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16. ABSTRACT

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FLEXIBLE PAVEMENT MAINTENANCE REQUIREMENTS AS DETERMINED BY DEFLECTION MEASUREMENT

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By

Ernest Zube* and Raymond Forsyth**

SYNOPSIS

This paper is a report on the results of the use of the deflection method by the California Division of Highways for the evaluation of existing flexible pavements and the recommendation of suitable reconstruction. Since 1960, some 75 projects including state highways, county roads, and city streets, have been subject to deflection investigation by the Materials and Research Department of the California Division of Highways. The prime purpose of these investigations was the recommendation of the appropriate corrective treatment. As a result of this intensive program, a large volume of data on the deflection attenuation properties of various roadway materials has been accumulated and is presented in this report, along with the results of individual deflection studies. The test procedure, method of evaluation of deflection data, and design criteria which have evolved are examined in detail. In addition, economical and practical factors involved in making a specific recommendation are discussed.

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By

Ernest Zube* and Raymond Forsyth**

INTRODUCTION

The California Division of Highways has utilized deflection measurement for the evaluation of flexible pavements since 1938. Until 1954, deflection measurements were obtained using General Electric travel gages and a later modification, the linear variable differential transformer gage. During these early years, the limited amount of deflection data available was used to evaluate flexible pavement sections subject to distress investigation. In 1951 a comprehensive deflection research program was initiated by the Materials and Research Department. The principal objective of this study was the establishment of a tie between the level of pavement deflection and pavement performance or conditions. Secondary objectives included (1) establishment of the relationship between single axle load and pavement deflection, (2) a determination of the effect on pavement deflection of wheel configuration, and (3) an examination

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of the relationship between pavement deflection and pavement temperature. Approximately 400 General Electric gage units were installed on 43 projects throughout the State of California.

The test roadways included a wide variety of pavement structural sections since it was obvious from the beginning that thickness of asphalt concrete surfacing was a prime variable. Installations were made on both distressed and undistressed sections of the test roads. The rear axle loading for this and all subsequent deflection testing was 15,000 lbs. The results and conclusions of this study were published in 1955 by former Materials and Research Engineer, F. N. Hveem(1).

Examination of the data from this study with respect to level of pavement deflection versus pavement condition permitted the establishment of tolerable deflection criteria for a variety of structural sections. The selected roads were, without exception, "mainline", carrying approximately 10 million equivalent 5000 lb. wheel loads (EWL) during their 10 year design life. The criteria developed as a result of this study (shown by Table 1) are of fundamental importance since they provided the basis for the practical application of pavement deflection data for the determination of the maintenance requirements of a distressed roadway.

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It should be emphasized at this point that these values are applicable primarily to California highways since the methods of mix design, seasonal weather variations, and the characteristics of the construction materials, notably asphalt binder, are peculiar to this state. They are somewhat conservative in comparison to the criteria established by other agencies.

The installation of linear variable differential transformer gages for deflection measurement was a tedious and time consuming process. Because of this and the relatively high costs involved, only limited coverage was possible.

During the operational phase of the WASHO Road Test (1952-54), Mr. A. C. Benkelman of the Bureau of Public Roads developed an instrument for pavement deflection with the important advantages of versatility, simplicity, and speed. With this device, upwards of 300 measurements per normal working day are possible. The development of the Benkelman beam, therefore, greatly augmented pavement deflection research and the use of pavement deflection measurements for overlay design.

Between 1955 and 1960, the Materials and Research Department developed a semiautomatic deflection device, based upon the Benkelman beam principal, known as the traveling deflectometer (see Fig. 1). This instrument

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combines a truck-trailer unit with dual probes for deflection measurements under both sets of dual wheels simultaneously. The operation is electro-mechanical and it is capable of uniform and consistent measurement of pavement deflections at 12-1/2 foot intervals while traveling steadily at 1/2 mile per hour. Between 1500 and 2000 individual deflection measurements are possible during the average working day. The development of the traveling deflectometer and the results of several of these early deflection studies were described in detail in a paper presented in 1962 at the International Conference on Structural Design of Asphalt Pavements(2).

By 1960, sufficient information on the deflection reduction properties of various roadway materials had been accumulated to permit reasonable estimation of the effectiveness of specific types of reconstruction for roadways evaluated by deflection study. The traveling deflectometer provided the means of obtaining a large volume of deflection test data within a relatively short period of time. The use of pavement deflection measurement for determination of roadway maintenance requirements, such as overlays, has been used with ever increasing frequency since that time.

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This report describes the evolution of a deflection test method as used by the California Division of Highways and presents the results of follow-up measurements on projects built in accordance with recommendations resulting from operational deflection studies. Detailed descriptions of five projects of particular interest will be included. A portion of the report will be devoted to a review of the scope and objectives of the current pavement deflection research program of the California Division of Highways.

DEFLECTION TEST PROCEDURE

Prediction of Deflection Attenuation

Accumulation of deflection attenuation data has been accomplished by two methods, the first of which has been follow-up measurements over projects constructed according to recommendations resulting from a deflection study. Another very important source has been test data from projects selected specifically for peculiarities in structural section; i.e., an unusually thick surfacing or base. From May of 1960 to July 1965, some 80 separate deflection studies of an operational nature were conducted for the Division of Highways, counties, and cities involving deflection measurements and recommendations for corrective treatment for 250 individual roadways. As a result of this experience, the Division of Highways

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continues to accumulate a considerable amount of data on deflection attenuation. A plot reflecting the sum total of our experience to date with 17 projects is presented by Fig. 2. Per cent 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. It not only establishes a general trend in the deflection reduction afforded by various materials but also indicates the results of specific types of reconstruction on individual projects.

In addition to the general deflection attenuation trends resulting from this program, our experience with the deflection method so far has shown that: (1) In absolute terms, the reduction in deflection afforded by a given thickness of material is in a large extent dependent upon the initial deflection level. Stated another way, the reduction in absolute units of deflection resulting from the placement from 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

*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.

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realistic to estimate reduction in deflection 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. (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.

Variation in Tolerable Deflection with Traffic

As discussed in the Introduction, the present limiting deflection criteria were established based upon data from heavily trafficked selected test roadways. It has been long recognized that application of these criteria to secondary state highways, county roads, and city streets would be unrealistic and uneconomical. For this reason,

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an interim method for adjustment of tolerable deflection level according to variations in traffic volume has been developed by the Materials and Research Department. This adjustment is based upon AC surfacing fatigue tests by the Materials and Research Department. The results of this work indicated that while the fatigue life of individual AC specimens varied widely, presumably due to variation of mix design, age and number of previous traffic loadings, the slopes of their load repetition versus deflection lines were relatively uniform when plotted as logarithmic functions. By utilizing an average AC surfacing fatigue line slope and pivoting lines through known deflection criteria at the 9.0 traffic index (T.I.)* level, Fig. 3 was developed for the purpose of making "rule of thumb" adjustment in tolerable deflection for varying traffic volumes. Although these curves are based solely on laboratory surfacing fatigue data and have not yet been correlated with field performance, they appear quite reasonable within the ranges of 6.0 to 10.0 T.I.

Selection of Test Section

Prior to making deflection measurements on a certain

*The traffic index 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.

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road, the project file is studied for information on variations in structural section, traffic volume, foundation and drainage conditions, and unusual occurrences during construction which may have had an effect upon the performance of the roadway. From this and visual examination of the project, test sections considered to be representative are selected. Approximately 1000 feet per center line mile is tested on each project. Deflection test data is separated into the categories of fill, cut, cracked, uncracked, travel lane, passing lane, and inner and outer wheel track. Further breakdowns or divisions are established as warranted by peculiarities of the project. Examination of average deflections for each of these categories can frequently indicate the nature or cause of early pavement distress and the practicability of utilizing more than one type of corrective treatment. In those cases where deflection is relatively uniform, an evaluated* deflection level (80 percentile) is established by recombining all outer wheel track readings from the test section. This value reflects the deflection characteristics of the section as a whole rather than isolating possible causes of distress or placing undue emphasis on an isolated condition.

*The deflection value at which 80 per cent of the measurements are higher and 20 per cent are lower.

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Selection of Required Maintenance Treatment

The problem of recommending suitable reconstruction is not simply a matter of establishing a representative deflection level and prescribing a treatment which would reduce this deflection to a tolerable limit. Several other factors are carefully considered to arrive at a satisfactory design. These are:

1. Existing vertical controls (curbs and gutters)
2. Anticipated use of the roadway
3. Extent and nature of cracking
4. Anticipated traffic volume

The existence of curbs and gutters or the presence of an excellent passing lane next to a distressed travel lane often makes the utilization of a travel lane digout feasible. Where no such vertical control exists and a major reconstruction is warranted, a flexible base or cement treated base (CTB) with an asphalt concrete (AC) blanket is usually recommended so that the residual strength of the old pavement can be incorporated into the new construction.

The anticipated future use of a roadway frequently determines whether we shall "live" with a deflection condition through utilization of a thin blanket or eliminate the problem with major reconstruction.

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The extent and nature of cracking is frequently very important in determining whether a blanket will act independently of the old surfacing or become an integral part of the existing surfacing, thereby increasing surface rigidity with a corresponding decrease in the level of tolerable deflection.

The presence of large block or ladder type cracks indicates that the existing surfacing has a good deal of residual slab strength and could thus be expected to act in conjunction with a new blanket. Thus, the AC surfacing would consist of the original and the repair blanket, acting as a unit. Because of this, the tolerable deflection level would be much lower than that for a new blanket applied to a continuously cracked AC surfacing in which surface distress is in the form of relatively small blocks as is sometimes the case with badly "alligator" cracked roads. Here, because the new blanket can be considered independent of the old, the tolerable deflection level can be assumed to be determined by the thickness of the new blanket only.

It should be borne in mind that the deflection method for the design of reconstruction is assumed to be valid when roadway distress is attributable to excessive impression and rebound of the structural section. Evidence

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of the instability of the structural section as manifested by wheel track depression or rutting or indication of significant permanent deformation on the deflection traces reveals a problem beyond the scope of the deflection method. In these cases, design of corrective treatment is based upon the standard R-value procedure.

In order to illustrate the method of analysis and procedure for recommendation of corrective treatment based upon deflection data, we shall examine what might be considered a typical case history of a particular roadway. The information contained in Table 2 was actually acquired during a recent deflection investigation of a medium size city in the central valley of California. The subject roadway had a structural section consisting of 2" of AC surfacing over 4" of aggregate base over 4" of aggregate subbase. The design T.I. was assumed to be 6.5.

The evaluated deflection levels for the two test sections ranged from 0.064" to 0.106". For Test Section No. 1, however, we note a mean outer wheel track deflection level of 0.055". The wide discrepancy between the mean (0.055") and the evaluated (80 percentile) (0.106") levels indicates that the evaluated deflection level was greatly influenced by a few isolated high readings and, thus, is not representative of the test section as a whole. With

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this in mind, the evaluated deflection level of Test Section No. 2 (0.064") is selected as the design deflection level. Based upon a T.I. of 6.5 and the utilization of a 3" AC surfacing, it is determined from Fig. 3 that a deflection level of 0.030" can be tolerated. It is, therefore, necessary to effect a reduction in the deflection level of 0.064" minus 0.030", or 0.034". This requires a 53% reduction in deflection. From Fig. 2 we note that an increase of 10.5" in gravel equivalence is required to reduce the deflection level by 53%. For a 3" AC surfacing the gravel equivalence is 3.0 x 1.9" = 5.7". It will, therefore, be necessary to provide 10.5" minus 5.7" = 4.8" of additional gravel. A possible reconstruction would, therefore, be the placement of a 3" AC surfacing over 5.0" of aggregate base directly over the existing roadway.

Another more economical and practical approach to the same problem takes into consideration the type of distress on the roadway. Here we note intermittent to continuous alligator cracking in both wheel tracks. Because alligator cracks are usually small (2" to 5" in diameter) we can reasonably assume that the existing pavement will act independently of the new surfacing in much the same manner as an aggregate base. Therefore,

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consideration should be given to the possibility of the placement of a thin AC blanket which would permit a higher tolerable deflection level. This approach could be considered "living" with a high deflection condition rather than eliminating it by a major reconstruction. For a 2" AC surfacing, Fig. 3 indicates a tolerable deflection of 0.040". It would, therefore, be necessary to reduce the design deflection level of 0.064" to 0.040" which requires a 38% reduction in deflection. From Fig. 2, a 2" AC blanket (3.8" gravel equivalence) provides a 37% reduction in deflection. This is considered close enough to recommend a 2" AC surfacing for the repair of this facility.

In either case, isolated areas of high transient deflection or advanced distress should be subject to substantial digout type repair prior to the application of the corrective treatments described above.

RESULTS OF SPECIFIC INVESTIGATIONS

The following are brief histories of five past deflection studies which are of particular interest by way of illustrating unusual problems and conditions. The criteria utilized in recommending corrective treatment for these projects has been changed somewhat due to a recent revision of gravel equivalences of base and AC surfacing and modification of the deflection attenuation curves which were used at that time.

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V-Mon-118-Salinas

In July 1961 District 05 Materials Personnel sampled the inplace structural section of this facility at several locations. It was found that within the city limits of Salinas the asphalt surfacing varied from 3" to 6" in thickness and the base material varied from 2½" to 11". Average passing and travel lanes deflection measurements taken in August of 1961 are shown by Table 3. Based upon the above average deflection levels of 0.067" and 0.058" for the travel lanes, it was determined that an increase in gravel equivalence of 12" was required. For the passing lanes, because of their generally good appearance, lower deflection levels and lighter traffic load, an increase of only 4" in gravel equivalence was recommended. The existence of curbs and gutters and buried utility lines near the surface placed severe limitations on the thickness of both an overlay or digout type repair for the travel lanes. As a result, the travel lanes were scarified to a depth of 8". Upon removal of the existing base and surfacing, 8" of an untreated Class 2 aggregate base was placed and compacted bringing them back to the existing finished grade. Both the passing and the travel lanes were then blanketed with 0.25' of AC surfacing.

The net result of the reconstruction of the travel lanes was the replacement of a cracked AC surfacing with

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an uncracked 3" AC blanketing and the replacement of the existing base with a new lift of aggregate base material. The placement of a 3" contact blanket over the passing lanes, however, resulted in the full utilization of the residual strength of the old surfacing. The results of deflection measurements before and after reconstruction for one test section are shown by Fig. 4. The average per cent reduction in deflection was significantly greater in the passing lane section than in the travel digout sections (45% as opposed to 16%). This project illustrates what has been found to be a basic truism with regard to overlay design; that is, whenever possible, reconstruction should fully utilize the residual structural strength of an existing roadway which more often than not is considerable even for badly cracked pavements.

V-SLO-2-PBch,E

Originally constructed in 1949, the structural section included 4" of AC surfacing over 6" of crusher run base covering 12" of imported subbase material. Because of the appearance of early surface distress, a portion of the roadway was resurfaced in 1954 with a 3" AC blanket. In 1959 District 05 materials personnel conducted an investigation in order to determine the cause of surfacing distress which had reappeared since the placement of the 1954 contact blanket. Even though cracking was

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almost continuous throughout the length of the project, the structural section was found to be entirely adequate in thickness and quality. It was, therefore, suspected that excessive pavement deflection had induced premature fatigue cracking of the surfacing.

In January, 1960, Materials and Research personnel made visual observations, pavement deflection measurements, and cored into the structural section at two locations. Visual inspection of the roadway revealed almost continuous "alligator" type cracking with some spalling in both the inner and outer wheel tracks of the outer lane (see Fig. 5). Little evidence of pavement rutting or pumping was observed however. Deflection measurements were found to be uniformly low, averaging 0.016" in the travel lane outer wheel track and 0.012" in the passing lane outer wheel track. The results of tests on AC surfacing cores, however, indicated that the asphalt binder in the 1954 surface course had reached a state of hardness such that it could not withstand even the relatively low deflections characteristic of the roadway. This is shown by the results of tests on recovered asphalt from cores taken at two different locations on the roadway. These data are presented by Table 4.

The 1954 surfacing binder had reached a critical state of hardness as indicated by recovered penetrations of 7 and 3 and ductilities of 8 and 0. These values show a much

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greater degree of hardness than found for the 1949 surface course with recovered penetrations of 33 and 13 and ductilities of 100+ and 22. As a result, the 1954 overlay surfacing was cracked to a much greater extent than even the original 1949 pavement.

In view of the low deflection characteristic of the travel lanes, it was recommended that a 2" AC blanket be placed over the entire roadway. Because the 1954 surface course had cracked into relatively small blocks, it was believed that the possibility of reflective cracking into the new blanket would be minimal. A 2" AC blanket was placed as recommended, in 1960. To date, after nearly 5-1/2 years of service, there has been no further manifestation of surface distress. The use of deflection measurements therefore resulted in a real savings since, based purely on visual observation, a much greater degree of reconstruction would normally have been recommended.

Greenwood Avenue (City of Newman)

This roadway is typical of the many county and city streets tested during the past two to three years over which surprisingly low levels of transient deflection were noted in spite of relatively thin structural sections. In this case, the structural section consisted of 2" to 4" of oiled earth and rock. Visual appearance of the roadway

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was generally good with isolated areas of shrinkage and "alligator" cracking. No wheel track depressions or other evidence of instability were observed. Deflection measurements made in April 1965 produced relatively low evaluated deflection levels ranging from 0.023" to 0.038" which, based upon existing criterion for a 3" AC surfacing at 6.0 T.I. (0.035"), did not indicate a need for corrective treatment. Consequently, a double screening seal coat was recommended to improve roadway appearance and seal off the section although, based upon conventional strength tests, it is likely that a much heavier reconstruction would have been indicated. The good visual appearance and low deflection level of this facility can probably be attributed to age hardening of the AC coupled with an increase in load carrying capacity of the basement soil resulting from successively heavier applications of traffic throughout the years. It is unlikely, therefore, that a similar but newly constructed structural section would prove successful in view of the heavier volume of traffic which would utilize the facility immediately after construction.

05-SLO-2B
(Between Atascadero and Paso Robles)

This project was constructed to its present 4-lane divided alignment in 1951. The original structural section consisted of 4" of AC surfacing and a variable thickness of

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base material which had 2 to 3% cement added to the upper 8". In 1958, as a result of extensive block cracking in the travel lanes, a 1" AC blanket was placed over the entire roadway. This was in addition to regular maintenance of a sporadic nature which, by 1960, was estimated to cost nearly $2000 per mile per year. In June 1961, just prior to a deflection study, a field review of the road was completed. Visual observations indicated that the travel lanes were badly cracked, with spalling evident in some areas. Only very slight distress was observed in the passing lanes. The nature of the cracking indicated reflection from block cracks in the cement treated base as the primary cause of surface distress. The results of the deflection measurements are presented in tabular form below. Mean outer wheel track deflection levels ranged from 0.032" to 0.051" while individual measurements in the travel lane varied from 0.012" to 0.084". These data confirmed the results of visual observations by indicating the cement treated base was providing little or no slab strength. A relatively high deflection level over uncracked areas suggested that even these sections were in a state of incipient distress. Sign Route U.S. 101, one of the two major highways between San Francisco Bay area and Los Angeles is subject to extremely heavy truck traffic. Because of this and its

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relatively high level of transient deflection, a major repair was indicated. It was estimated that a minimum 5" AC blanket would be necessary to reduce travel lane deflections to a tolerable level. Because such an overlay would have required substantial shoulder reconstruction and was not required in the passing lane, it was recommended that the existing AC surface and cement treated base be pulverized to a depth of 10" below the existing finish profile grade in the travel lanes only and that sufficient cement be added for the construction of new cement treated base 8" in thickness having a minimum 7 day compressive strength of 500 lbs. per square inch. It was further recommended that the travel lane be blanketed with 2" of AC over the cement treated base bringing it back to its original grade and that both lanes then be surfaced with a 2" AC blanket. With two minor modifications, the roadway was reconstructed as recommended. The thickness of CTB was increased from 8" to 10". Also, a 3/4" open graded AC surfacing was placed over both lanes in addition to the dense graded AC blanket originally recommended. The results of deflection measurements over a typical test section are shown by Fig. 6. The level of deflection in the outer wheel track was reduced by an average of 87% to below 0.005".

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The results of this and similar projects demonstrate that successful cement treatment of existing base and surfacing materials can greatly strengthen an existing section without significantly raising profile grade. Hence, this technique has proved economical and effective for the reconstruction of roadways subject to the existing vertical control of curbs, gutters, or undistressed interior lanes.

06-Kin,Tul-235-B,A

Where it is possible to utilize an existing structural section in its entirety, placement of reconstruction directly over the existing surfacing permits comparable results with a thinner reconstruction. This is demonstrated by the results of a deflection study on road 06-Kin,Tul-235-B,A. The results of tests before and after reconstruction are presented graphically by Fig. 6. Based upon a design deflection level of 0.068", an increase of 10" of gravel equivalence was recommended. Consequently, a 6" layer of cement treated base (CTB) and a layer of 3" of AC surfacing was placed over the original roadway which reduced the transient deflection level by an average of 71%. The reconstruction of this project was considered quite successful since the deflection levels after application of corrective treatment were reduced below the critical level for a cement treated base.

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Full utilization of the deflection test method is of such recent origin that only a portion of the projects subject to deflection study and corrective treatment have been constructed. Even so, the potential of the deflection test method for effecting substantial savings in the maintenance and reconstruction of existing roadways has been convincingly demonstrated on several occasions. In the October 1964 Public Works Magazine[4], Mr. Donald Winton, Assistant City Engineer, Fresno, California, stated that large savings were realized by utilizing the recommendations resulting from a pavement deflection study of the Fresno city streets. The Materials and Research Department recommendations, when compared to the cost of the previously anticipated reconstruction, allowed a cost reduction of several hundred thousand dollars.

The costs involved in making the typical deflection study have so far been quite reasonable in consideration of the coverage possible with the traveling deflectometer. Normally 10 to 12 one thousand foot road sections representing approximately 10 miles of roadway are tested during a given working day. The cost of the deflectometer crew and equipment is approximately $275 per day. This does not include flagmen which are usually supplied by the highway district, city, or county requesting the survey. Most deflection studies have been conducted at a cost of

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between $500 and $1000 including the completed report.

CURRENT DEFLECTION RESEARCH

Pavement deflection research by the California Division of Highways is, at the present time, concentrated into three general problem areas. The first and by far the largest program involves the establishment of a tie between tolerable deflection levels, structural section, and traffic volume, or Traffic Index. As was mentioned earlier, the present limiting criteria for maximum allowable deflection were established in 1955 as a result of a comprehensive study throughout the State of California. It is not unlikely that the values developed as a result of this investigation tend to be conservative when applied to roadways with light and medium traffic volumes, since the initial investigation was conducted over heavily trafficked roads (9.0± T.I.).

Another very important reason why these values may be subject to some alteration is the improvement in AC durability and thus AC surfacing fatigue resistance which has undoubtedly been brought about by a recent modification of our AC mix design method. The principal objective of this study, therefore, is the establishment of new maximum deflection criteria, which make allowances for a more durable asphalt concrete and which can be adjusted for

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variations in predicted traffic volume. This project, which is being financed by the Bureau of Public Roads' research funds, has been under way for over a year. Twenty-five roadways throughout the state, meeting the following requirements, were selected for a five year comprehensive pre-test program:

1. They are AC surfaced roadways over which reliable traffic data are available.
2. They are newly constructed roadways which have not been in operation for more than three years.
3. They have a reasonably large variation in structural section and deflection level.

The test program, which is being carried out during the spring of each year, consists of deflection measurements obtained with the traveling deflectometer over selected test sections of each roadway. These sections consist of 3 to 5 one thousand foot lengths of the roadway, depending upon the size and the nature of the project. In addition to deflection measurements, a precise crack survey and rut depth determination is made over each test section. Four and twelve inch diameter AC cores are taken in and between the wheel tracks. These samples are subject to flexural strength, microviscosity, permeability, stability, cohesion, density, and per cent voids tests.

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The yearly test program outlined above will be continued until each test section manifests distress to a predetermined level considered to be failure. It is believed that this study is of sufficient scope to permit a valid appraisal of the effect of transient deflection, fatigue characteristics, asphalt quality, mix design, and traffic volume, on asphalt concrete performance.

The second 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 measurement alone. A proponent of the "radius of curvature" concept presented at the 1962 International Conference on Flexible Pavement Design at the University of Michigan in August, 1962, a new device for measurement of radius of curvature with data resulting from its use[3]. 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. By placing it between the wheels, it is possible to measure the middle ordinate of a curve one foot in length in the deflected basin from

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which a radius of curvature can be calculated.

This device has been fabricated by us and used on several projects in conjunction with conventional deflection measurements. The data are shown graphically on Figs. 7 and 8. On Fig. 7, 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 was 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 aggregate base structural sections is shown by Fig. 8. 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 zone of overlap between 0.020" and 0.030". Based upon the limited amount of data presented by Figs. 7 and 8, it

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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 its 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.

CONCLUSION

The Significance of Pavement Deflection

With the steadily increasing reconstruction of existing roadways, the need for a method to determine the minimum degree of reconstruction required to restore an existing roadbed to a state in which it may serve present-day traffic and provide maintenance-free service for an extended period has become increasingly important.

The problem encountered in the design of reconstruction is, of course, entirely different from that which occurs with all new construction. In the latter case, samples of basement or embankment soils are tested statically under moisture and density conditions which are estimated

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to be the worst that will occur during the lifetime of the pavement. From the results of these tests, subgrade bearing capacity is determined with which the necessary thickness of base or subbase can be calculated to provide the required cover in accordance with the appropriate design formula. The design of reconstruction for an existing roadway presents quite another problem, however, since the most economic reconstruction requires that full benefit be derived from the materials in the structural section. In this case, a laboratory strength value cannot be considered quite valid, since the conditions of moisture and density assumed during preliminary design may not have occurred. Also, it is a well-known fact that many years of successively heavier traffic loadings tend to gradually increase in-place soil strength. Another factor which is difficult to evaluate is the residual strength of an AC surfacing or cement treated base. Here, the hardening or curing induced by age may lend considerable slab strength to the system even though there is continuous visible distress. The real significance of pavement deflection data, therefore, is that it gives the highway engineer an indication of the total in-place structural strength of an existing roadway and, thus, provides an extremely valuable tool for the determination of the minimum degree of required reconstruction.

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Fig. 1

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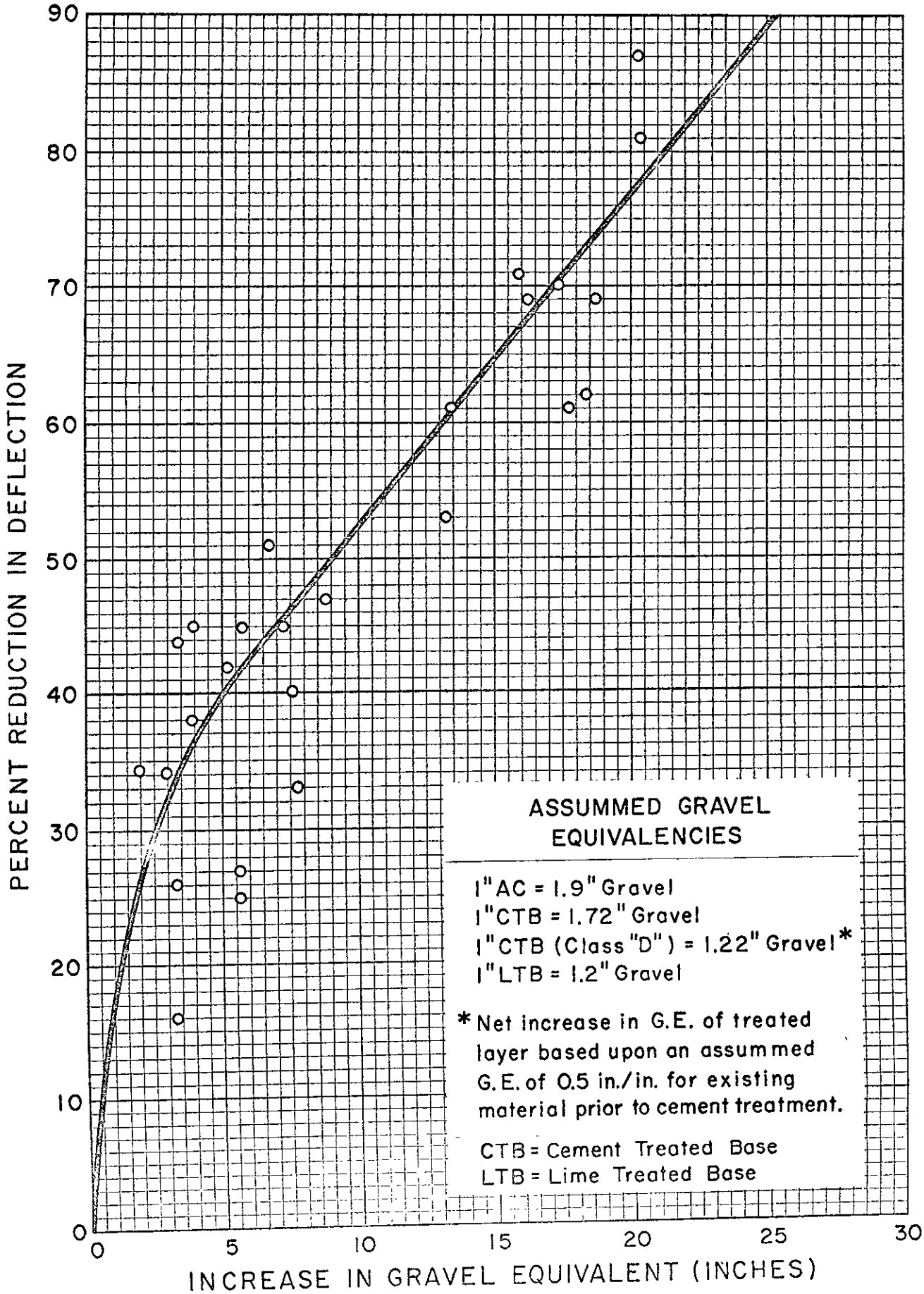
Figure 2

REDUCTION IN DEFLECTION RESULTING FROM PAVEMENT RECONSTRUCTION



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VARIATION IN TOLERABLE DEFLECTION BASED ON A.C. FATIQUE TESTS

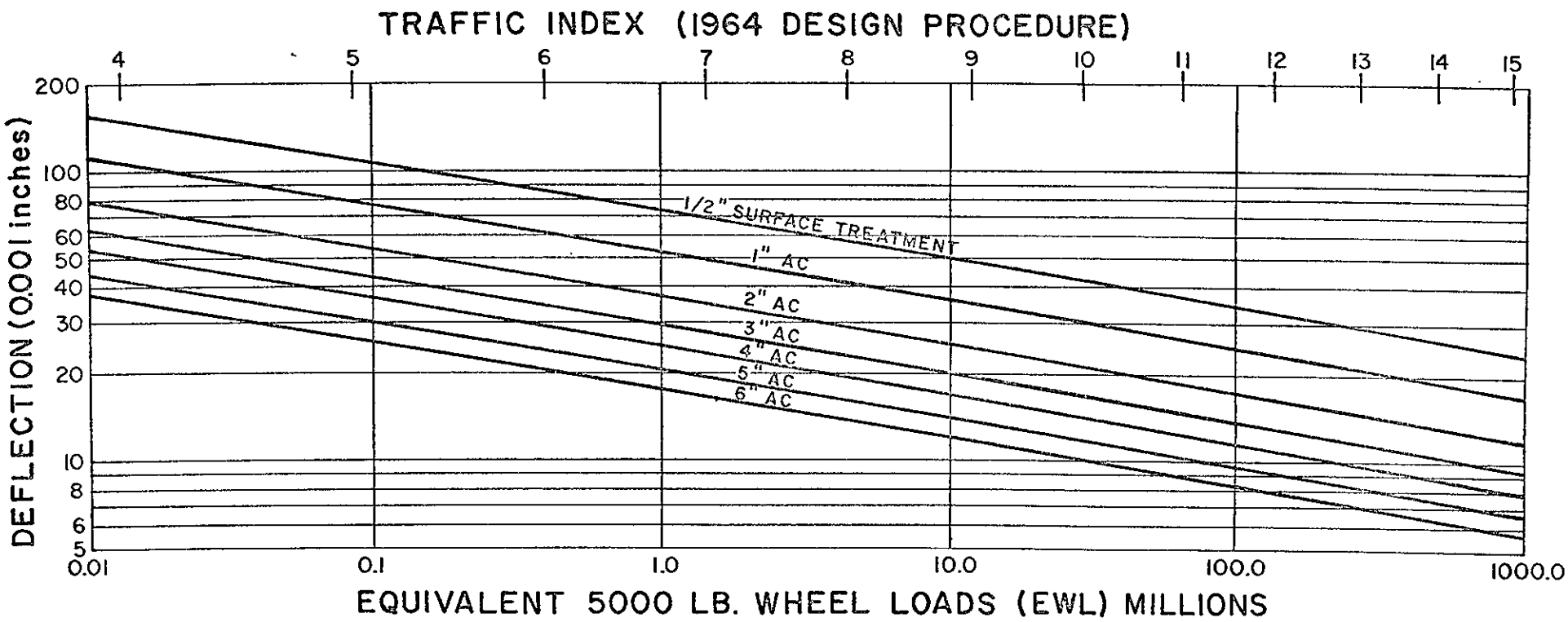

Figure 3

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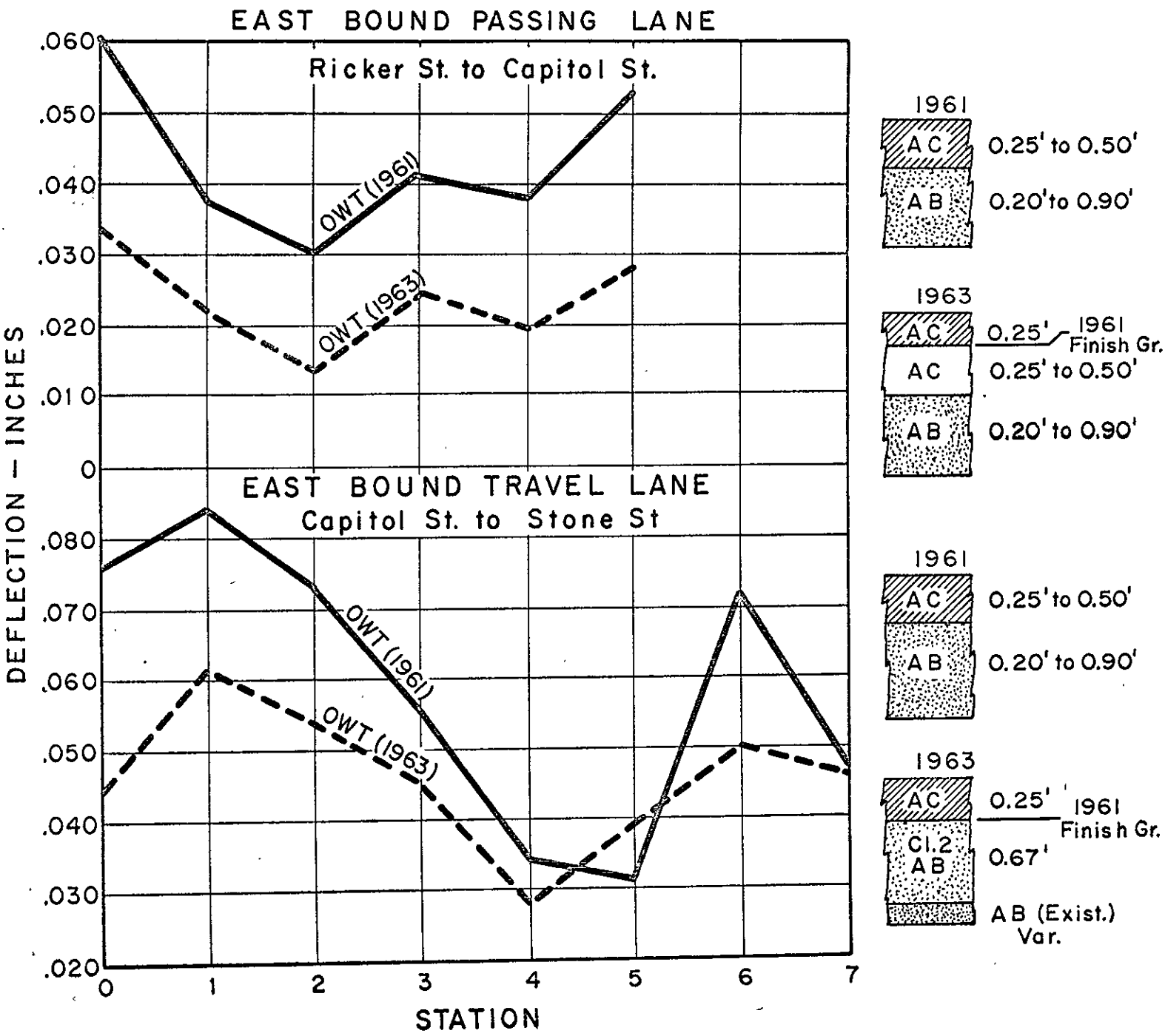
ROAD V - Mon - 118 - SALINAS



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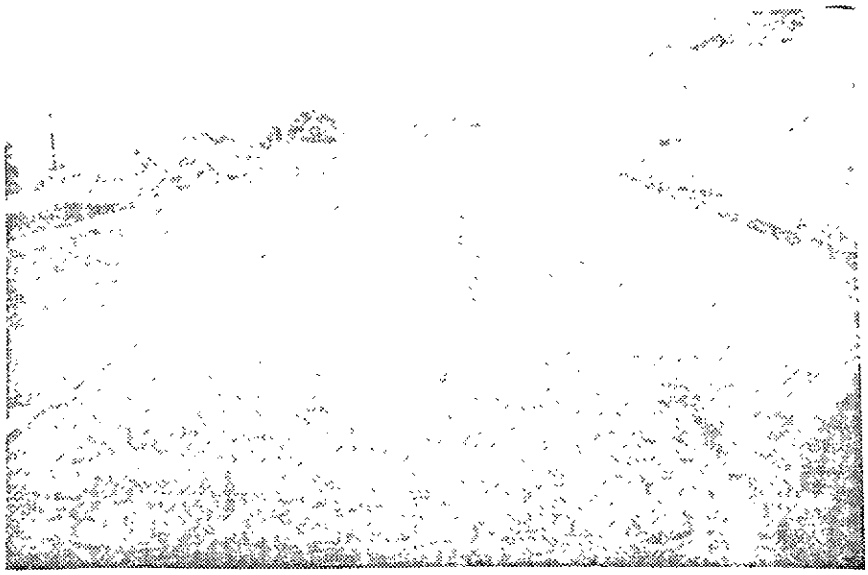

Fig. 5
Road V-SLO-2-PBch,E
Northbound Travel Lane

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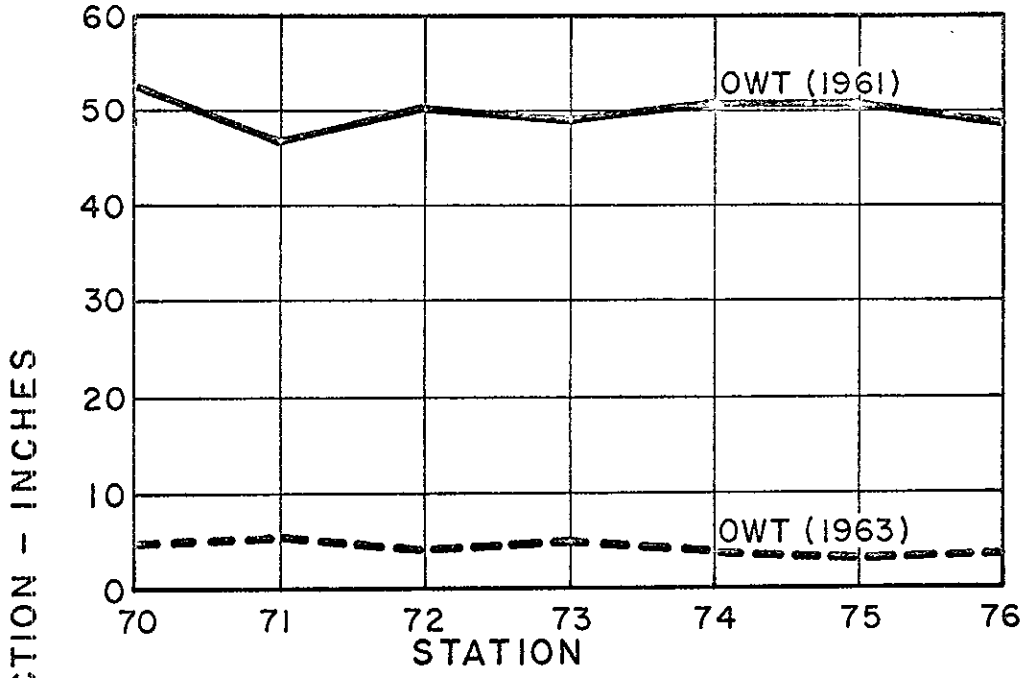
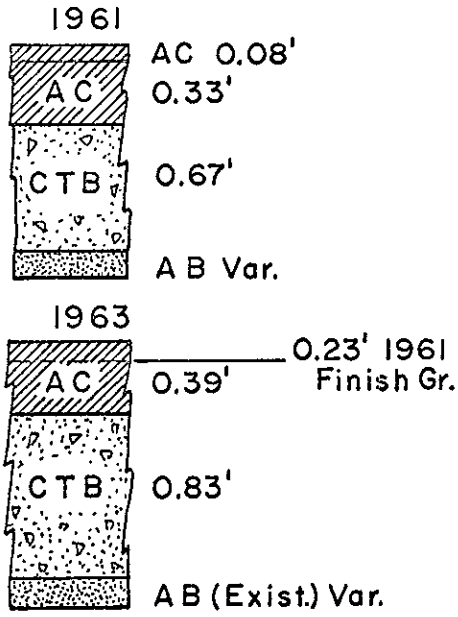
ROAD V - SLO - 2 - B

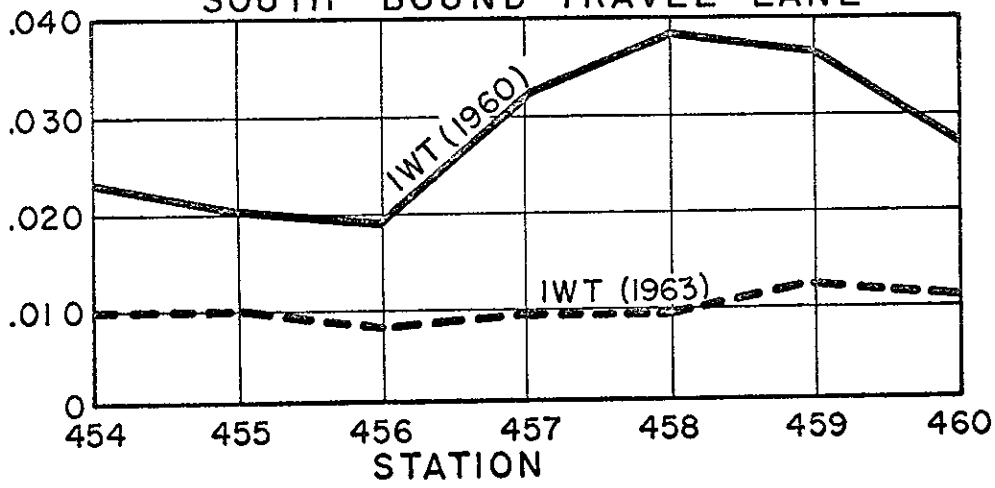
NORTH BOUND TRAVEL LANE

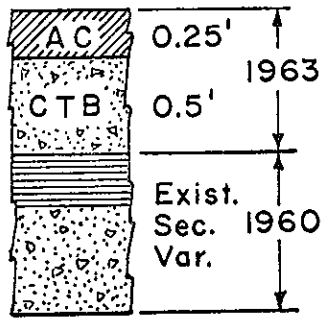




ROAD VI - Kin, Tul - 135 - B, A

SOUTH BOUND TRAVEL LANE





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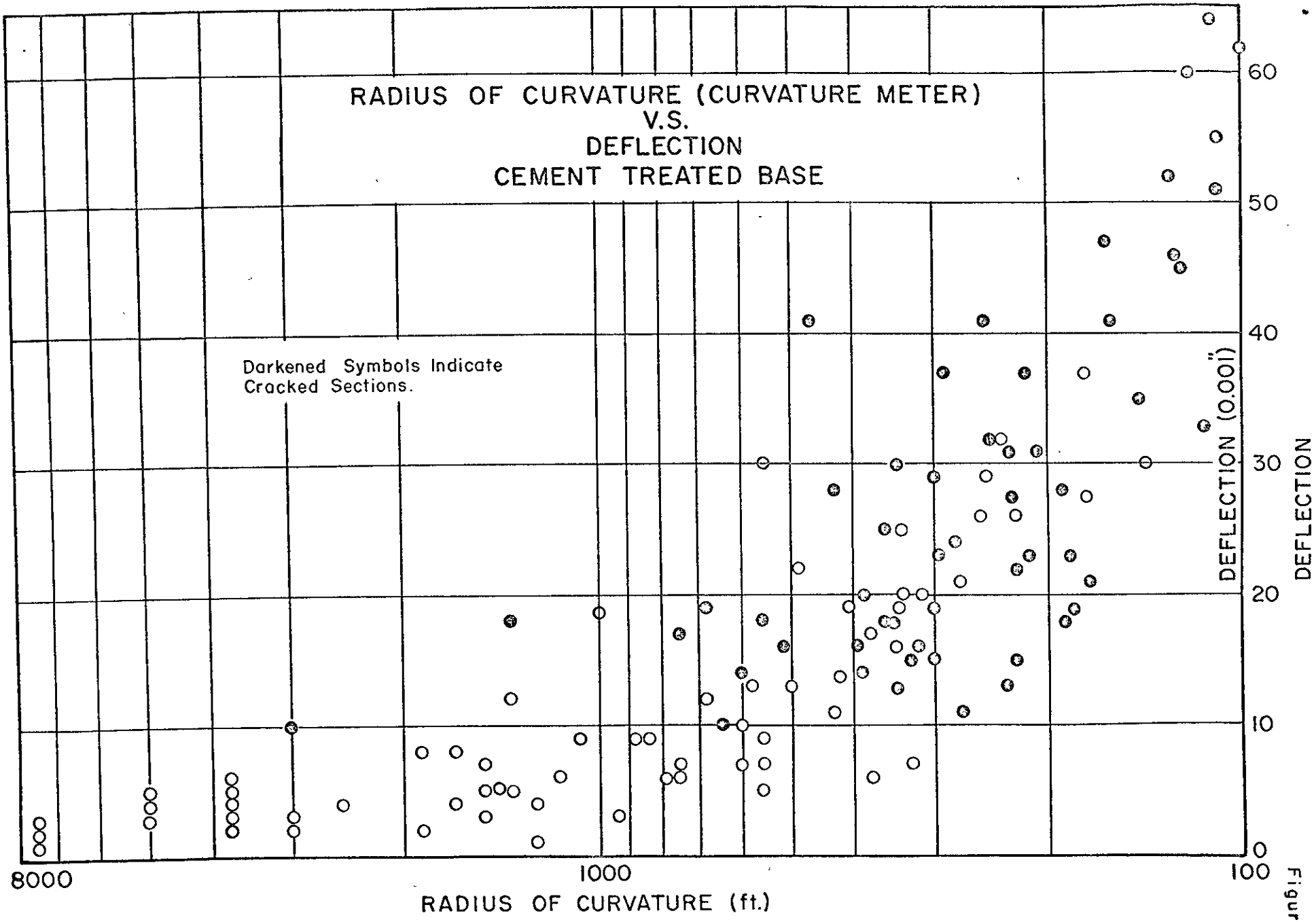

Figure 7

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Figure 8

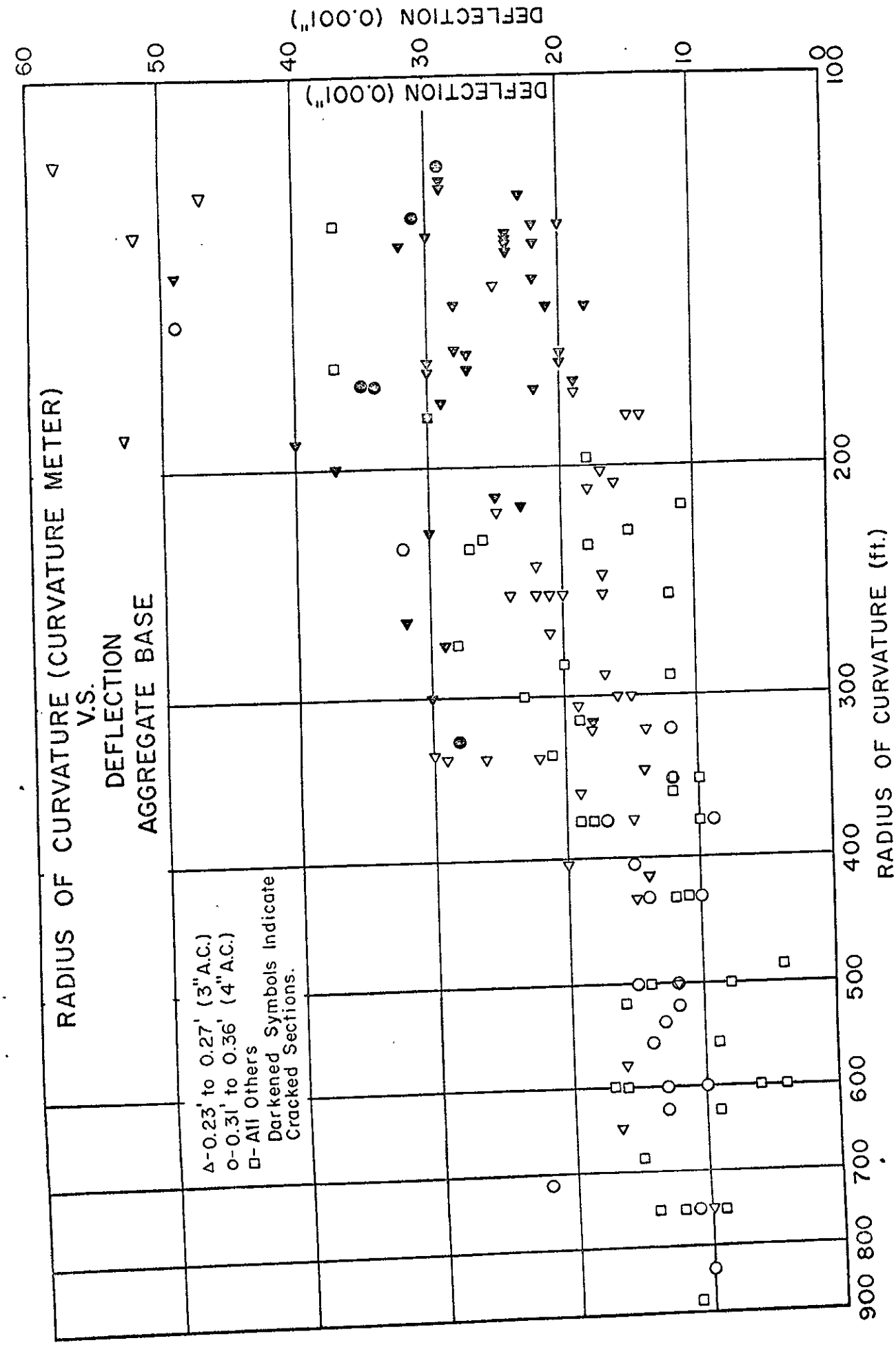

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TABLE 1

Thickness of Pavement	Type of Pavement	Max. 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	0.017-in.
3-in.	Plant Mix on Gravel Base	0.020-in.
2-in.	Plant Mix on Gravel Base	0.025-in.
1-in	Road Mix on Gravel Base	0.036-in.
1/2-in.	Surface Treatment	0.050-in.

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TABLE 2

Test Section	Deflection (Inches) Mean OWT	Mean IWT	Evaluated (80% level)	Appearance
1)	0.055"	0.028"	0.106"(35)	Intermittent "alligator" cracking and shrinkage cracking.
2)	0.043"	0.031"	0.064"(28)	Continuous to intermittent "alligator" cracking in both wheel tracks of all lanes.

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TABLE 3

	Location	Lane	Mean Deflection (Inches) Outer Wheel Track
1.	Between Lincoln and Vale Streets	Westbound Travel	0.067"
2.	Between Stone and Capitol Streets	Westbound Passing	0.034"
3.	Between New Street and West City Limits	Westbound Travel	0.038"
4.	Between Capitol and Stone Streets	Eastbound Travel	0.058"
5.	Between Riker and Capitol Streets	Eastbound Passing	0.042"
6.	Between Clark and New Streets	Eastbound Travel	0.029"

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TABLE 4

Station	Binder	Core	Depth	Asphalt Properties: Pen. 77F	Asphalt Properties: Ductility 77F 5 cm/min.
"N" 244+64 Northbound Travel Lane--Outer Wheel Track	120-150 Pen.	1954 Surf. Course	0-1-1/2	7	8
	SC-5	1954 Level Course	1-1/2	157	100+
	200-300 Pen.	1949 Surf. Course	3-3/4 8	33	100+
	200-300 Pen.	1949 Level Course	8-10	4	12
"N" 240+50 Northbound Travel Lane--Outer Wheel Track	120-150 Pen.	1954 Surf. Course	0-1-1/2	3	0
	SC-5	1954 Level Course	1-1/2 3-3/4	48	-
	200-300 Pen.	1949 Surf. Course	3-3/4	13	22
	200-300 Pen.	1949 Level Course	7-9-1/2	4	7

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