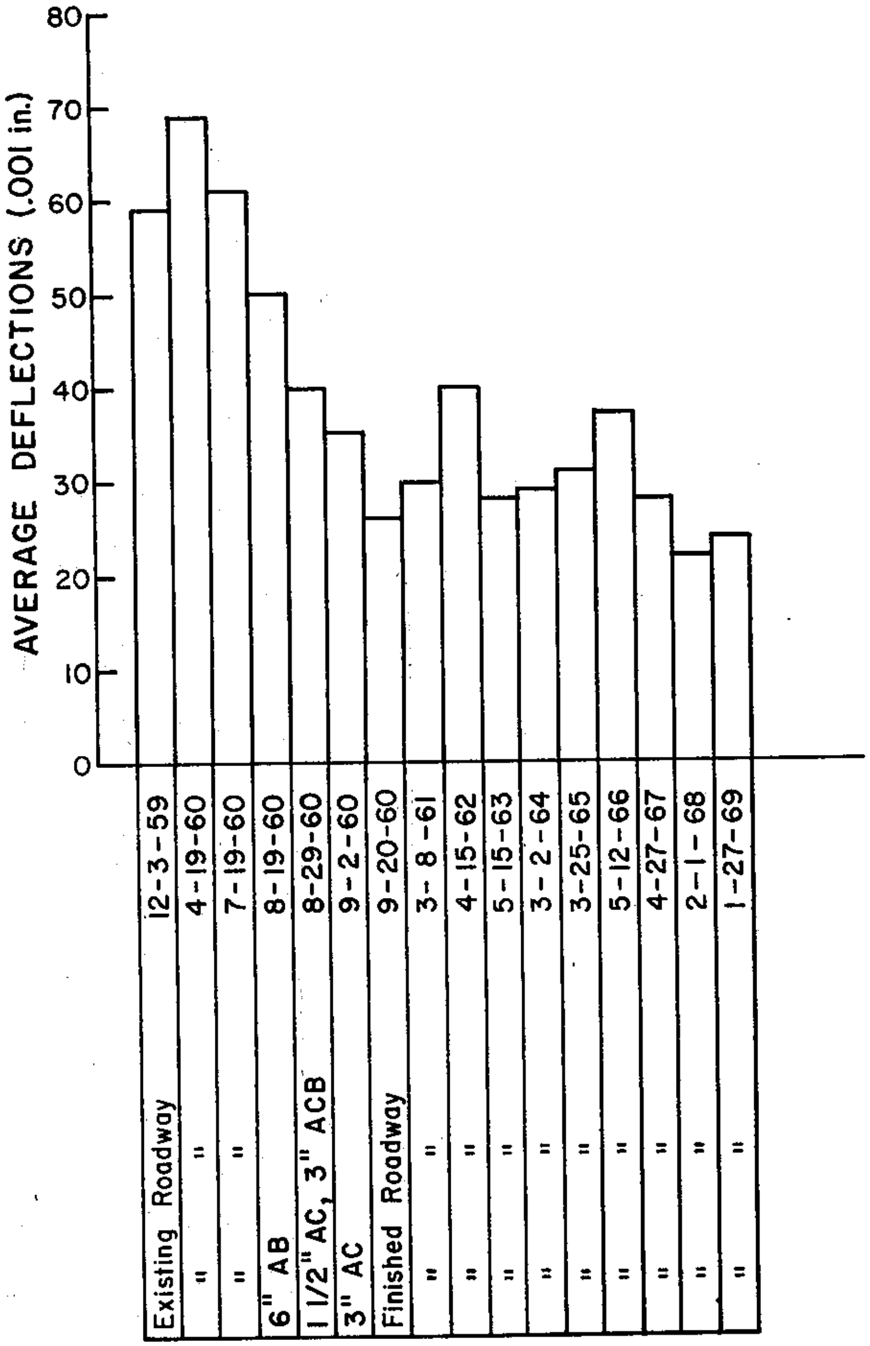


Figure 25

AVERAGE DEFLECTIONS
SECTION 10 AB
Station 321+00 to Station 326+00
Northbound Lane

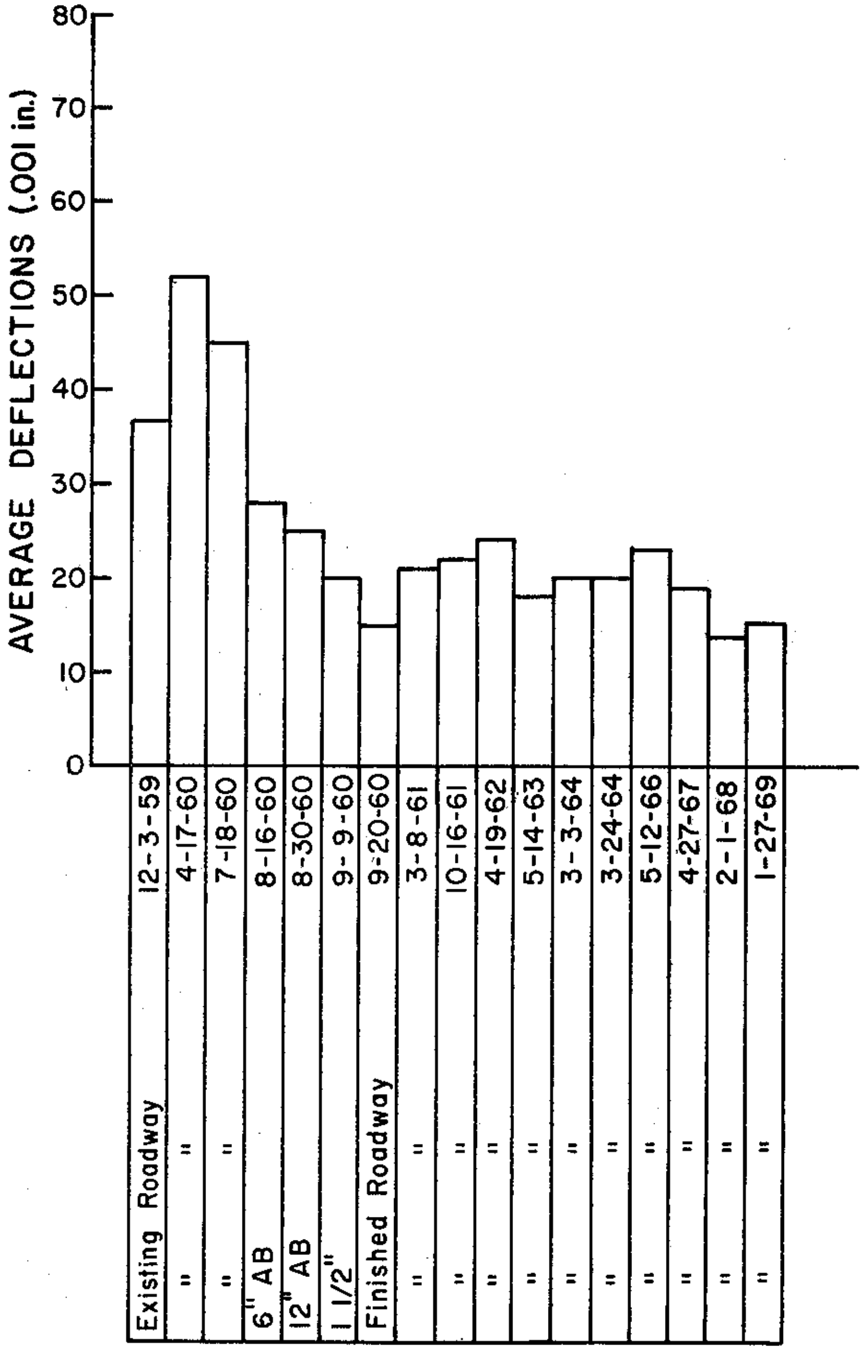


Figure 26

AVERAGE DEFLECTIONS
SECTION II AB
Station 342+30 to Station 352+30
Southbound Lane

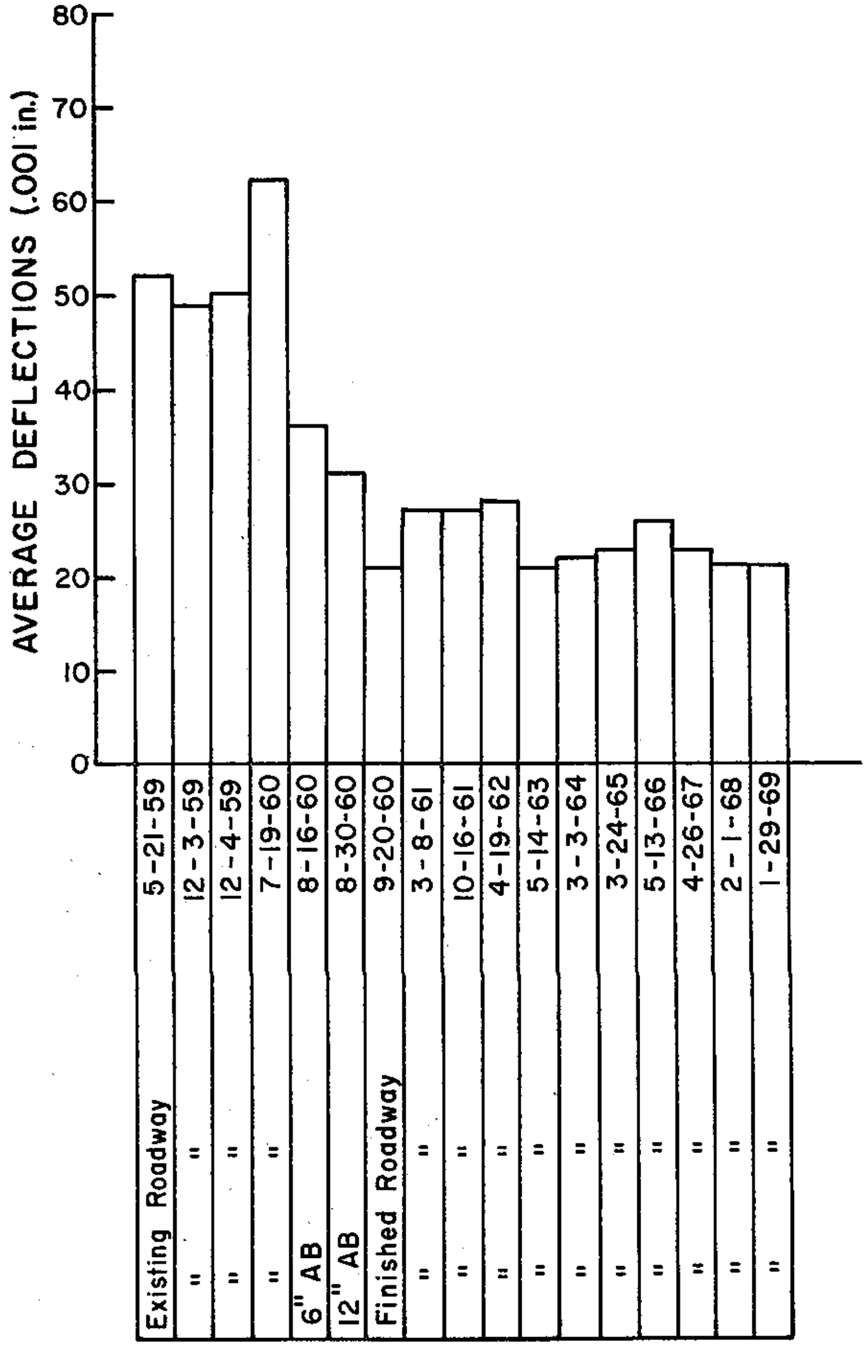


Figure 27

AVERAGE DEFLECTIONS
SECTION 12 AB
Station 466+00 to Station 471+00
Southbound Lane

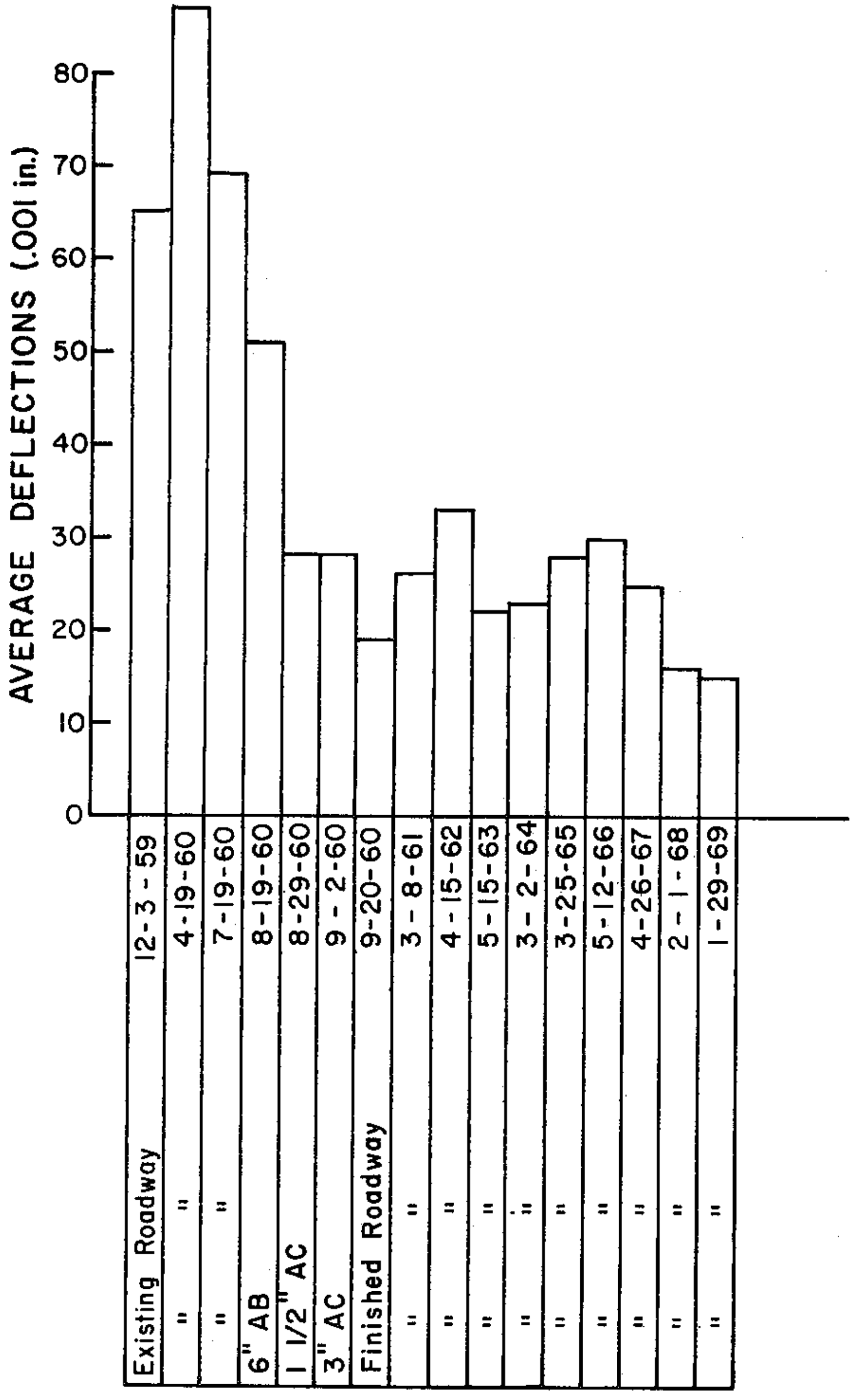


Figure 28

EFFECT OF MEAN DAILY TEMPERATURES ON DEFLECTION READINGS