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This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

Pavement deflection measurements are utilized to evaluate residual "in-place" strength of flexible pavement sections. Asphalt concrete structural overlay thickness requirements for 10-year service life extensions are determined based on reduction of initial deflections to tolerable deflection levels for given conditions.

Asphalt properties were studied to determine effects upon pavement performance and deflections of flexible pavements.

Experimental materials and methods are studied under various climatic and traffic conditions in efforts to minimize or control pavement reflection cracking through AC overlays.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

December 1978

FHWA No. D-5-5
TL No. 633167

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

STATEWIDE FLEXIBLE PAVEMENT
PERFORMANCE AND DEFLECTION STUDY

Study made by .... Roadbed & Concrete Branch

Under the Supervision of .... John B. Skog, P.E. and
Donald L. Spellman, P.E.

Principal Investigator .... James A. Matthews, P.E.

Report Prepared by .... John B. Skog, P.E.
James A. Matthews, P.E.
Gary W. Mann, P.E. and
Donald V. Roberts, P.E.

Very truly yours,

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

GWM:lb

Attachment

ACKNOWLEDGEMENTS

This final report titled "Statewide Flexible Pavement Performance and Deflection Study" was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

The authors wish to thank the researchers from the Transportation Laboratory who performed much of the work on this study; namely, Mr. Raymond Forsyth, Mr. Donald Tueller, Mr. Hal Munday (deceased), Mr. Joseph Hannon and Mr. Roy Bushey. Recognition is also given to the personnel who performed data collecting, field testing and laboratory testing; in particular, Mr. Orvis Box, Mr. Walter Cox, Mr. Stephen Allen, Mr. Wesley Dwyer, Mr. Earl Boerger, Mr. Glenn Kemp and Mr. Nelson Predoehl.

Appreciation is given to District Maintenance personnel who provided traffic control so that field tests could be performed on State highways. Appreciation is also given to District Traffic personnel who supplied the traffic data used in this study.

CONVERSION FACTORS

English to Metric System of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)	25.4	millimetres (mm)
		.0254	metres (m)
	feet (ft)	.3048	metres (m)
	miles (mi)	1.6093	kilometres (km)
Area	square inches (in^2)	6.4516×10^{-4}	square metres (m^2)
	square feet (ft^2)	.092903	square metres (m^2)
	acres	4046.9	square metres (m^2)
		.40469	hectares (ha)
		.40469	square hectometres (hm^2)
		.0040469	square kilometres (km^2)
	square miles (mi^2)	2.590	square kilometres (km^2)
Volume	gallons (gal)	3.7854	litres (l)
		.0037854	cubic metres (m^3)
	million gallons (10^6 gal)	3785.4	cubic metres (m^3)
	cubic feet (ft^3)	.028317	cubic metres (m^3)
	cubic yards (yd^3)	.76455	cubic metres (m^3)
	acre-feet (ac-ft)	1233.5	cubic metres (m^3)
		.0012335	cubic hectometres (hm^3)
		1.233×10^{-6}	cubic kilometres (km^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
		.028317	cubic metres per second (m^3/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
		6.309×10^{-5}	cubic metres per second (m^3/s)
	million gallons per day (mgd)	.043813	cubic metres per second (m^3/s)
Mass	pounds (lb)	.45359	kilograms (kg)
	tons (short, 2,000 lb)	.90718	tonne (t)
		907.18	kilograms (kg)
Power	horsepower (hp)	0.7460	kilowatts (kW)
Pressure	pounds per square inch (psi)	6894.8	pascal (Pa)
Temperature	Degrees Fahrenheit (°F)	$\frac{tF - 32}{1.8} = tC$	Degrees Celsius (°C)

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INTRODUCTION

The California Department of Transportation has utilized deflection measurements for the evaluation of flexible pavements since 1938. In 1951, a series of comprehensive deflection research studies were initiated by the Transportation Laboratory in an effort to establish a tie between pavement deflection levels and pavement performance. Since the first formal study began in 1951 several projects have been completed and reports made. This report first summarized the significant findings of the early work and then describes work completed since 1976. The results and conclusions of the first formal study were published in 1955 (1). An evaluation of the data from this study with respect to pavement deflections versus pavement conditions permitted the establishment of the concept of "tolerable deflection" criteria for a variety of structural sections. The term "tolerable deflection" as first used and shown in Table 1 is that level beyond which repeated deflections of that magnitude will produce fatigue cracking in the surface.

TABLE 1

Thickness of Pavement	Type of Pavement	Max. Permissible Deflection
8 in.	Portland Cement Concrete	0.012 in.
6 in.	Cement Treated Base (Surfaced with Bituminous Pavement)	0.012 in.
6 in.	Asphalt Concrete	0.012 in.
4 in.	Asphalt Concrete	0.017 in.
3 in.	Asphalt Concrete	0.020 in.
2 in.	Asphalt Concrete	0.025 in.
1 in.	Road Mixed Asphalt Surfacing	0.036 in.
1/2 in.	Surface Treatment	0.050 in.

The tolerable deflections (maximum permissible deflection) presented in Table 1 provided the basis for the application of pavement deflection data to overlay design.

Since this earlier work, various related studies were combined and expanded. These studies have covered a period of about 16 years. A chronological list of the projects titles and reports is as follows:

Interim Reports, Papers and Test Method Published Under This Study:

1. "Flexible Pavement Maintenance Requirements as Determined by Deflection Measurements", January 1966 by E. Zube and R. Forsyth (covered work done between 1960 and 1966 and included some background information covering work done since 1938).

2. "Pavement Deflection Research and Operations Since 1938", April 1966 (covered background work in more detail).

3. "Interim Report on Statewide Follow-Up Deflection Study of Overlays and Roadway Reconstruction", August 1966.

4. Interim Report, "Statewide Flexible Pavement Performance and Deflection Study", December 1968.

5. Test Method, "Methods of Test to Determine Overlay and Maintenance Requirements by Pavement Deflection Measurements", April 1969.

6. HRB Paper, "Overlay Design Using Deflections", August 1970.

7. Interim Report, "Structural Overlays for Pavement Rehabilitation", July 1974.

8. Interim Report, "Experimental Overlays to Minimize Reflection Cracking", September 1976.

General summaries of these sutdies are given later in Phase I of this report.

Due to an asphalt specification change in 1960, further studies were initiated to refine the tolerable deflection values presented in Table I. Fatigue testing of asphalt concrete samples was performed in the laboratory to represent tolerable deflection criteria for various traffic loadings (2). The original tolerable deflection data was accumulated over roads with traffic loadings having a TI of about 9.0. From this early research, adjustments were made to tolerable deflection values and a deflection reduction chart (for a broad range of TI's) was established. These charts were the basis for California's first overlay design method which was published in August of 1969.

In October of 1966 the Transportation Laboratory combined an on-going State financed project with a Federally funded project to continue the work on pavement deflections and flexible pavement performance. The primary objectives of the combined efforts were: (1) to establish a relationship between tolerable deflection levels and traffic volumes for utilization in the design for reconstruction of existing roadways, and (2) to determine the relative importance or effects of variable traffic volumes, deflection level, and asphalt properties on the performance of AC pavements. Data for the study were first utilized to refine the deflection reduction chart as described in an interim report (3). This was first incorporated into our overlay design method in October of 1972 and later used to modify the overlay design guide issued in July 1976.

During October of 1970, an addendum to the 1966 work plan was added to include the evaluation of systems to minimize reflection cracking. Test installations were established at several locations throughout the State during the summers of 1972 to 1974. Initial findings on this study were reported in the interim report published in September of 1976 (4).

Continued evaluation of the deflection data resulted in two revisions to the California overlay design method during the period from 1970 to 1974. Deflection reduction characteristics and tolerable deflection levels of asphalt concrete were revised based on the performance of highway projects under review since 1960. An AC overlay design guide was developed which simplified the procedure for determining overlay thicknesses. This was first published in July 1976.

California's current overlay design method is presented in Appendix B. It should be noted the present reduction in deflection with increases in gravel equivalence was again placed in the test method. The original overlay design guide was established to be primarily used with untreated bases or treated bases which have deteriorated to the point where little slab strength remains. For treated bases (CTB) with good in-place strength it is necessary to design the overlay using the 'percent deflection reduction' curve.

This (1978) final report is divided into three phases. Phase I contains the summaries and conclusions of each of the interim reports and publications written on this project since 1966. Phase II evaluates the variables of traffic volume, deflection level and asphalt properties with respect to the performance of asphalt concrete from the period 1964 to 1978. Phase III is a final evaluation of the various systems investigated to minimize reflection cracking.

FINDINGS AND CONCLUSIONS

1. Pavement deflection measurements provide a reliable andication of in-place strength of the total pavement structural section.

2. Reasonable tolerable deflection values have been determined for various AC thicknesses and estimated traffic volumes.

3. When a given thickness of AC is placed over an existing roadway, the percent reduction in deflection is dependent on the initial deflection prior to placement of the overlay.

4. Using the above findings and conclusions California developed an overlay design method to determine overlay requirements utilizing pavement deflection levels, tolerable deflection criteria and estimated traffic volumes to determine structural adequacy.

5. Measured deflections can either increase, decrease or remain the same with time. Therefore pavement deflection measurements alone cannot be used to predict when an overlay would be required. They do indicate a present condition for which an overlay would be appropriate.

6. The California overlay design method at the present time does not provide for adjustments for temperature. Deflection differences caused by moisture changes in the base and subgrade throughout the year completely overshadow the magnitude of temperature adjustments that might be made. Our method attempts to determine pavement deflections during the worst condition (by testing in the spring or early summer) when the moisture content is at the highest level.

7. For 22 projects investigated for nearly 15 years, a relationship was found between fatigue cracking and tolerable deflection levels previously determined for various thicknesses of AC and traffic volumes. Seventy-three percent of the pavements that exceeded tolerable deflection levels had fatigue cracking in excess of 10 percent of their area, regardless of asphalt properties.

8. The following general observations were noted regarding asphalt properties and pavement performance:

(a) Ductility values usually drop from 70 to 100+ (new AC) to less than 30 when AC pavements reach 10 percent fatigue cracking, regardless of the time period to reach 10 percent cracking. Pavements that exhibited 10 percent fatigue cracking approximately 6 to 8 years after construction had ductility values nearly 50 percent lower (from construction to failure) than pavements reaching 10 percent fatigue cracking approximately 13 to 15 years after construction.

(b) Penetration values of asphalt used for new AC (usually greater than 40) generally have dropped to less than 15 by the time 10 percent fatigue cracking occurs. No appreciable penetration differences were noted for good and poor performing pavements.

(c) Modulus of rupture, softening point and cohesion values generally tend to increase throughout the pavement life. Pavements with slightly higher modulus of rupture, softening point and cohesion values were quicker to reach 10 percent fatigue cracking than pavements with lower values.

9. Of the 22 projects investigated in this study, one percent fatigue cracking was reached an average of 9.2 years after construction. Ten percent fatigue cracking occurred an average of 11.7 years after construction. This marked increase in fatigue cracking over a short interval confirms results found on the Zaca-Wigmore Test Road, and indicates that failure is not directly proportional to time.

10. A good relationship (r = 0.86) was established between the two primary factors (asphalt properties and destructive factor) resulting in the fatigue failure of an asphalt concrete pavement.

Percent Alligator Cracking =
-8.25 + 0.0012(Cumulative Deflection) + 0.043(Stiffness @77°F)

11. The following general observations were noted for the material and/or systems used to control reflection cracking:

(a) The Petromat fabric has been effective in extending the life (time to a specified amount of reflection cracking) of those 0.08 foot maintenance blankets on test sections that exhibited alligator cracks less than 1/8-inch wide (fatigue failure) prior to the overlay, and were in areas noted for mild climates. The test sections with Petromat and AC overlays greater than 0.10 foot in thickness have not been in service long enough to determine their performance since neither the control nor fabric test sections have yet failed.

(b) None of the stress-relieving interlayer (SRI) systems tested to date (emulsion slurry seal, rubberized slurry seal) have been effective in reducing reflection cracking.

(c) On one of the test sections where an additional thickness of AC (0.12 foot) was placed to compare economically with the cost of using other experimental products (Petromat, SRIs, etc.) the additional thickness of AC performed better than the experimental test section (02-Las-395).

Similar comparisons in other areas of the State have not been in service long enough to draw firm conclusions on the relative effects of the additional thickness of AC.

(d) The binder modifiers, Petroset "AT" and Reclamite, did not effectively reduce reflection cracking.

(e) Test sections with dense-graded AC overlays placed over open-graded mixes have not had sufficient time to determine their performance (both control and test sections have not failed to date).

IMPLEMENTATION

1. The deflection analysis method of overlay design was implemented by the Transportation Laboratory with the adoption of Test Method No. Calif. 356 in 1969 after publication of Interim Report No. 4 for this research project. It has been used as an alternate method for overlay design when this service was requested by a Transportation District, County, City, Airport Authority, or other public agency.

2. The California Department of Transportation is in the process of implementing a Pavement Management System. All eleven Transportation Districts are now beginning to utilize the deflection method of design for structural overlays for rehabilitation of existing flexible pavements showing distress. This method is being selected as the standard procedure when a structural analysis is determined to be the appropriate strategy based upon biennial pavement condition survey data as taken by the Office of Maintenance.

3. Presently, the use of Petromat or other similar fabrics to reduce reflection cracking has been approved for use over pavements exhibiting fatigue cracking in the form of alligator cracking where the cracks are less than 1/8-inch wide. Additional uses presently approved are: (1) in areas where vertical controls make it advantageous to restrict or reduce the overlay thickness by 0.1 foot AC (structures, curbs and gutters, etc.); (2) economic considerations on multilane highways where the use of fabric will reduce the thickness required on the outer lane (truck lane) and therefore greatly reduce the amount of material needed to be placed on the less damaged inside lanes to maintain grade.

PHASE I - SUMMARY AND CONCLUSIONS OF THE INTERIM REPORTS

Publication No. 1 - Flexible Pavement Maintenance Requirements as Determined by Deflection Measurements (Jan. 1966)

This paper reports the results of the use of the deflection method by the California Division of Highways for the evaluation of existing flexible pavements and the recommendations for suitable reconstruction. Eighty projects including State highways, county roads, and city streets were subjected to deflection investigation by the then Materials and Research Department of the California Division of Highways. The prime purpose of these investigations was to develop recommendations for appropriate corrective treatment. The results of this study produced a large volume of data on the deflection attenuation properties of various roadway materials, along with the results of individual deflection studies. The test procedure, method of evaluation of deflection data, and design criteria which have evolved were examined in detail. In addition, economical and practical factors involved in making a specific recommendation were also discussed. A separate section of the report was devoted to a review of current deflection research including work on the establishment of maximum deflection criteria which may be adjusted for variations in traffic volume. An analysis of radius of curvature data obtained with the Dehlen Curvature Meter was also included.

Conclusions

1. Laboratory strength values to determine the in-place strength of a structural section cannot be considered totally valid, since the conditions of moisture and density assumed during preliminary design may not have occurred.

2. The residual strength of an asphalt concrete surfacing is difficult to evaluate. 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.

3. Laboratory fatigue tests showed that the fatigue life of individual AC specimens varied widely although 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 level, a chart was established for the purpose of making adjustments in tolerable deflection for varying traffic volumes.

Publication No. 2 - Pavement Deflection Research and Operations Since 1938 (April 1966)

This report was a discussion to date of all the research initiated by the then California Division of Highways on pavement deflections since 1938. First installations utilized General Electric travel gauges to measure deflections. As a result of these studies, in 1955, the maximum tolerable deflection criteria was established. These criteria provided the basis for future application of pavement deflection measurements to distress investigations on overlay design. A discussion on the establishment of the tolerable deflection criteria and test sections was included.

Background information was discussed with regard to the development of present deflection equipment. During the operation of the WASHO Test Road in 1952 and 1953, a device for obtaining rapid and accurate deflection measurements was developed by A. C. Benkelman of the then Bureau of Public Roads. This instrument, termed the "Benkelman beam", thus stimulated deflection research by this department and other agencies. By 1960, this department had developed and put into operation a fully automatic pavement deflection device utilizing the Benkelman beam principle on a tractor-trailer combination which became known as the California Deflectometer.

Discussion of the deflection attenuation research that began in 1955 and accelerated with the development of the Benkelman beam and Deflectometer was included. The results produced a sufficient amount of information on deflection attenuation of various materials to provide a reasonable basis for estimating the amount of required reconstruction.

The procedure for the use of pavement deflection measurements for overlay design was discussed. A review of some projects designed by this method and the other factors to be considered was presented.

Publication No. 3 - Interim Report on Statewide Follow-up Deflection Study of Overlays and Roadway Reconstruction (August 1966)

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

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

A third objective of this study was to evaluate areas of influence as determined by radius of curvature measurements compared to conventional lineal deflection measurements. Radius of curvature measurements obtained using the Dehlen Curvature Meter on a number of aggregate base and cement treated base projects were compared with conventional measurements over the same sections.

Conclusions

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

1. Inspection of deflection data on new pavements one to four years of age indicates that significant reductions in deflection usually occur during the first three years of service. This is presumably due to the curing of the AC surfacing and some additional traffic compaction. Approximately four years after construction, deflection levels tend to increase. This is presumably due to the presence of micro-cracks and changes in the moisture condition of the structural section.

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

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

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

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

6. The reduction in deflection resulting from cement treatment of an in-place material is somewhat greater than presently indicated by established gravel equivalent factors.

Publication No. 4 - Statewide Flexible Pavement Performance and Deflection Study (Interim Report) December 1968

Data representing the present status of various projects comprising a total of 25 different structural sections with varying levels of traffic and pavement deflection were briefly discussed. Studies to evaluate pavement performance, deflection attenuation properties of various roadway materials and radius of curvature of various highway pavements by the Dehlen Curvature Meter were also discussed. Contrary to the findings presented in the last interim report, (Publication No. 3) pavement deflections continued to decrease after the pavement had reached an age of four years probably due to traffic compaction and further AC aging. It was reported that preliminary computer analyses indicated that accumulative 5,000 pound equivalent wheel loadings were the most significant variable in predicting pavement distress.

Since the last interim report (5), August 1966, the scope of this project was expanded to include the "Statewide Flexible Pavement Study." This study was proposed for inclusion because in addition to being closely related to other on-going work, it would eliminate administrative and report duplication. Although the objectives differed somewhat, the investigational procedures were much the same and involved the same laboratory personnel. This phase of the study was designed to provide information on the quality of structural section materials as well as evaluate design and construction procedures and relate these factors to pavement performance. Approval for consolidating the two projects was obtained on December 20, 1966.

The purpose of this 1968 report was to present the results of testing and data collection since the last interim report dated August 1966.

This study involved 20 different paving projects throughout the state plus a series of streets in the City of Woodland, California.

A comparison between the 1968 data and that which was presented in the 1966 interim report was made. The changes in asphalt properties, deflection levels and surface condition were presented for one test section per project. From this data, no clear-cut trends or conclusions could be established. However, some preliminary computer analyses of data from one test section from each of five different

Traffic Index-Deflection projects were performed. The results suggested that accumulative 5,000 pound equivalent wheel loadings were the most significant variable in contributing to surface distress. The second most significant factor was the penetration value of the recovered asphalt binder, and next important was the pavement deflection. Since this was only a "trial run", it may have had little bearing on final results and conclusions when all data are considered.

During the interim period, follow-up deflection measurements were made over 16 different projects constructed subsequent to the last report. Also since the last (1966) report, 177 city, county and state roadways totaling over 500 centerline miles have been investigated for purposes of determining reconstruction and maintenance requirements. Appropriate reconstruction strategies were recommended based on present deflection criteria.

A computer analysis was performed on all deflection data thus far collected. The results indicated the deflection attenuation design criteria were still valid.

Another area of study that is continuing consists of the determination and analysis of the area of influence or radius of curvature of a pavement under load, and the relationship of this variable to pavement performance. For this the Dehlen Curvature Meter was used to collect data on all projects which are subject to deflection measurement.

Correlation curves relating radius of curvature to pavement deflection for both cement-treated and untreated aggregate base construction have been established by computer analysis. The results reveal a coefficient of correlation of 0.73 for the untreated base sections and 0.84 for the cement treated base sections. The standard error of the estimate in terms of Benkelman beam deflection was found to be ±0.008 inch for the untreated base sections and ±0.007 inch for cement treated base sections. This suggests that it is possible to estimate the deflection level of a particular roadway by means of radius of curvature measurements.

Another phase of the study involved visual inspection of mainline AC pavements which have been constructed since 1961 and have been in service at least three years. The purpose was to evaluate present design standards and accumulate detailed information related to the effectiveness of construction methods and materials used in highway construction throughout the State of California. To gain information on different projects, District Maintenance Engineers and Area Maintenance Superintendents were first contacted and requested to report unusual or early distress which was occurring on individual roadways. On projects where early distress was evident, an engineer from the Materials and Research Department made a field review which included photographs and condition surveys. From this, test programs were planned. If fatigue cracking was observed, deflection measurements would then be obtained over representative test sections in cracked and uncracked areas. Detailed crack surveys and rut depth measurements were to be made and AC core samples and samples of the other elements of the structural section would be obtained for testing.

Generally about 20 projects were to be reviewed each year but only three or less were actually tested. A log of projects was kept and reviewed on an annual basis as new project were added. If failures developed, testing would be initiated. Thus far, (1968) only a few projects have been tested as early failures were more or less nonexistent.

Conclusions

1. Contrary to the findings presented in the 1966 interim report, deflection levels continue to decrease after the pavement has reached an age of four years. This is presumably due to additional aging of the AC surfacing and additional traffic compaction. However, the rate of decrease in deflection level is considerably less than that of the first four years. Increases in deflection level are suggested in areas of block cracking where additional moisture has entered the structural section.

2. Preliminary computer analyses during this interim period of data from one test section from each of five of the Traffic Index-Deflection projects suggest that accumulative 5,000 pound equivalent wheel loadings are the most significant variable in predicting distress, second is the hardness of the recovered asphalt binder in terms of penetration, and third, the pavement deflection.

Publication No. 5 - Test Method No. Calif. 356 (April 1969)

This was the first publication of the overlay design method "Method of Test to Determine Overlay and Maintenance Requirements by Pavement Deflection Measurements".

Scope of Test Method

This test method describes the use of four pavement deflection measuring devices and the procedures used for determining overlay requirements for existing asphalt concrete roadways by deflection analyses. Basically, the method consists of measuring the total pavement deflection resulting from the application of a 15,000 pound single axle load (7,500 pound dual wheel load). The deflection readings are then compared to previously determined allowable limits for a similar structural section and traffic volume in terms of equivalent 5,000 pound wheel loads. Corrective treatment is described as the cover (thickness of overlay material) required to reduce the deflection to a level at which the surface will be unlikely to fail due to fatigue. This cover is expressed in thickness of gravel equivalence and the actual required thickness of asphalt surfacing is determined by the use of gravel equivalent factors of the specific materials to be used.

Publication No. 6 - Overlay Design Using Deflections (August 1970)

This report was written for presentation at the western summer meeting of the then Highway Research Board in August 1970. The report contained a summary of the background information pertaining to the development of the overlay design method. A review of the development of deflection equipment was also included. The use of the pavement evaluation system was explained in some detail with examples. The factors to be considered for a satisfactory design were discussed.

A method for determining the K-values of an existing bituminous roadway from deflection measurements was developed and included in this report. The method was developed from the correlation study made by the Canadian Good Roads Association between Benkelman beam deflection measurements under an 18,000 pound single axle load and plate bearing tests.

Conclusions

1. The satisfactory results of designs for overlays, based upon deflection measurements, for approximately 400 roadways, have indicated the value of pavement deflection as a tool for designing overlay thickness.

2. Experience has shown that other factors such as drainage, traffic and type of distress must also be evaluated in an overlay design.

3. A correlation was found between the California Deflectometer and Canadian Good Roads Association static deflection measurements.

4. A method for determining the K-value of an existing bituminous roadway from deflection measurements has been developed. This allows for the design of a portland cement concrete overlay using existing design formulas.

Publication No. 7 - Structural Overlays for Pavement Rehabilitation (July 1974)

Comprehensive deflection research programs have been in progress in California since 1951. Results and conclusions were first published in 1955. Tolerable deflection levels for various pavement thicknesses were first established at that time. Using this data and fatigue tests in the laboratory on specimens cut from various AC pavements, the then California Division of Highways developed test Method No. Calif. 356 as its pavement overlay design method. Since 1960 this test method has been utilized for the overlay design of approximately 450 roadways. This report explains the modifications made to the design method through additional research and refinements.

Deflection reduction characteristics and tolerable deflection levels of asphalt concrete were revised based on the performance of highway projects under study since 1960. Deflections were measured with the California Deflectometer. Most of the deflection measurements were taken during the spring or early summer when the moisture content in the roadbed is high and the temperature moderate. This was done to minimize the error caused by a change of moisture content in the roadbed, and to base the overlay design on the worst condition the pavement structural section would be in during a given year.

This study showed the previously developed tolerable deflection values for AC thicknesses of 0.20 and 0.30 foot were substantially verified by experience for California conditions. However, thicker AC pavements of 0.40 and

0.50 foot were found to be able to tolerate more deflection than originally established. Because of this study, the tolerable deflection for 0.50 foot AC section was increased by 20 percent.

A comparison of predicted versus measured deflections was made of 69 projects where deflection measurements were taken before and after reconstruction. Predicted deflections compared favorably with the measured deflections. The collected data also indicated that the reduction in deflection is dependent on the initial deflection before placing an overlay.

Conclusions

1. On 69 overlay projects the design method's predicted deflection compared favorably with the measured deflection. The coefficient of correlation is 0.90 and the standard error is 0.004 inch.

2. Our previously developed tolerable deflection values for overlays between 0.20 and 0.30 foot (61 and 91 mm) thick have been substantially verified by experience for California conditions while about a 20 percent increase in tolerable deflection is justified for a 0.50 foot (152 mm) thick AC overlay.

3. For a given AC overlay thickness, the amount of the reduction in deflection is dependent on the initial deflection before overlay placement.

4. The revised tolerable deflection curves and the deflection attenuation curves have been combined to produce a design guide for AC overlays. Use of this design guide rather than a trial and error process involving values picked from two charts greatly simplifies the method of selecting overlay thicknesses. The revised overlay design test method was published in April of 1975.

<u>Publication No. 8 - Experimental Overlays to Minimize Reflection Cracking (September 1976)</u>

The potential problem of reflection cracking may be the controlling factor when determining the thickness of an asphalt concrete (AC) overlay for existing asphalt concrete or portland cement concrete (PCC) pavements. At present, rule of thumb procedures are used to determine AC overlay thicknesses when the governing criterion is reflection cracking. The thicknesses required to prevent excessive reflection cracking are substantial and usually range from 0.25 foot upward for California climatic conditions.

Previous efforts to prevent reflection cracking have been mainly concerned with paving over PCC surfaces, and a number of methods have been field tested. Since 1971 research has been conducted on experimental asphalt concrete overlays to minimize reflection cracking. An evaluation of various methods and systems was made to determine their effectiveness in reducing reflection cracking in bituminous overlays. The purpose of this interim report was to present information on the construction of the experimental overlay projects and to report on their performance to date.

Experimental overlays were constructed on eight projects at various locations throughout the State. Table 2 shows a summary of the project locations and the systems and/or materials tried. Detailed crack surveys of the test sections were made prior to the pavement being overlaid and control sections were established during the construction phase. Climatic conditions for each project were noted. At various intervals after construction condition surveys were conducted for evaluation purposes by comparing the performance of the test sections with the established control areas.

As of this interim report (September 1976) significant differences on many test sections had not developed. However, experience to date did reveal that the Petromat fabric, while not always a benefit, would extend the useful life of an overlay in some areas of the State on pavements originally exhibiting hairline to 1/8-inch wide alligator-type cracking. Asphaltic emulsions were found to be less desirable as a tack coat for fabrics due to the delay caused by the period of time required for the emulsion to "break". Asphalt cement, AR2000 or AR4000 viscosity grade, is best suited for the tack coat with an application rate of about 0.25 gallon per square yard but no less than 0.20 gallon per square yard.

The emulsion slurry seal, rubberized slurry seal and Petroset did not effectively reduce reflection cracking in these tests.

TABLE 2

TEST SECTIONS

PRO-JECT NO	DIST., CO., RT.	GENERAL LOCATION	CNSTR. DATE	TYPE. OF EXIST. SURF. & CRACKING PATTERN	CONTROL SECTIONS		REFLECTION CRACKING RETARDING METHOD OR SYSTEM									
1	02-Los-395 29.8/31.8 50.6/51.2 02-Los-36 SUSANVILLE	DOYLE	AUG. 1972	AC SURF SEVERE MAP & BLOCK CRACKING	0.08' AC	0.20 AC	0.08' AC + STRESS RELIEVING INTERLAYER (SRI)	0.08' AC + EMULS SLURRY SEAL (ESS)	PETROSET "AT" EMULS. ON 0.08' AC	0.08' AC + PETROMAT	0.08' AC + PETROLASTIC CRACK SEALER ON 0.30 GP/SY RS-2	"RECLAMITE" EMULS. ON 0.08' AC				
2	03-Pla-80 31.3/33.2	COLFAX	JUL 1974	AC SURF LONG. & TRANS CRACKS (CTB BASE)	0.20' AC	0.30' AC			PETROSET "AT" EMULS. ON 0.20' AC	0.20' AC+ PETROMAT			INVERT OVERLAY 0.1' OG.AC + 0.1' DG.AC	INVERT OVERLAY 0.1' OG.AC +0.2' DG.AC		
3	05-Slo-101 8.0/12.2	ARROYO GRANDE	SUMMER 1972	AC AND PCC PVTS. LONG. & TRANS. CRACKS									INVERT OVERLAY ON AC & PCC 0.06' OG.AC +0.30' DG.AC			
4	06-Ker-43 0.1/8.0	BAKERSFIELD	FALL 1972	AC SURF "ALLIGATOR" CRACKING										HEATER REMIXING & RECLAMITE+ AC BLANKET		
5	07-LA-1 3.4/8.3	LONG BEACH	JAN 1973	AC. SURF. "ALLIGATOR" CRACKING PCC TRANS. & LONGI. CRACKS	0.15' AC	0.20' AC				0.10', 0.15', 0.20' AC OVER PETROMAT						
6	08-Riv.-15 28.0/28.5	RIVERSIDE	SEPT 1972	AC SURF. "ALLIGATOR" CRACKING	0.08' AC	0.35' AC				(0.08' AC+ PETROMAT) (0.35 AC+ PETROMAT)						
7	11-SD-78 7.5/15.6	VISTA	DEC 1972	AC SURF. "ALLIGATOR" CRACKING	0.08' AC				PETROSET "AT" EMULS. ON 0.08 AC	(0.08' AC+ PETROMAT) (1 SECTION PETROMAT+ PETROSET ON AC)		"RECLAMITE" EMULS. ON 0.08' AC				
8	11-Imp-115 22.0/23.9	BRAWLEY	SPRING 1974	AC SURF. BADLY "ALLIGATOR" CRACKED	0.20' AC	0.35' AC				(0.10' AC+ PETROMAT) (0.20' AC+ PETROMAT)						RUBBERIZED CHIP SEAL

Conclusions

Significant differences on many test sections have not developed because of the short test period, but the following conclusions appear warranted:

1. To date, the additional 0.12 foot AC placed in conjunction with a 0.08 foot maintenance blanket in one of the sections is performing better than the other experimental test sections on the 02-Las-395 project. It has extended the life of the overlay by more than two years.

2. Based on performance to date, the life of a 0.08 foot AC overlay has been extended more than two years on projects 08-Riv-15 and 11-SD-78 by placing Petromat with the overlay on pavements that exhibited alligator cracks less than 1/8-inch wide.

3. The emulsion slurry seal, rubberized slurry seal, and Petroset did not effectively reduce reflection cracking on project 02-Las-395.

4. Asphalt cement, AR2000 or AR4000 viscosity grade, is best suited for a tack coat when installing Petromat to avoid a time delay caused by waiting for an emulsion to break, especially during cool weather and during the early morning.

5. Problems were encountered during construction with Petromat, Cerex, and rubber slurry seals when the overlay was placed by windrowing the AC material. The heat of the stockpiled material, equipment pushing and shoving, and paver pickup caused problems in keeping the materials in place.

6. Cerex, a spun-bonded nylon product manufactured by Monsanto, Inc., could not be satisfactorily placed with a windrow paver operation and an RS-2 emulsion (02-Las-395 project).

7. Test installations of Petromat fabric on each of four project locations in California show that the test sections are thus far performing better than the adjacent control sections of equal AC overlay thickness without Petromat. The four projects are:

a) 02-Las-395-29.8/31.8
b) 02-Las-395-50.6/51.3
c) 08-Riv-395(temp. I-15)-28.09/28.53
d) 11-SD-78-7.5/15.6

8. The following tentative criteria appear to contribute significantly to the performance of Petromat fabric when used in conjunction with AC overlays:

a) Perform crack sealing on all cracks over 1/4-inch wide. Poor performance was noted when cracks greater than 1/4-inch wide were not sealed prior to placement of a tack coat and Petromat.

b) About 0.25 gallon per square yard of AR2000 or AR4000 paving grade asphalt should be placed as a tack coat prior to the Petromat installation. Our experience to date has revealed that poorer performance was obtained when application rates of less than 0.20 gallon per square yard were used. We found asphaltic emulsions to be less desirable as a tack coat because of the time delay referred to in finding No. 4, above.

c) While some minor wrinkling of the fabric is unavoidable, folding of the Petromat should be avoided during the placement. It appears that excess fabric in one fold (three layers of material) tends to allow rapid development of a crack immediately over a fold, especially in thinner AC overlays.

PHASE II - EVALUATION OF THE VARIABLES OF TRAFFIC VOLUME, DEFLECTION LEVEL AND ASPHALT PROPERTIES ON THE PERFORMANCE OF ASPHALT CONCRETE (1964 TO 1978)

Evaluation Program

Between 1959 and 1967 eighty-three test sections were established on twenty-four newly constructed roadways at various locations throughout the State. Projects were chosen after construction began rather than setting up 'pre-selected' test sections to assure routinely constructed projects. This approach was used to avoid delays in getting the program started.

Field testing included pavement deflections, cores to determine asphalt properties, condition surveys (crack counts), and maintenance history. The test data for each project are shown in Tables 3 to 24. Pavement deflections were first measured in 1964 and each year thereafter for approximately the first seven years. The frequency was then reduced to every other year until about 1975. Three different deflection devices were used to measure pavement deflections on the various projects. Deflections were measured with the Benkelman beam and the first California Deflectometer until about 1968. After 1968 and until the end of the study a second generation deflectometer was used (see Appendix A - History of Pavement Deflection Equipment). All measured deflections were converted to our current standard (Deflectometer with 18,000 pound axle load) prior to evaluation. Asphalt concrete cores were first taken on the various projects approximately two to four years after completion. Additional cores were taken every other year until about

1972. The following laboratory tests were performed on the recovered asphalt concrete material: specific gravity, cohesion and modulus or rupture. Tests on the recovered asphalt included penetration, softening point, ductility and percent asphalt.

Roadway condition surveys (crack counts) were taken on the various projects at the same time as deflections were measured. Transverse, longitudinal, and block or alligator cracks were plotted for each project. The majority of the test sections were 1000 feet long.

The traffic data (cumulative EAL's) were determined from data collected by special traffic counts by the Districts and traffic information compiled and published by the Caltrans Traffic Department.

DATA ANALYSIS

To determine a performance standard for the various projects, the number of years to 10 percent block cracking (entire lane) or 10 percent alligator cracking (wheelpaths only) was selected. It is generally acknowledged that when load associated cracking develops to this extent, it is serious enough that some form of rehabilitation is warranted. Projects investigated on this study were generally new construction with structural sections for each project determined from the estimated total number of equivalent 18,000 pound single axle loads for each project.

Of the original twenty-four projects investigated on this study, two projects were discontinued due to realignment of the roadway. Of the remaining 22 projects three projects lasted 6 to 8 years prior to 10 percent cracking, 10 projects lasted 9 to 12 years prior to 10 percent cracking and 7 projects lasted 13 to 15 years prior to 10 percent cracking.

Obviously there are many factors that influence the number of years a flexible pavement will last before corrective treatment is needed. Some of these are: structural section design; quality of construction materials, construction techniques, traffic loadings, and environmental factors. The projects selected on this study were from various locations throughout California; however, none of the locations represented extreme climatic conditions, such as mountainous or desert regions. Our data analysis for this study will mainly be confined to comparing roadway performance to (1) pavement deflections, (2) asphalt properties and (3) traffic loadings.

Deflections

Tolerable deflections were determined for the data presented in Tables 3 to 24 using Figure 17, Appendix B. These values were then plotted on the deflection charts in Tables 3 to 24.

It has long been established that the magnitude of deflections and traffic volume (tolerable deflection criteria) influences the longevity of a pavement. To determine the extent of this postulate for the projects studied, a decision tree was established that disregarded the influence of asphalt properties and the original design life (Figure 1).

Again, the criteria of 10 percent cracking (block or alligator) was selected as the point where pavements should be considered for corrective treatment. The projects were isolated into the four categories established and their performance determined (Table 25). As shown in the table, 73 percent of the projects supported the theory and 27 percent did not. It is important to note the best performance was achieved by the projects where deflections were less than tolerable levels, and block or alligator cracking was less than 10 percent. The average life of these projects was 13.7 years. It should also be pointed out that there were no projects that fell into column 3, that is, projects where deflections exceeded tolerable levels, but cracking did not develop. On the projects where deflections exceeded tolerable levels, an average performance life of 10.9 years was obtained.

On the projects investigated, it was observed that one percent block or alligator cracking occurred an average of 9.2 years after completion of each project. Ten percent block or alligator cracking was obtained an average of 2.5 years later, indicating that once cracking starts to develop, the process accelerates.

Asphalt Properties

Asphalt properties are an integral part of the performance of any flexible pavement. Asphalt pavements, no matter how well designed and constructed, will not last forever; the asphalt binder eventually hardens, and cracks will develop. A problem in studying pavement performance is to distinguish between load associated asphalt cracking (fatigue cracking) and cracking resulting from shrinkage or thermal stresses that may be influenced by asphalt properties.

In an attempt to determine the relationship between asphalt properties and performance, cores were taken periodically on the various projects. Twelve-inch cores were sectioned to obtain specimens suitable for modulus of rupture tests. Cohesion tests were performed on four-inch diameter cores using the Cohesiometer. Asphalt recovered by the Abson process was tested for penetration at 77°F, softening point, and ductility.

The paving grade asphalt used on the projects was from various production sources and crude sources available in California.

Monismith (6) in his original studies on fatigue of asphalt concrete mixes used the modulus of rupture test to determine failure. He found that the modulus decreased as he continued to fatigue his specimens. Therefore, it was decided to further study this finding in the field by measuring the modulus at various intervals of time. On the basis of Monismith's results, a decrease in modulus should indicate that the fatigue life of the pavement was being approached and large scale cracking could be expected to develop.

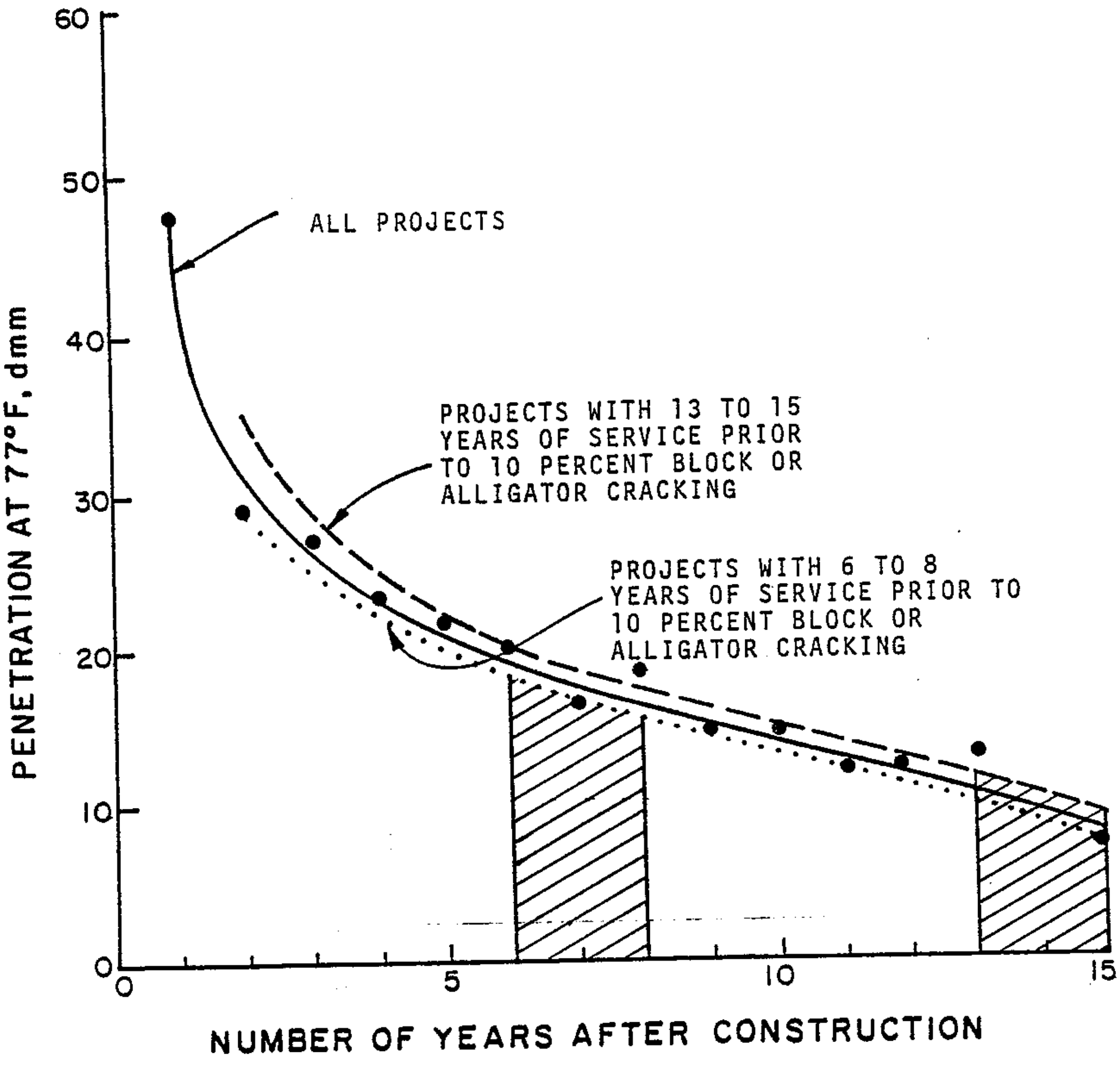
The recovered asphalt penetrations for any specific project when plotted against service time produced the normal curve of relatively rapid drop in the first thirty months and a lower decreasing rate thereafter. Therefore, the penetrations for all the projects were averaged and are shown in Figure 2. This chart also shows the average curves for projects with 13 to 15 years of service compared to 6 to 8 years service for equivalent amounts of alligator or block cracking. Although the difference in penetrations between the two curves is not very great, it is significant that the curves fall in the expected order. It is interesting to note that for equivalent amounts of cracking, pavements having 6 to 8 years service had a penetration range of approximately 15 to 18 but the projects having 13 to 15 years service had a penetration range of approximately 9 to 11. This observation clearly indicates the importance of the "destructive factor"* in the service life of the pavement. It appears that even ralatively small changes in penetration below 20 may have an important effect on the amount of fatigue cracking if deflections are about the same. There is some confirmation in these results for the continuing statements in the literature that when the penetration of the asphalt in a pavement is reduced to 20 or less and the ductility is also reduced, a "critical" state is reached. The extent of cracking will then depend on the magnitude of the destructive factor at this point in the service life.

Figure 3 presents the increase in average softening point readings for the various projects. The results confirm the findings for penetration reductions. However, one notes that the projects having only 6 to 8 years of service life before acquiring 10 percent block or alligator cracking have definitely higher softening points then corresponding projects having an average of 13 to 15 years service life before cracking reached 10 percent. Shear susceptibility determinations were not made on these samples, but the definitely

"*destructive factor" (in feet) = EWL's for given period multiplied by the average deflection in inches for the same period.

Figure 2

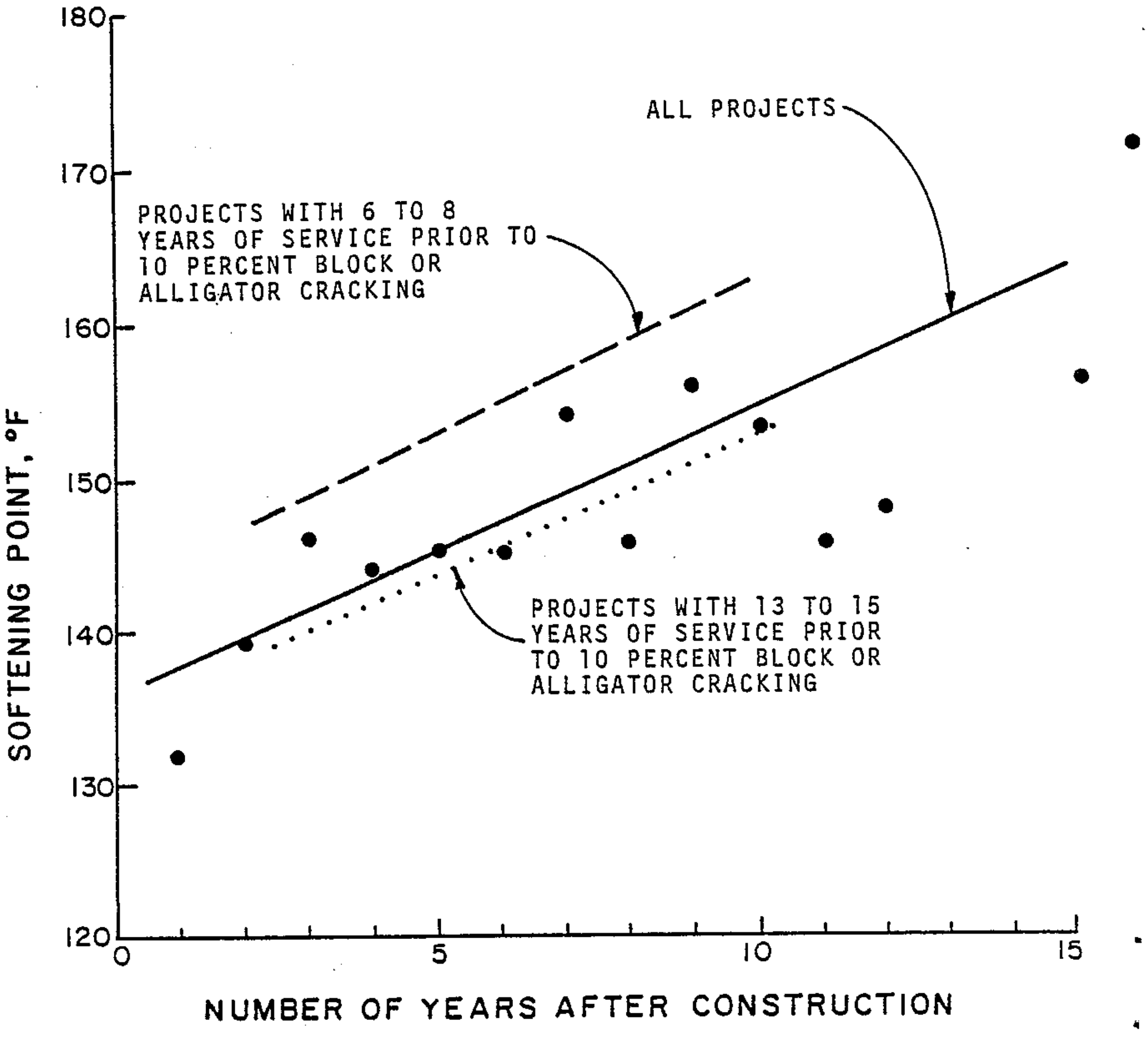
PENETRATION VERSUS TIME



● Average penetration value for all projects

Figure 3

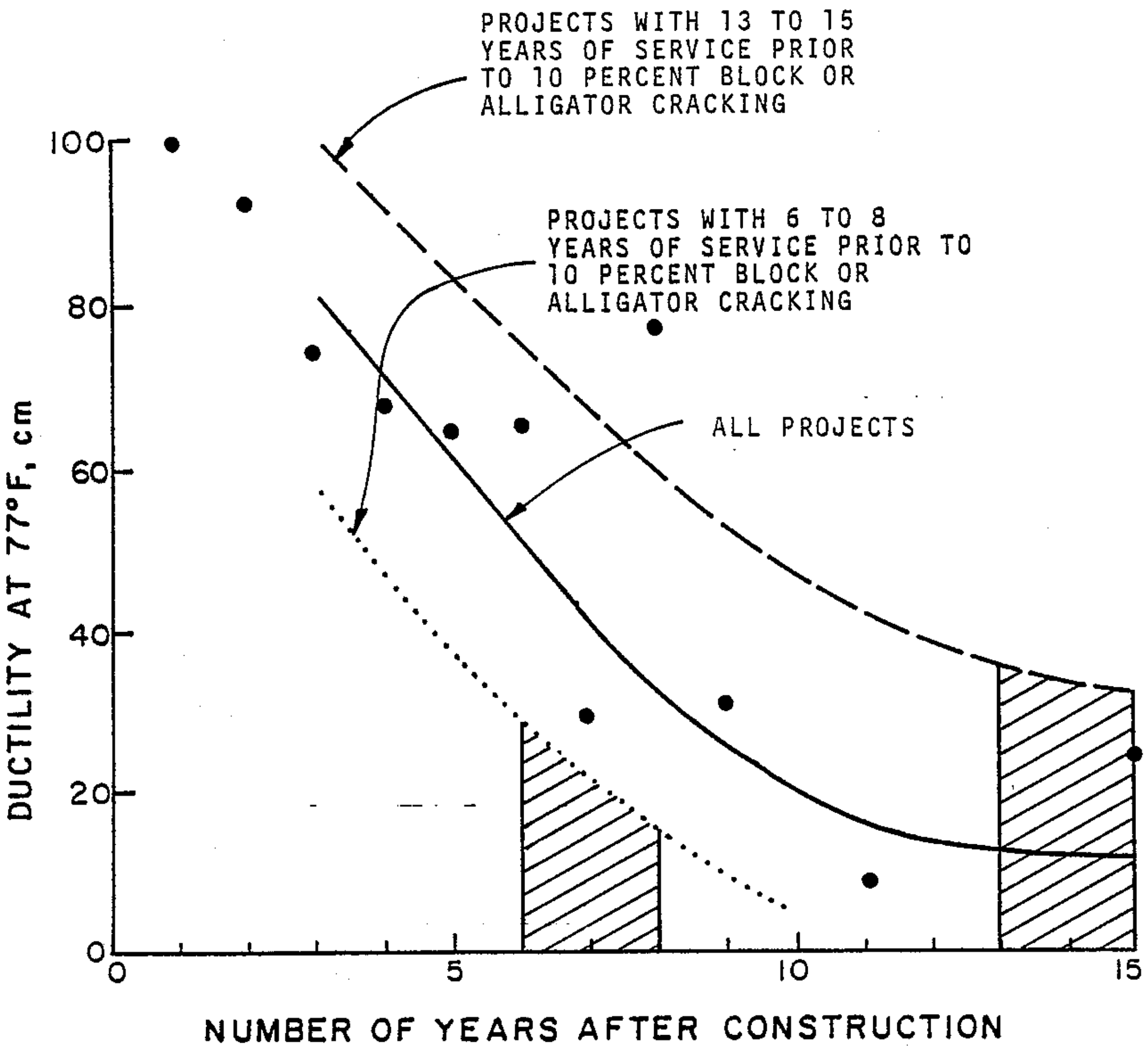
SOFTENING POINT VERSUS TIME



● Average softening point value for all projects.

Figure 4

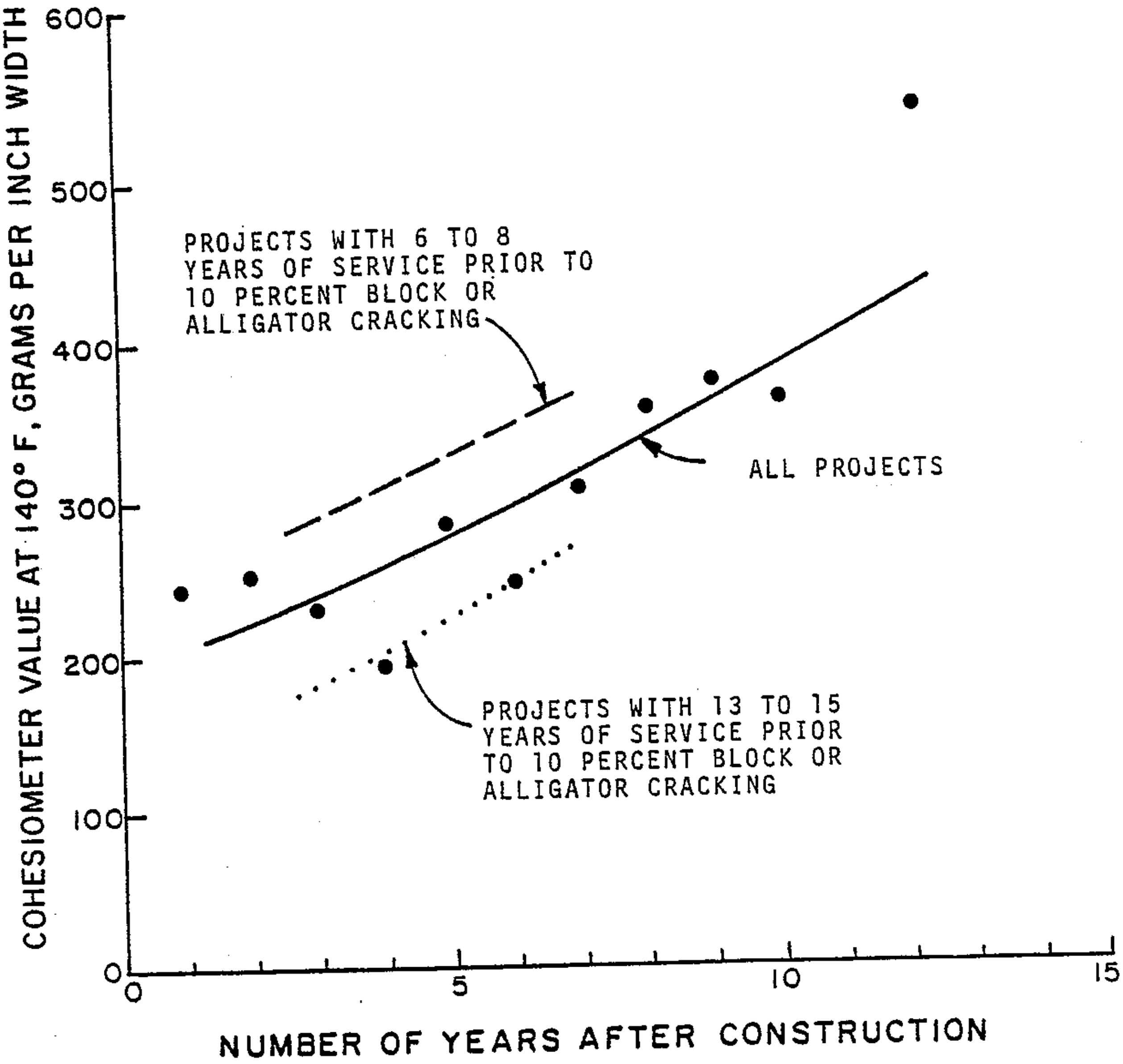
DUCTILITY VERSUS TIME



● Average ductility value for all projects

Figure 5

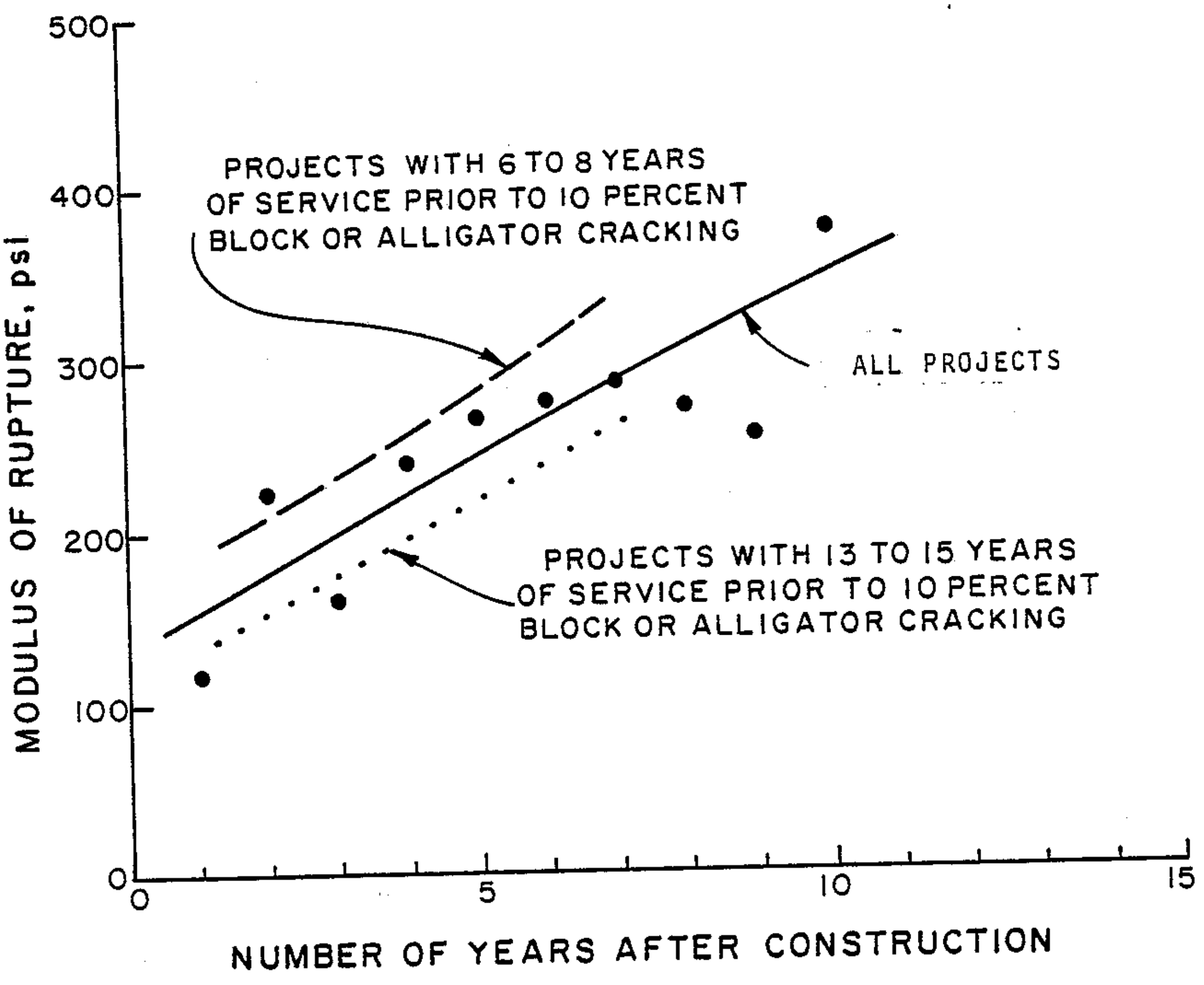
COHESION VERSUS TIME



● Average cohesion value for all projects

Figure 6

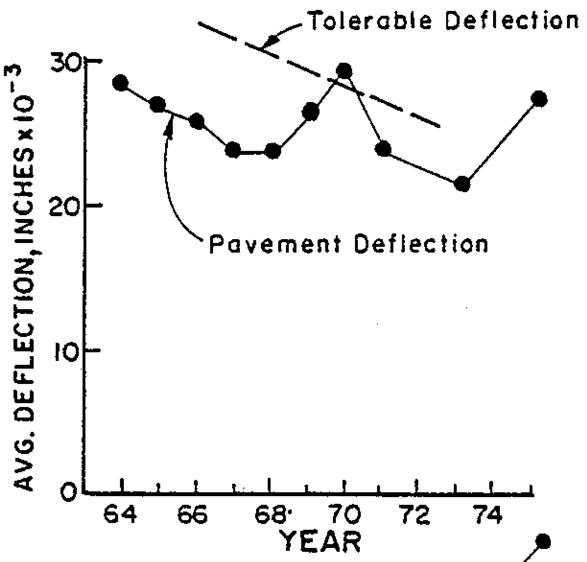
MODULUS OF RUPTURE VERSUS TIME

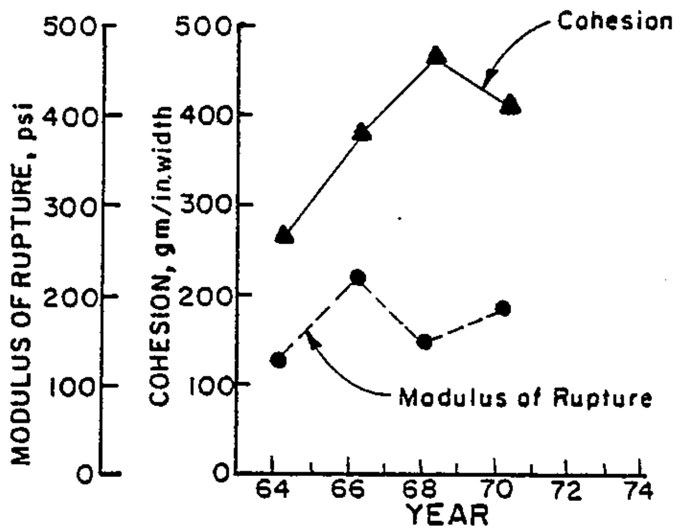


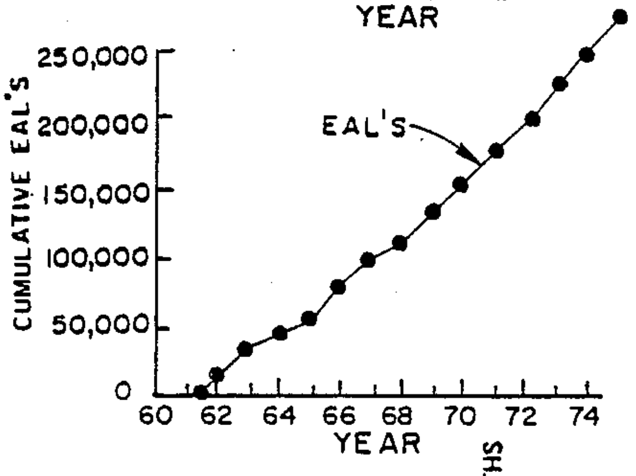
● Average modulus of rupture value for all projects.

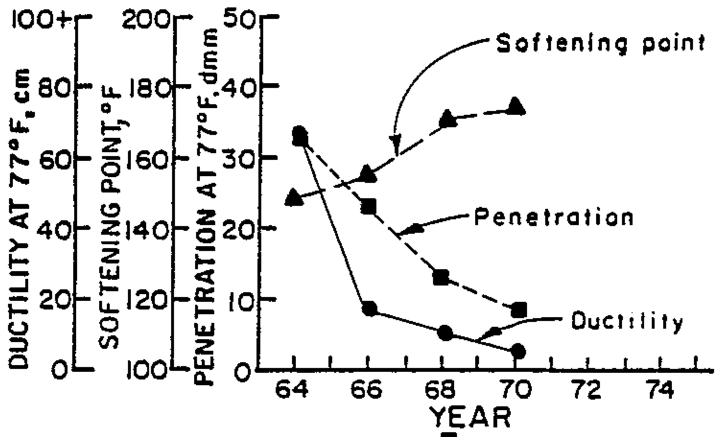
TABLE 3

PROJECT: I (03-Col-45)
CONTRACT NO: 61-3T13C20
TEST SECTION: P.M. 13.4 to P.M. 17.6 (Near Grimes)
STRUCTURAL SECTION: 0.25'AC, 0.50'AB, 0.83'AS
COMPLETION DATE: 9-6-61









NOTES

T.I. ≈ 7.0 (1970 Data)

Tolerable Deflection = 0.028". Deflections were greater than this in 1970. Alligator cracking accelerated rapidly after 1970.

1976 Maintenance Rating System shows 60% alligator cracks.

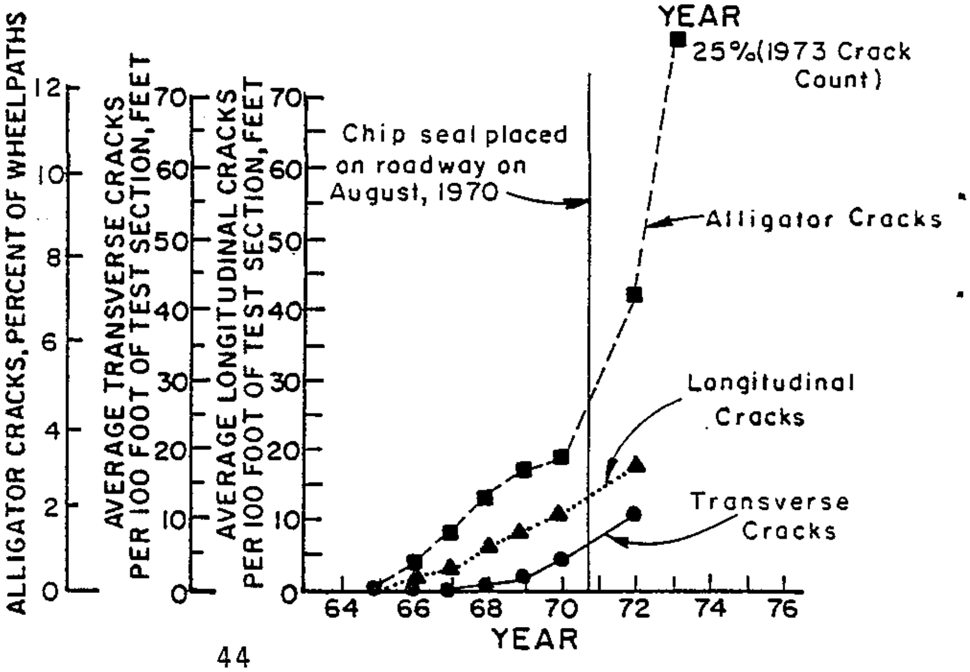
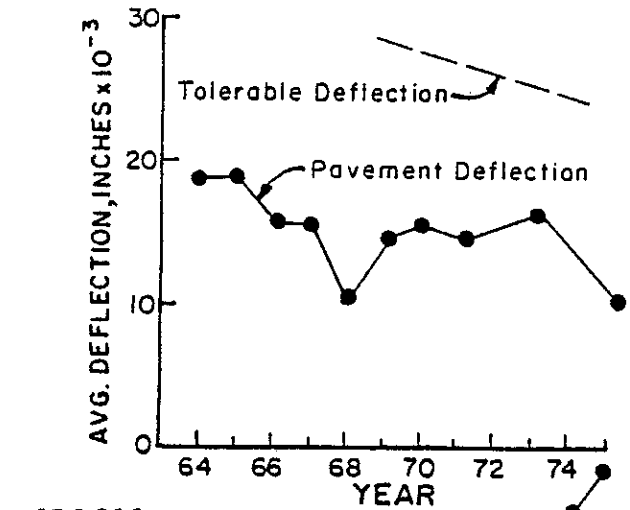
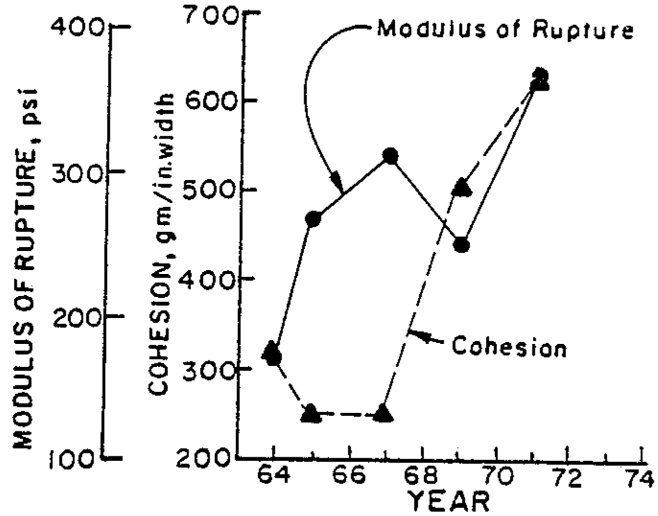
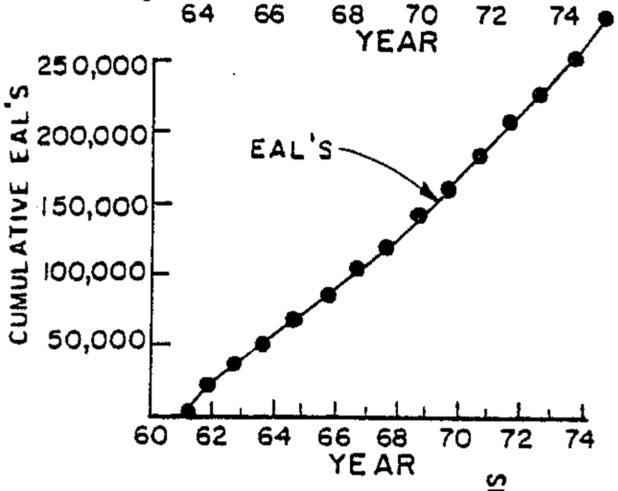


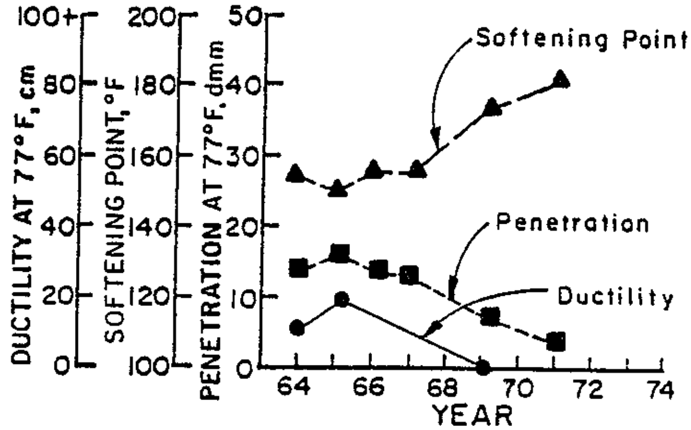
TABLE 4

PROJECT: 2 (03-Gle-162, 45B)
CONTRACT NO: 60-14TC22 F
TEST SECTION: P.M. 9.65 to P.M. 10.87
STRUCTURAL SECTION: 0.25'AC, 0.50'AB, 0.75'AS
COMPLETION DATE: 6-5-61









NOTES

T.I. ≈ 7.5 (1973 Data)

Tolerable deflection = 0.027".

Based on 1974 condition survey from Maintenance Rating System, there was no significant alligator cracking.

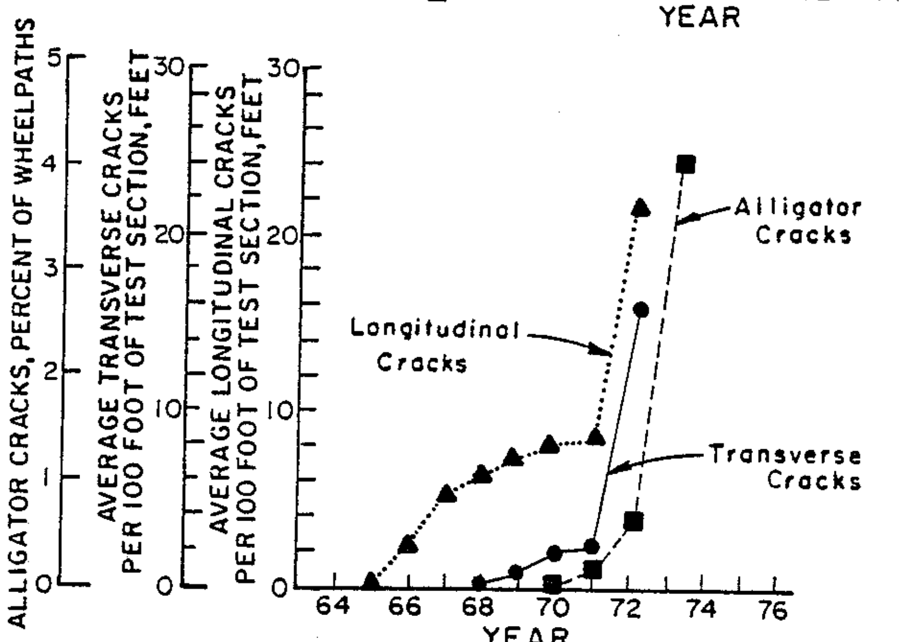
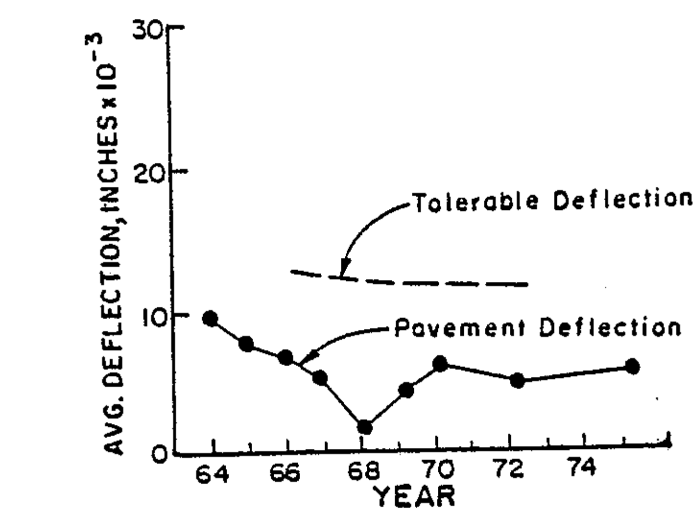
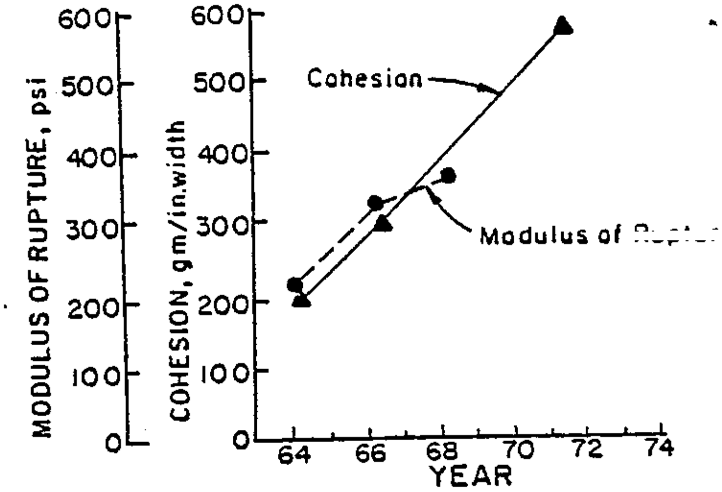
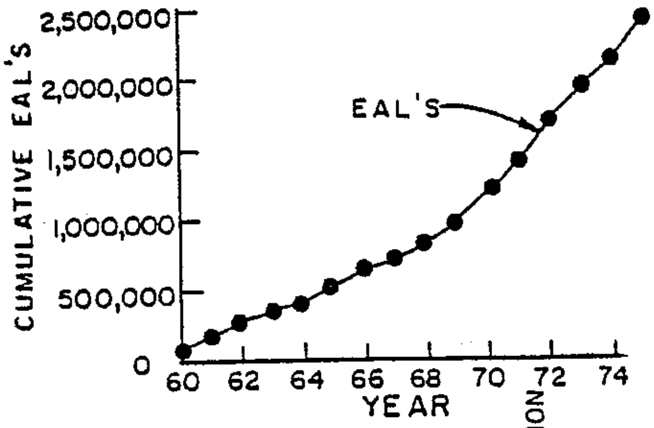


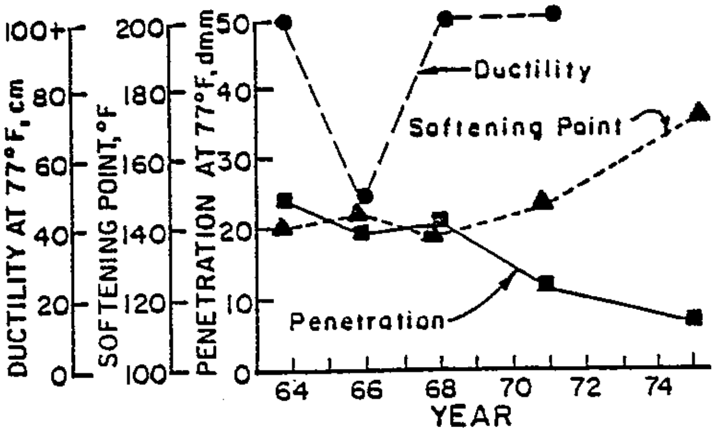
TABLE 5

PROJECT: 4A (03-Sac-99, 232 A)
CONTRACT NO: 60-3TC-20
TEST SECTION: P.M. 27.0 to P.M. 36.8
STRUCTURAL SECTION: 0.05' OGAC, 0.25' AC, 0.67' CTB, EXIST. PAV'T.
COMPLETION DATE: 10-22-59









NOTES

T.I. ≈ 9.0 (1970 Data)
Tolerable deflection = 0.012"
One inch A C overlay placed during the spring of 1968

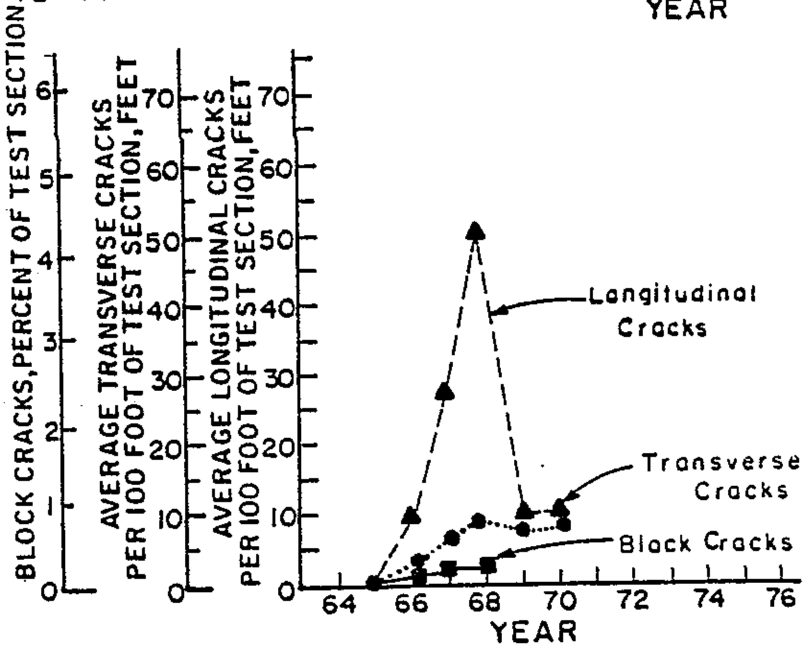
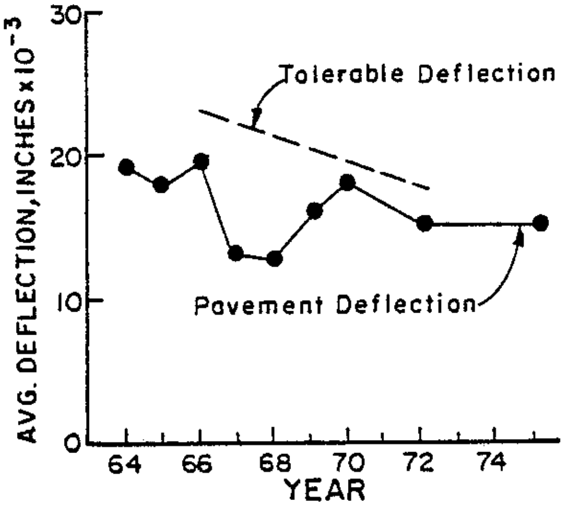
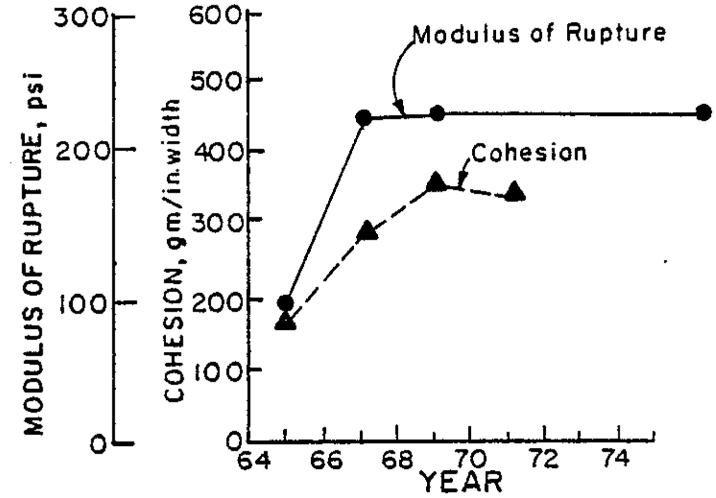
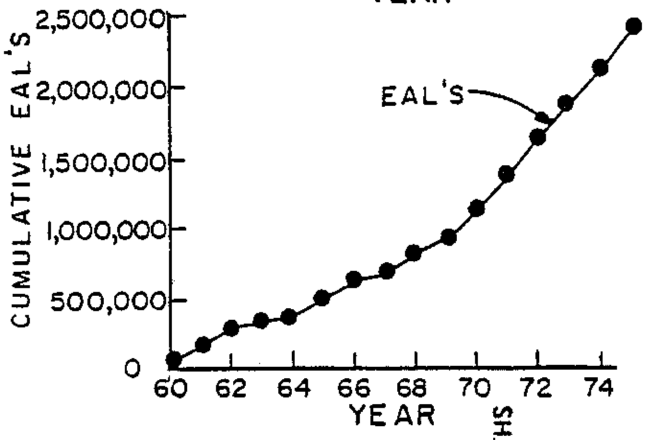


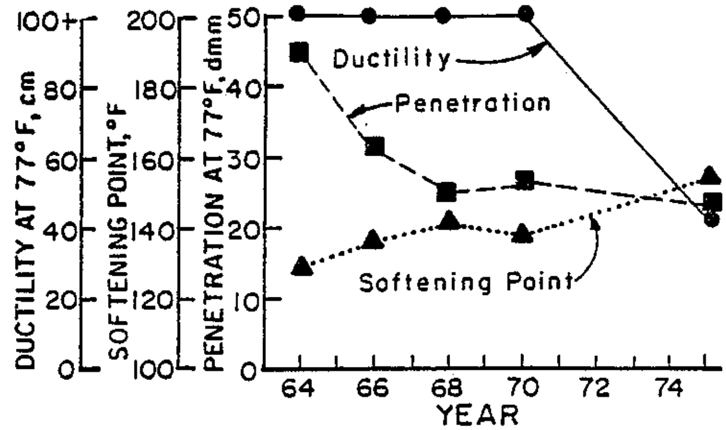
TABLE 6

PROJECT: 4B(03-Sac-99, 232 A)
CONTRACT NO: 61-3TC9
TEST SECTION: P.M. 27.0± to P.M. 36.8±
STRUCTURAL SECTION: 0.05' OGAC, 0.25' A C, 0.25' ACB, 0.50' AB, EXIST. PAV'T
COMPLETION DATE: 9-23-60





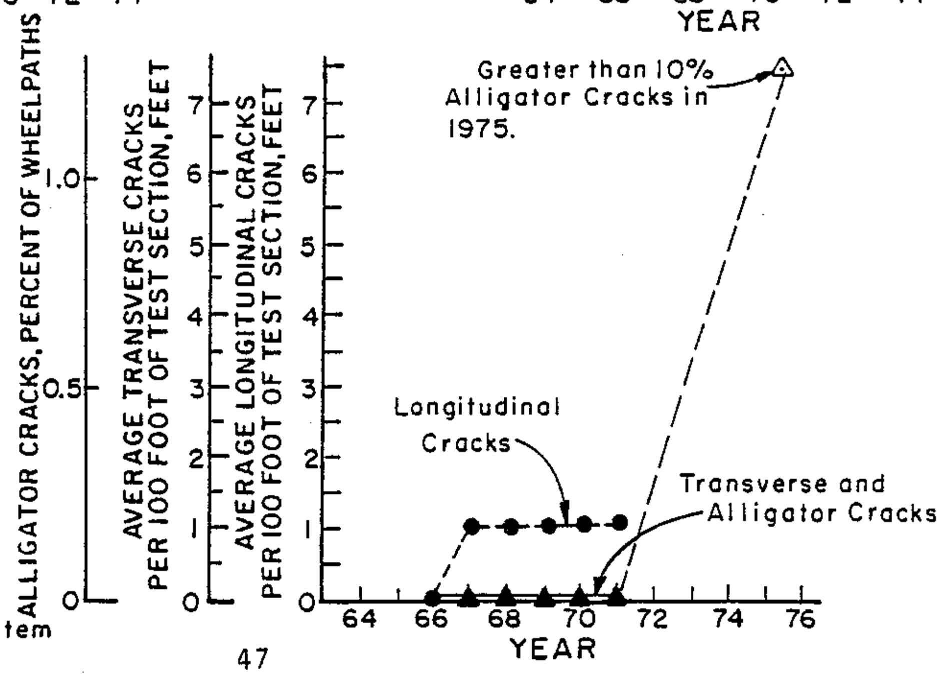




NOTES

T.I. ≈ 9.0 (1970 data)

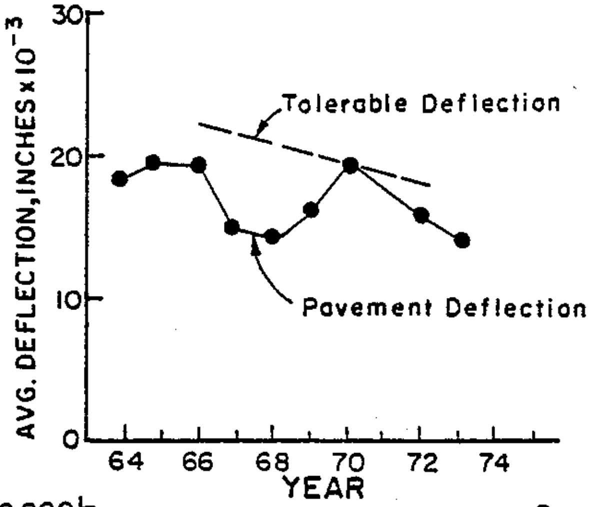
Tolerable Deflection = 0.014"

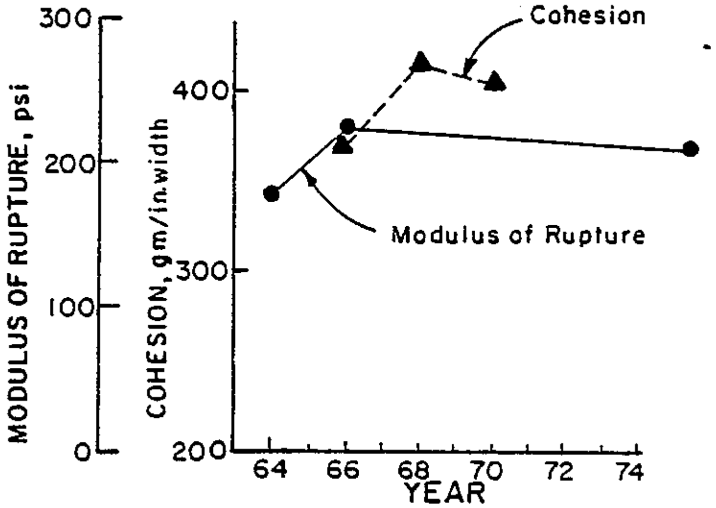


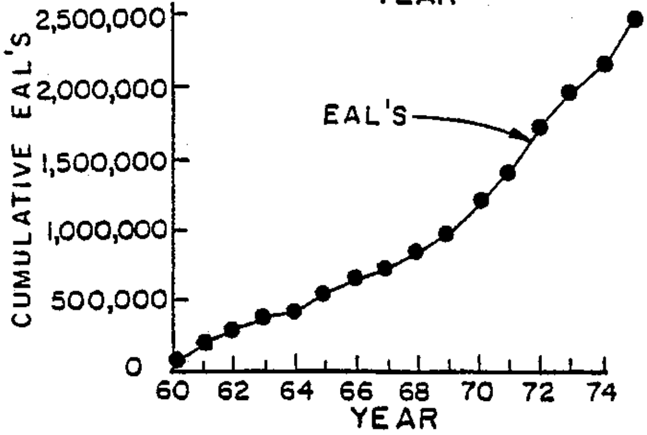
Δ - Maintenance Rating System

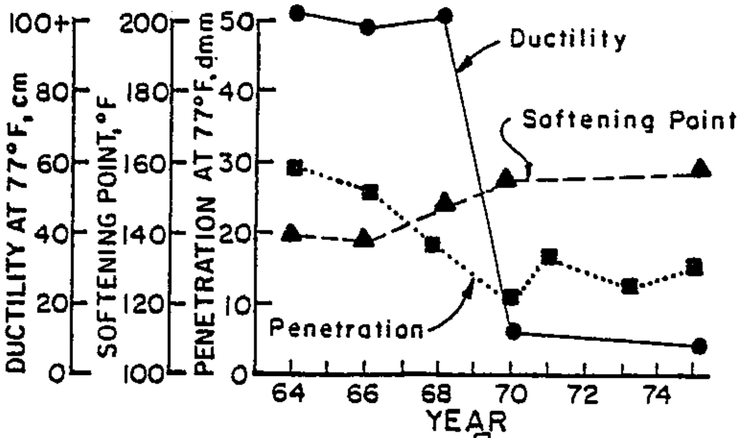
TABLE 7

PROJECT: 4C (03-Sac-99, 232 A)
CONTRACT NO: 61-3TC9
TEST SECTION: P.M. 27.0± to P.M. 36.8±
STRUCTURAL SECTION: 0.05' OGAC, 0.25' AC, 1.00' AB, EXIST. PAV'T.
COMPLETION DATE: 9-23-60









NOTES

T.I. ≈ 9.0 (1970 data)
Tolerable deflection = 0.020".
Alligator cracking started in 1970.
Deflection study requested by the District in 1972 (This section was failing).

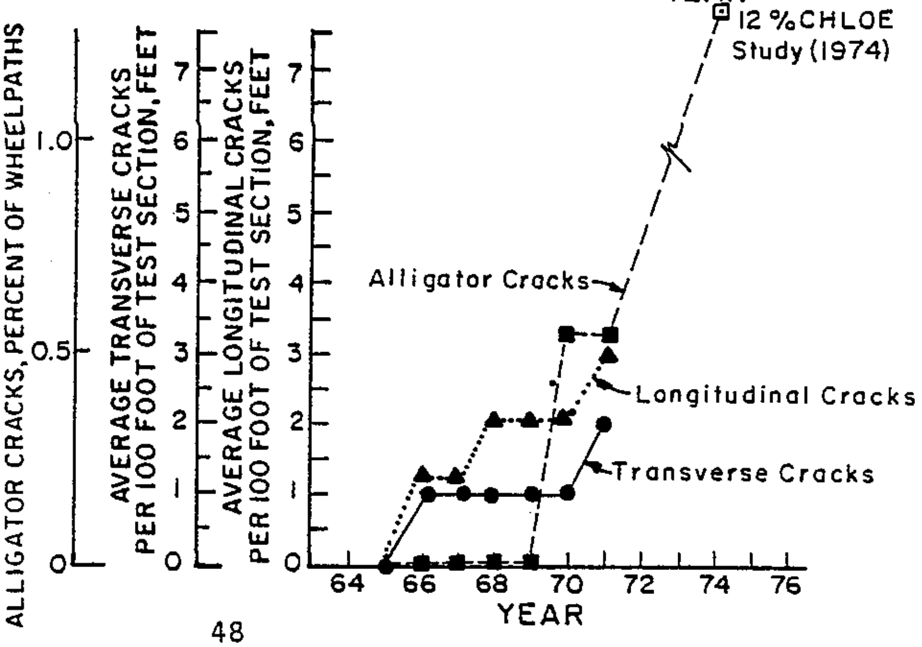


TABLE 8

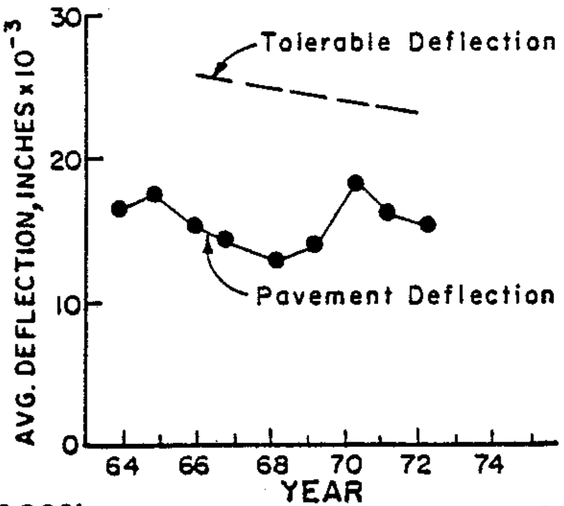
PROJECT: 5 (03-Yol-99.84)

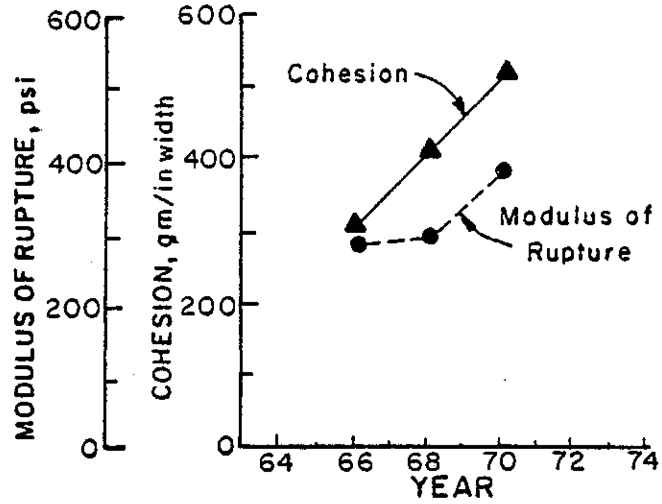
CONTRACT NO: 61-3T13C31

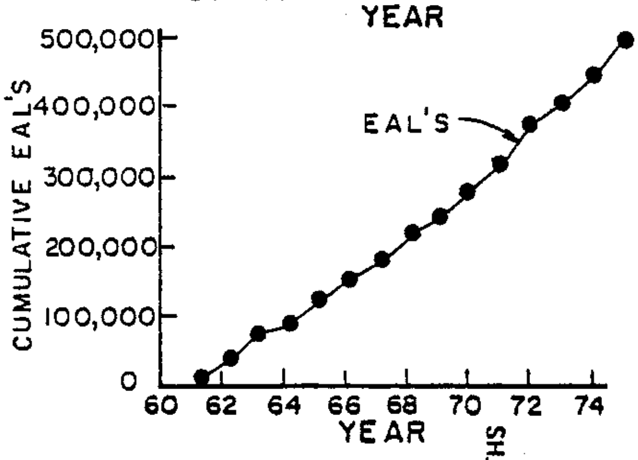
TEST SECTION: P.M. 18.0± to P.M. 21.8±

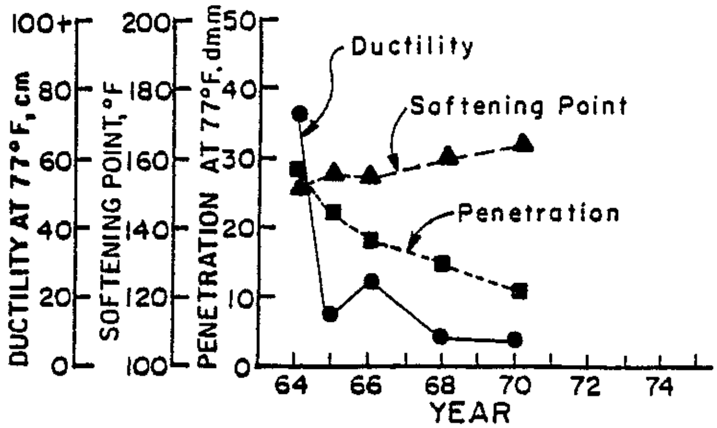
STRUCTURAL SECTION: 0.29'AC, 0.50'AB, 1.17'AS

COMPLETION DATE: 4-27-61









NOTES

T.I. ≈ 7.5 (1970 Data)

Tolerable deflection = 0.024". Although mean deflections were below tolerable values, alligator cracking accelerated from 1970.

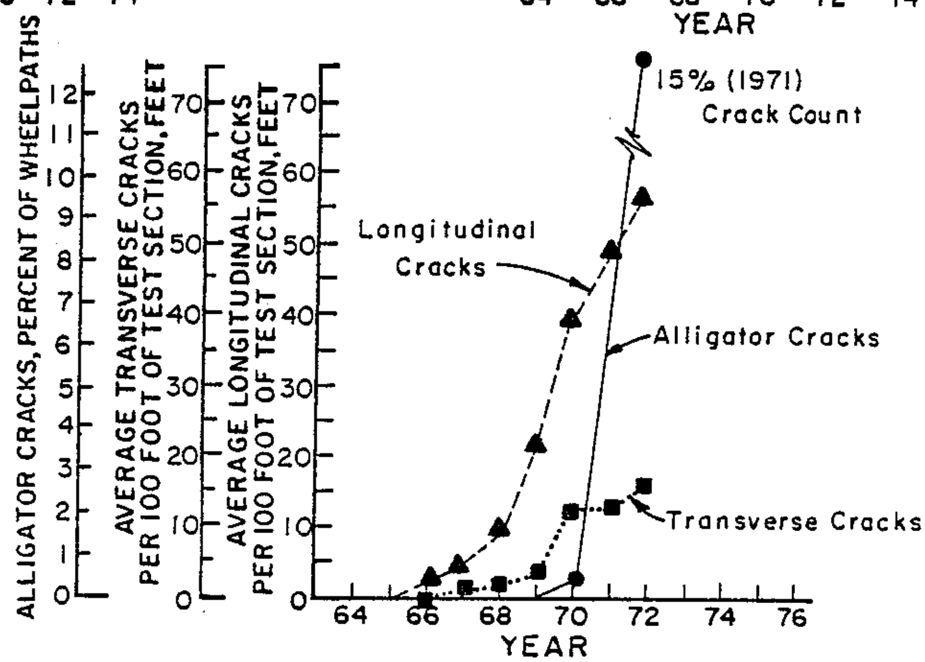
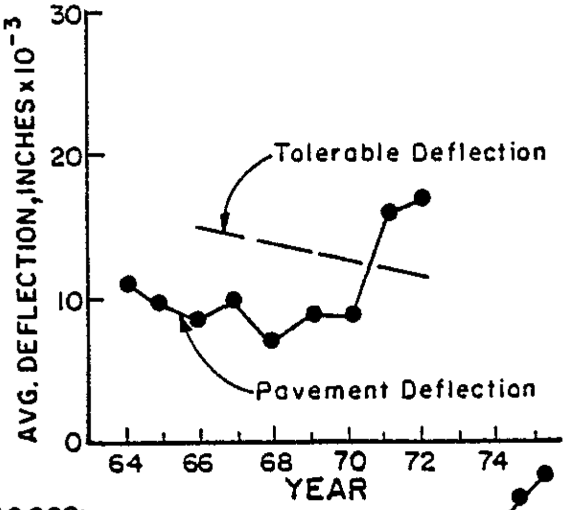
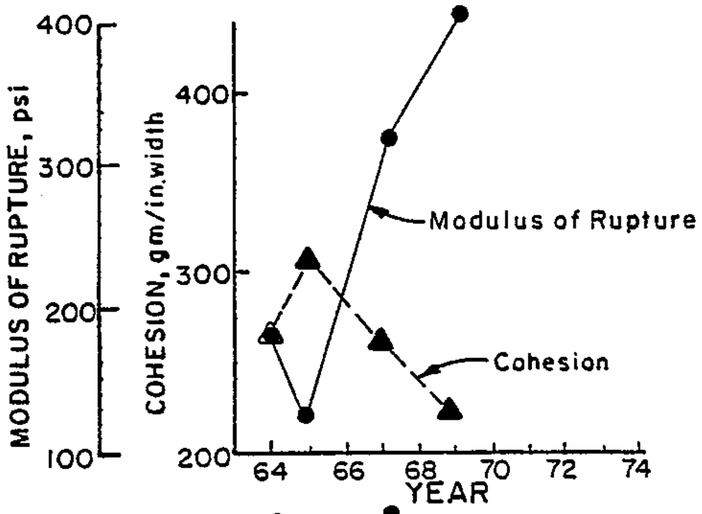
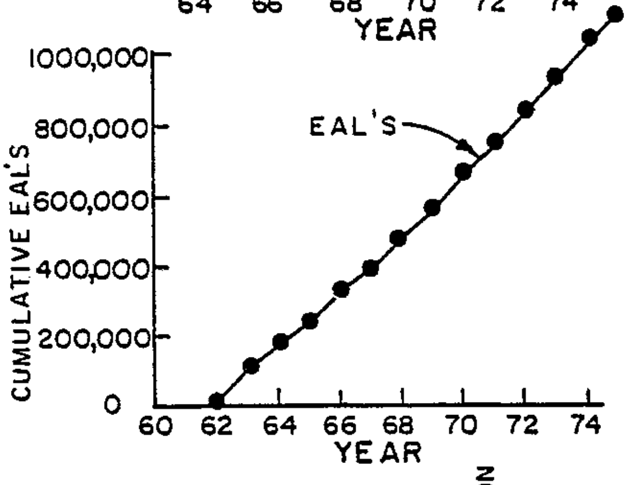


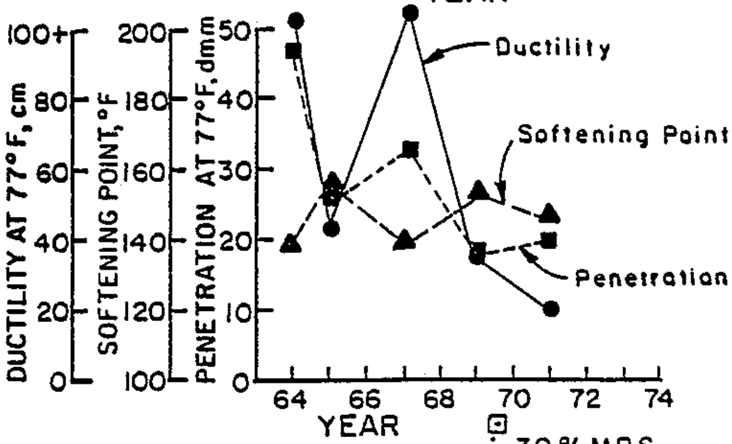
TABLE 9

PROJECT: 6 (04-Nap-121, 29)
CONTRACT NO: 62-4T13C5-E
TEST SECTION: P.M. 10.3± to P.M. 12.7±
STRUCTURAL SECTION: 0.25' A C, 0.67' CTB, 1.50' A S
COMPLETION DATE: 2-2-62









NOTES

T.I. ≈ 8.5 (1971 Data)

Tolerable deflection = 0.013".
Measured deflections exceeded the tolerable beginning in 1971.
1974 pavement condition survey from Maintenance Rating System shows approximately 30% block cracking. From rating system it appears that some work was done between 1974 and 1976.

⊡ Based on 1974 pavement condition survey from Maintenance Rating System

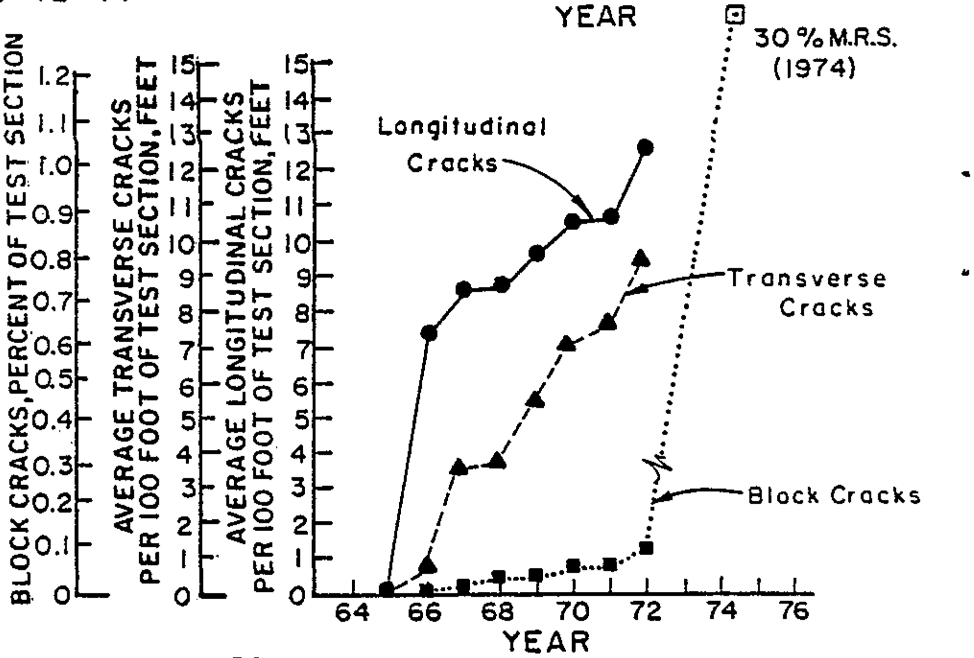
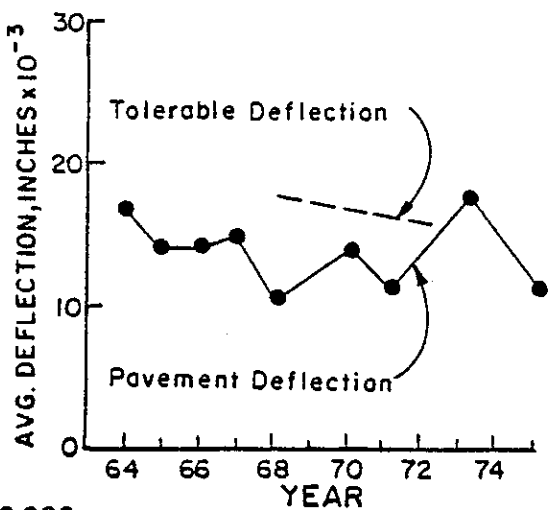
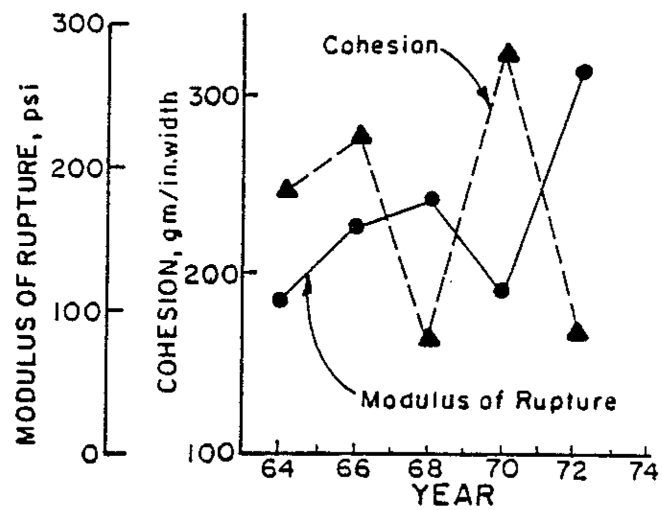
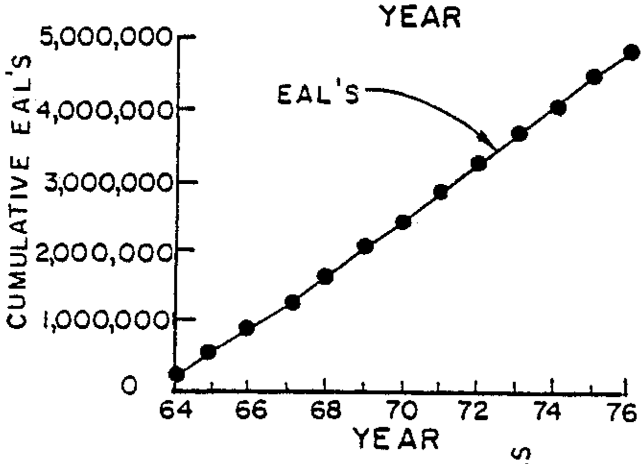


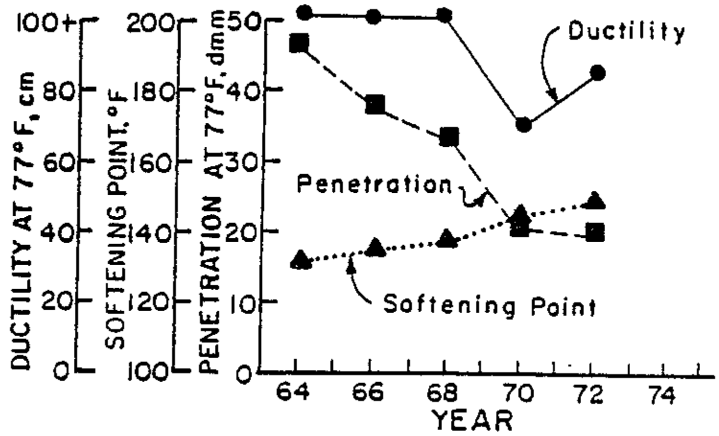
TABLE 10

PROJECT: 7(05-Mon-101,2C)
CONTRACT NO: 62-5T13C3-F
TEST SECTION: P.M. 69.3± to P.M. 73.9±
STRUCTURAL SECTION: 0.06' OGAC, 0.30' AC, 0.25' ACB, 0.50' AB, 1.25' AS
COMPLETION DATE: 7-16-63



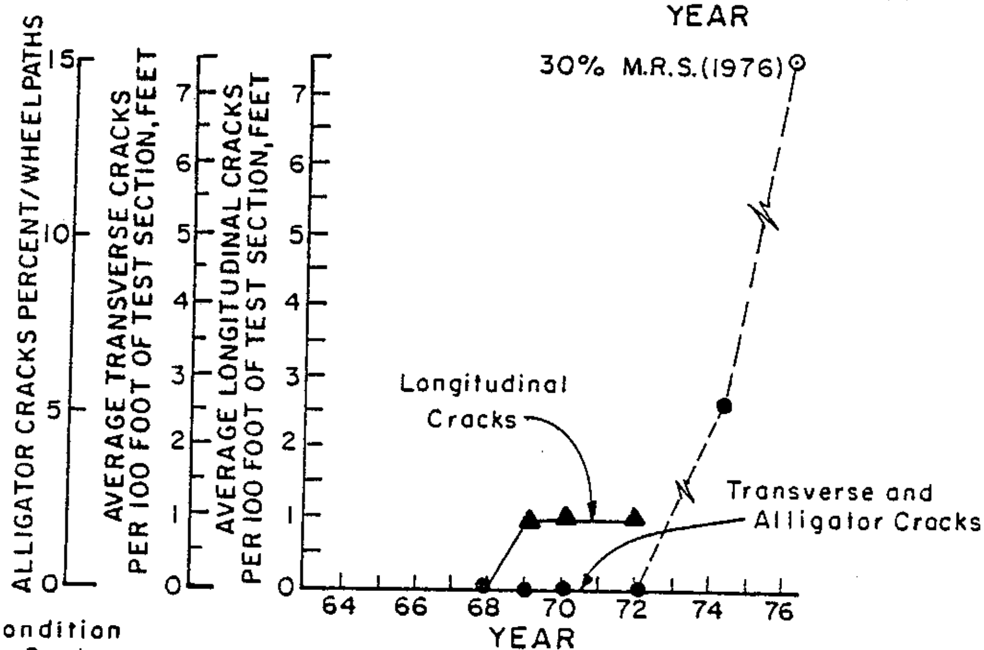






NOTES

T.I. ≈ 10.0 (1973 Data)
Tolerable deflection = 0.016".
No block cracking until 1972 then it progressed rapidly.
About 30% block cracking by 1976 as per Maintenance Rating System.
A 0.06' OGAC overlay was placed on this project in 1976.



⊙ Based on 1976 pavement condition survey Maintenance Rating System

TABLE 11

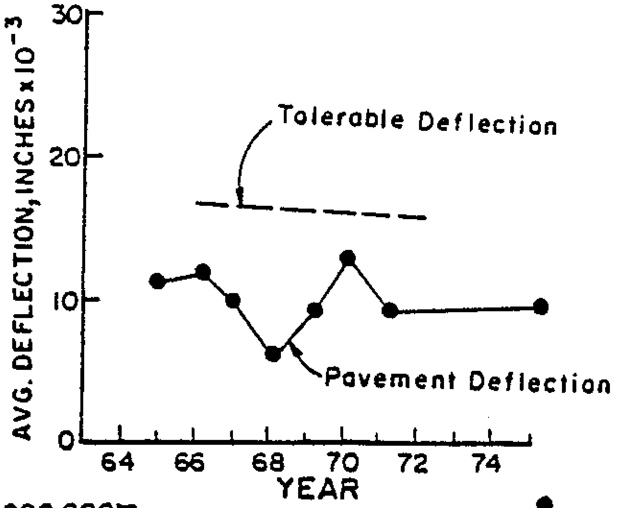
PROJECT: 8(05-Mon-101, 2D)

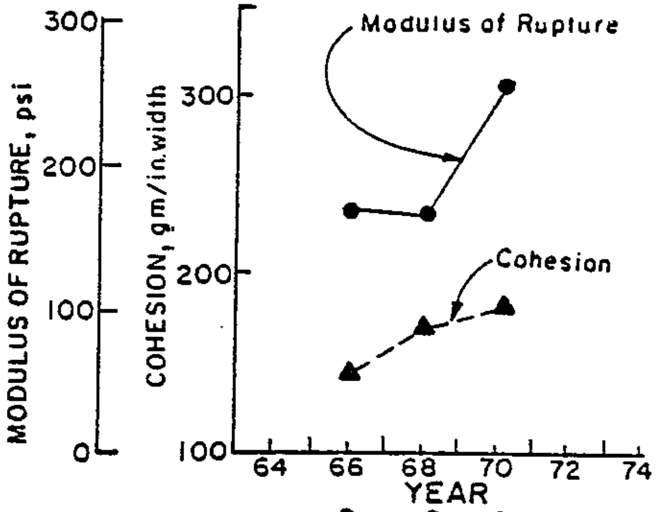
CONTRACT NO: 60-14TC1-F

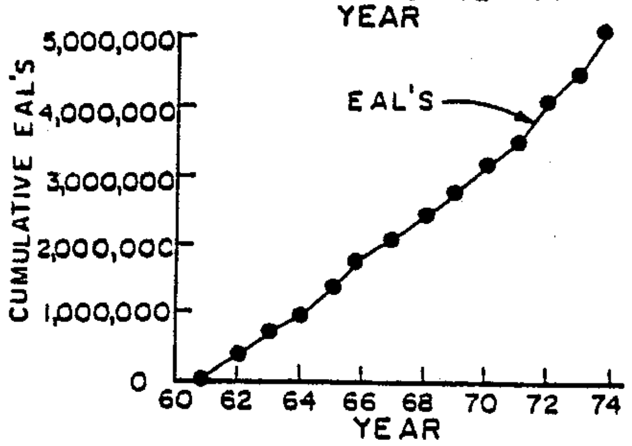
TEST SECTION: P.M. 61.8± to P.M. 62.8±

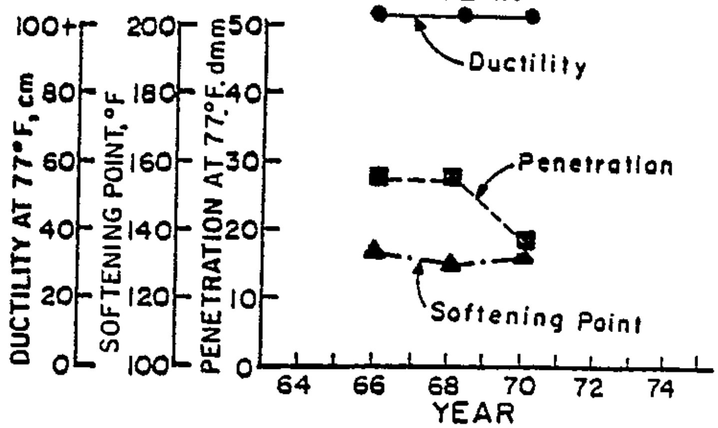
STRUCTURAL SECTION: 0.04' OGAC, 0.30' AC, 0.25' ACB, 0.50' AB, 0.92' AS

COMPLETION DATE: 12-13-60









NOTES

T.I. ≈ 10.0 (1970 Data)

Tolerable deflection = 0.016".

Block cracking started increasing significantly in 1972. Chip seal placed during April 1971. A crack count in 1975 showed 30% cracking. A 1974 pavement condition survey from Maintenance Rating System also showed about 30% cracking. Project was resurfaced in 1975, possibly after rating was finished.

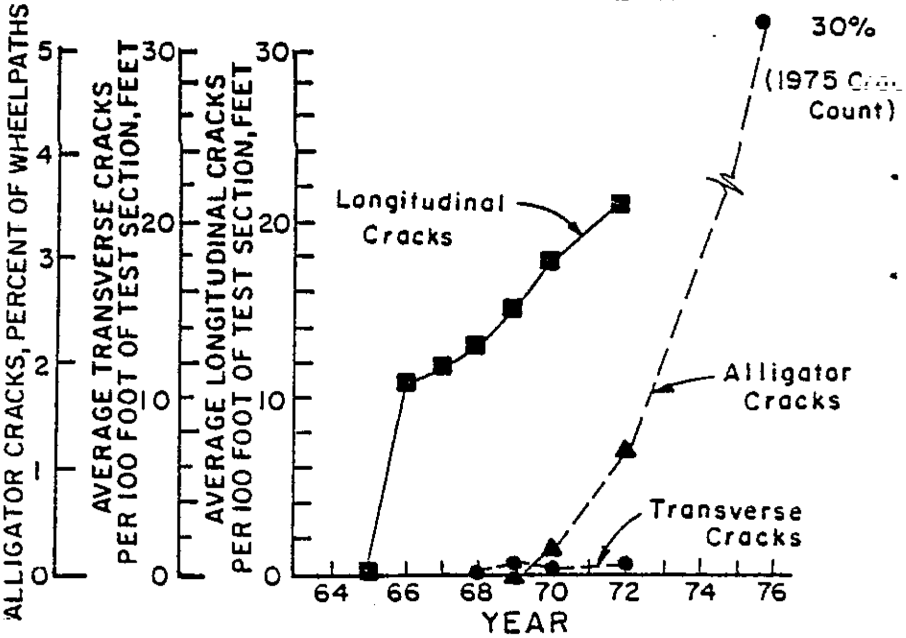
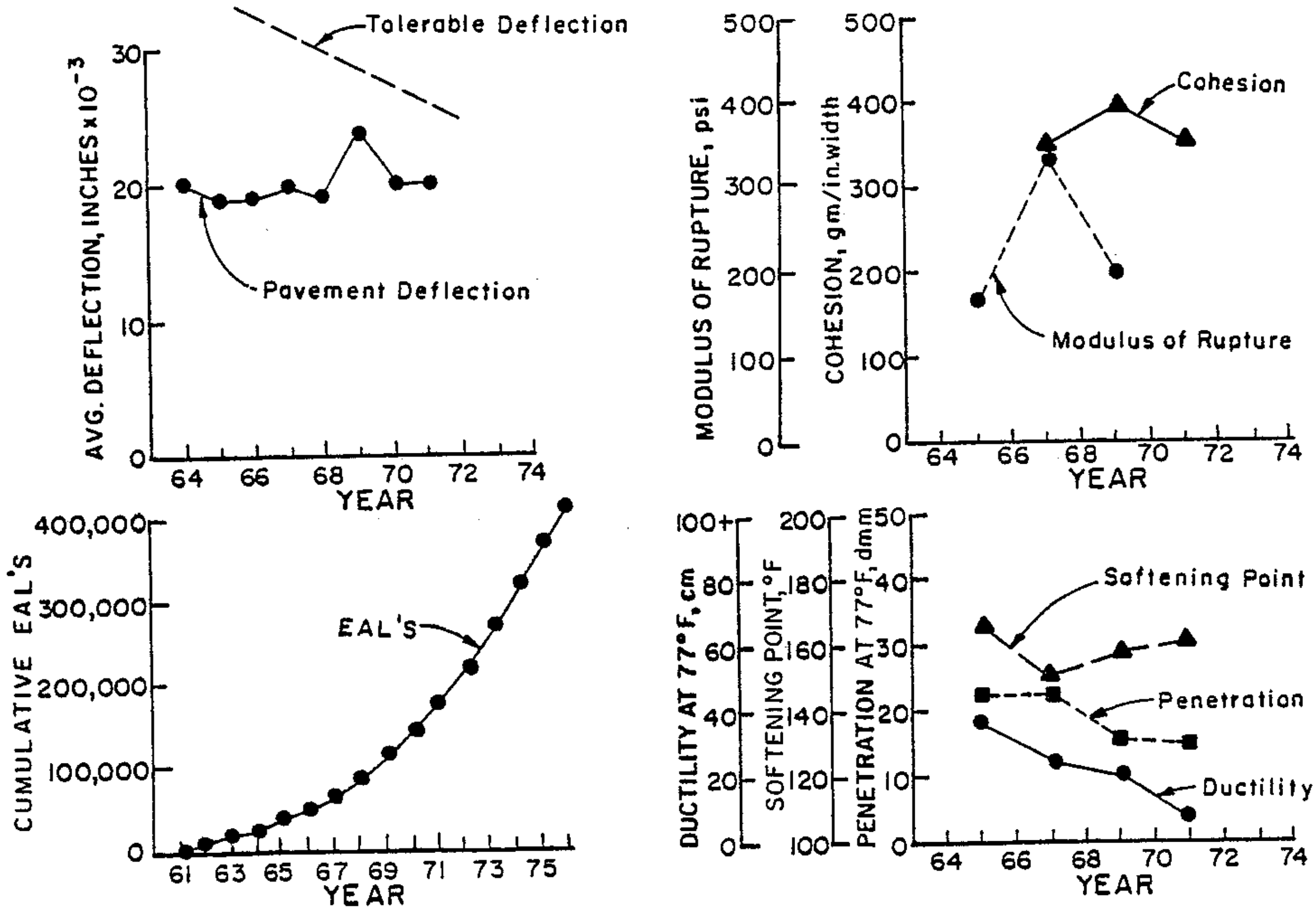


TABLE 12

PROJECT: 10(05-SB-246, 149 D)
CONTRACT NO: 61-5V13C9
TEST SECTION: P.M. 26.2± to P.M. 29.2±
STRUCTURAL SECTION: 0.06'OG, 0.25'AC, 0.50'AB, 0.50'AS
COMPLETION DATE: 4-17-61

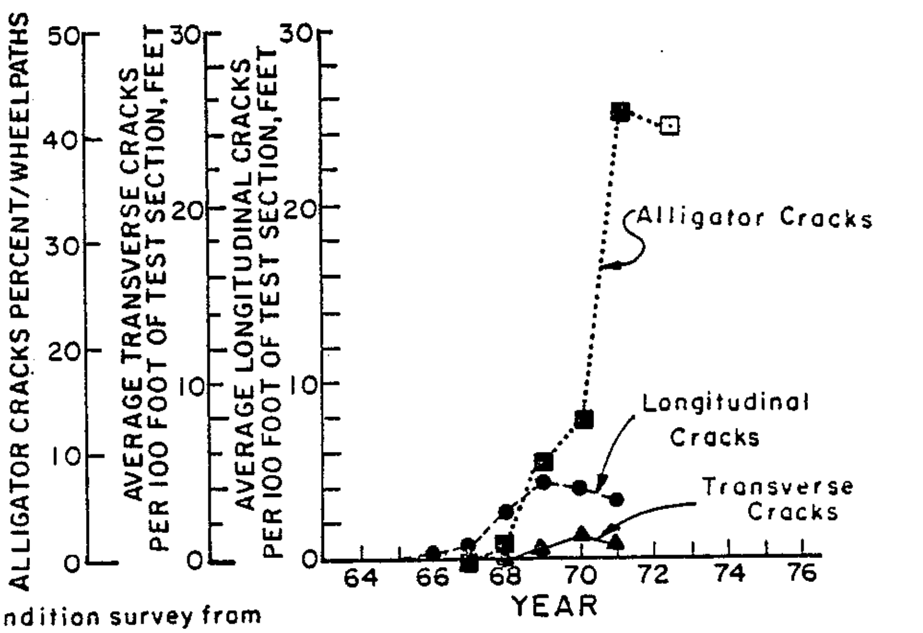


NOTES

T.I. ≈ 7.0 (1969 Data)

Tolerable deflection = 0.028".

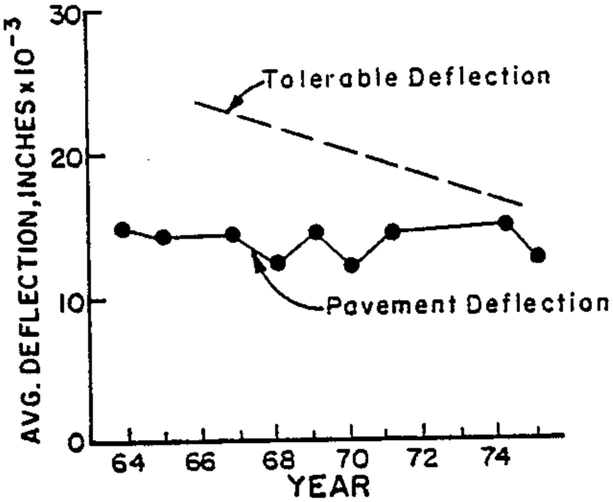
A one-inch AC blanket was placed on this project during 1972.

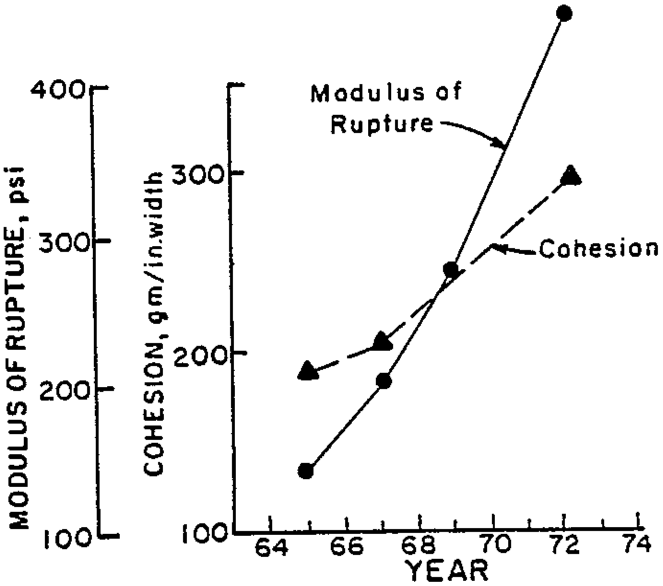


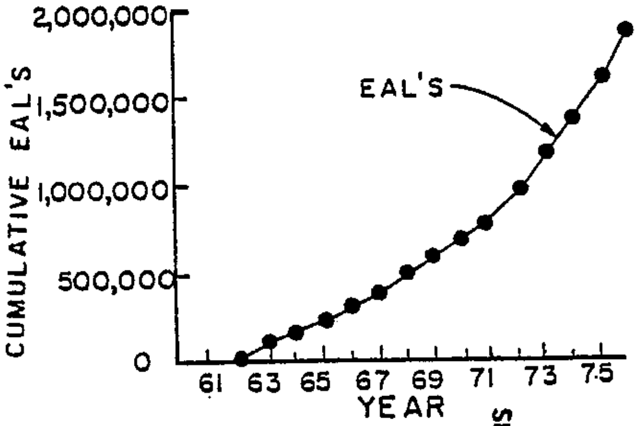
⊡ – Based on 1972 Pavement condition survey from Maintenance Rating System

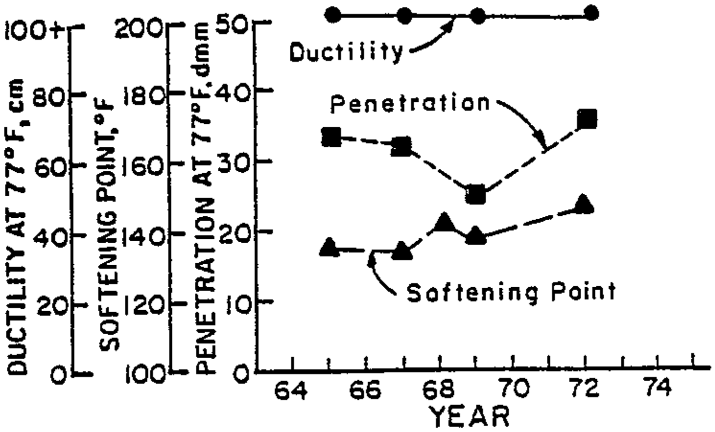
TABLE 13

PROJECT: 11(05-SBt-156,22-A)
CONTRACT NO: 62-5T13C2
TEST SECTION: P.M.5.0± to P.M.9.2±
STRUCTURAL SECTION: 0.06' OGAC 0.25'AC, 0.67'AB, 1.00'AS
COMPLETION DATE: 1-4-62









NOTES

T.I.≈9.5 (1974 Data)

Tolerable Deflection= 0.019".

Measured deflections below the tolerable level.

One-inch AC blanket placed in 1976.

Δ – Based on 1974 & 1976 pavement condition rating from Maintenance Rating System.

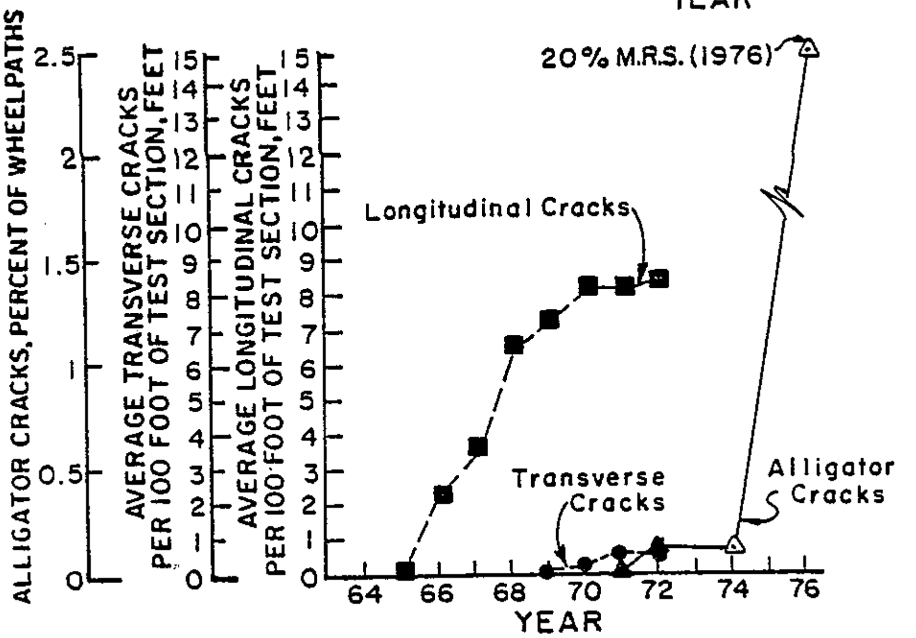
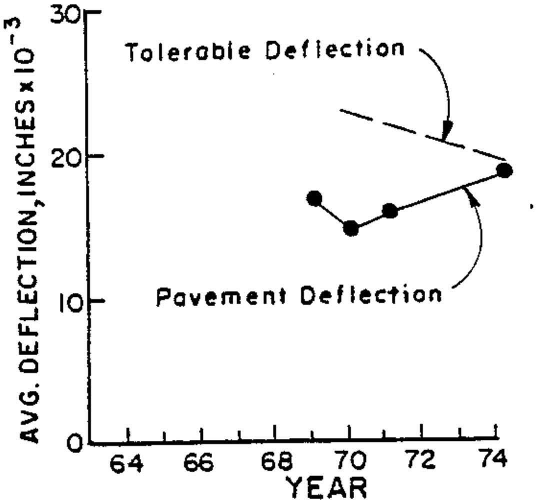
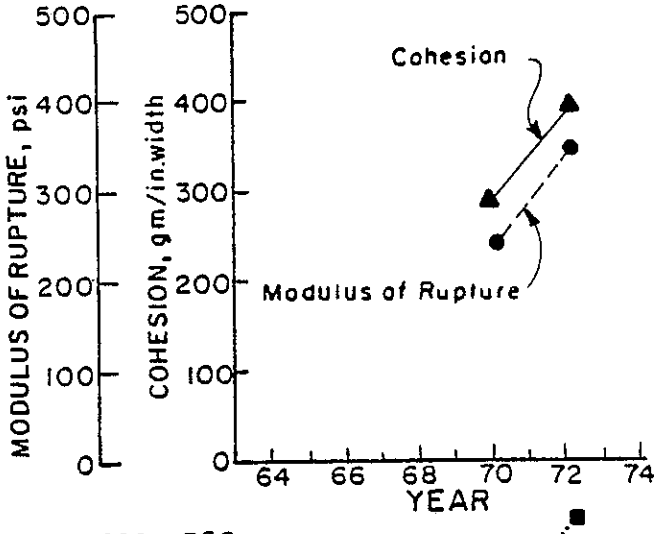
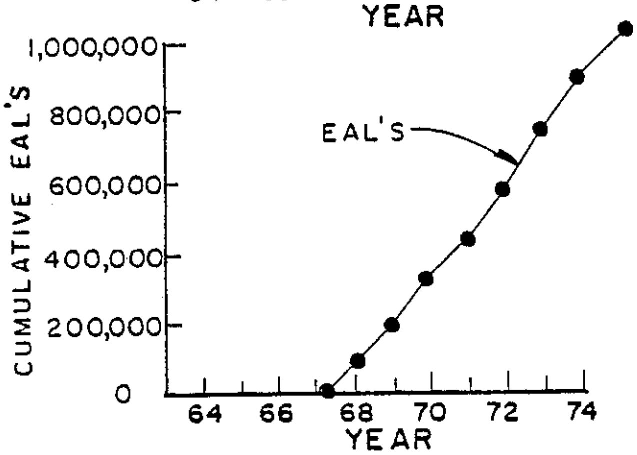


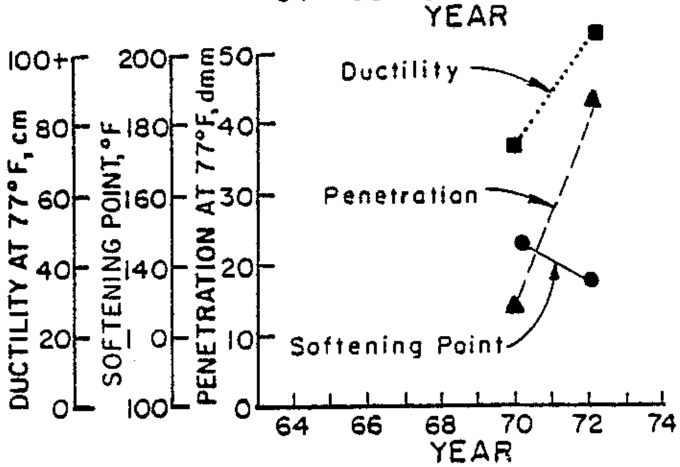
TABLE 14

PROJECT: 12 A (05-SBt-156)
CONTRACT NO: 05-021304
TEST SECTION: P.M. 13.3± to P.M. 18.4±
STRUCTURAL SECTION: 0.25'AC, 0.67'AB, 1.00'AS
COMPLETION DATE: April, 1967









NOTES

T.I. ≈ 9.0 (1974 Data)
Tolerable deflection = 0.020". Measured deflections close to tolerable level in 1974. Block cracking insignificant through 1972. Maintenance pavement ratings show alligator cracking of 15% in 1974 and 20% in 1976.

⊡ Based on pavement condition survey from Maintenance Rating System.

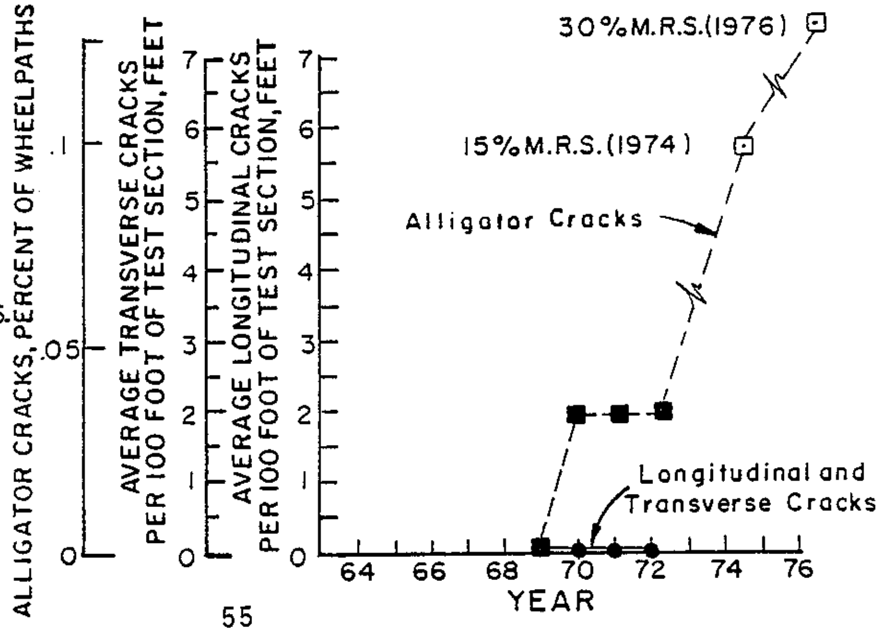
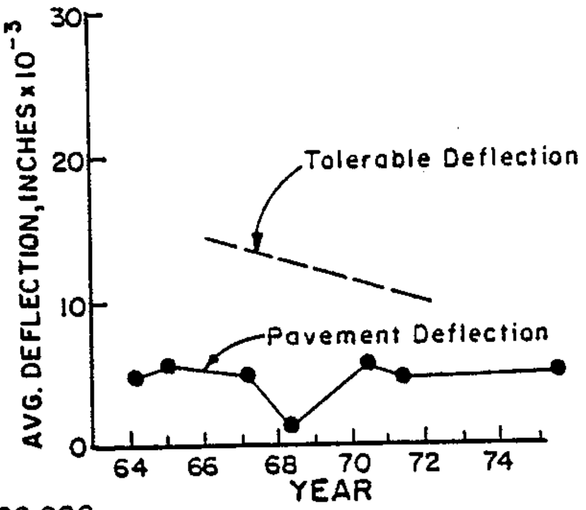
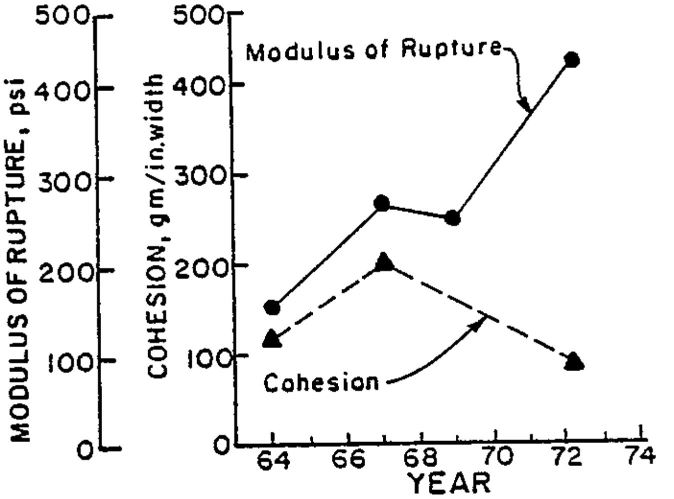
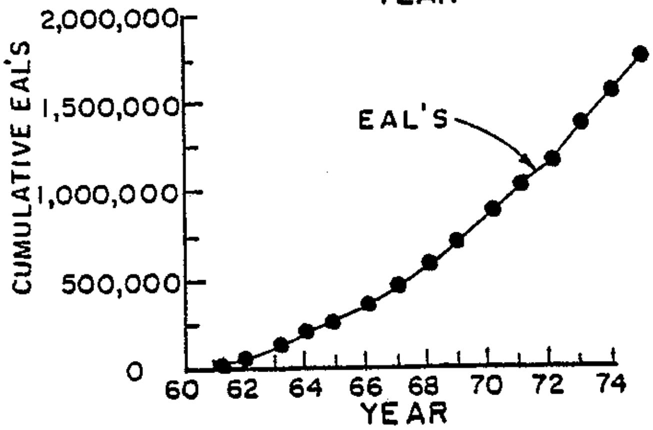


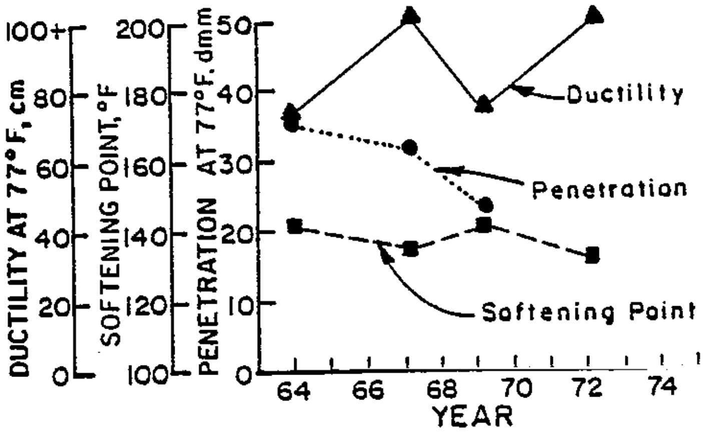
TABLE 15

PROJECT: 12 B (05-SBt-156)
CONTRACT NO: 61-5TC3
TEST SECTION: P.M. 3.0± to P.M. 5.0± (San Juan Bypass)
STRUCTURAL SECTION: 0.06' OGAC, 0.25' A C, 0.50' CTB, 0.17' A B, 0.75' A
COMPLETION DATE: 6-5-61



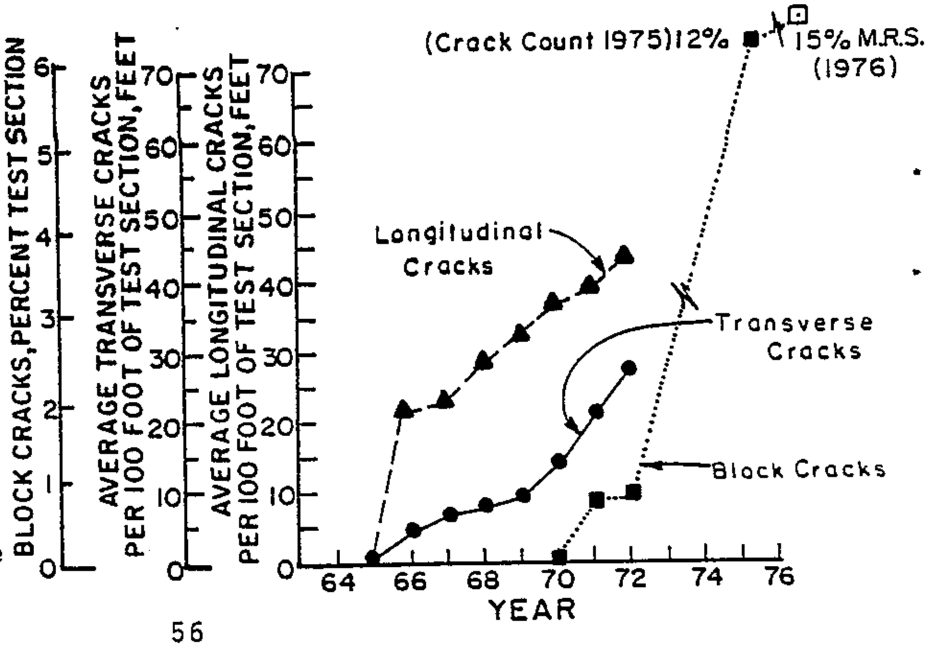






NOTES

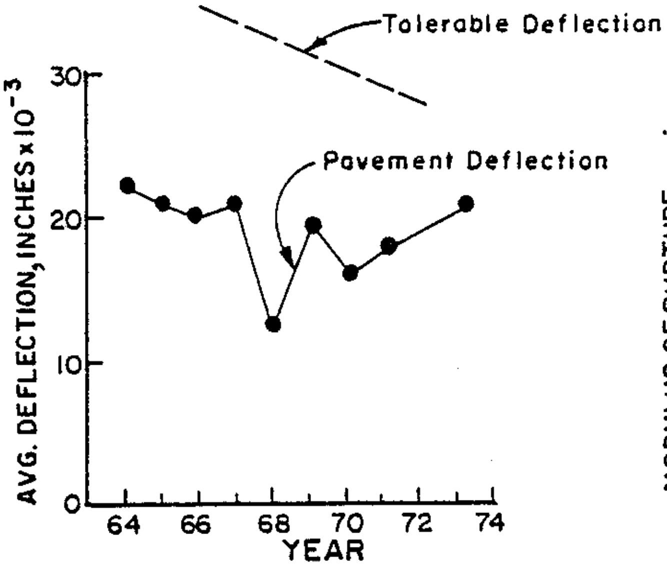
T.I. ≈ 9.0 (1970 Data)
Tolerable deflection = 0.012".
Measured deflections have not exceeded tolerable level.

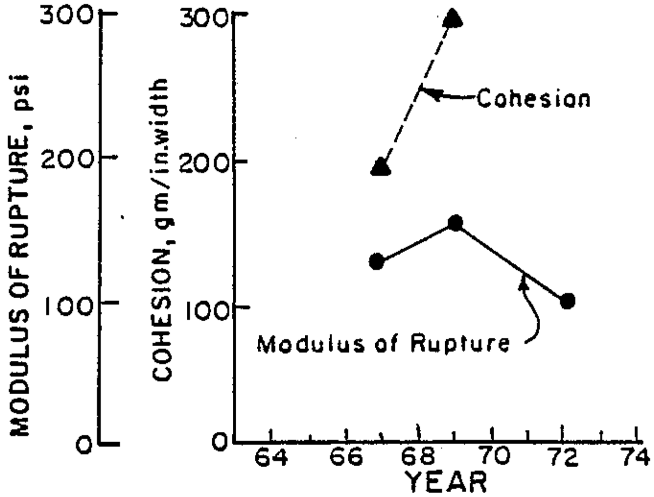


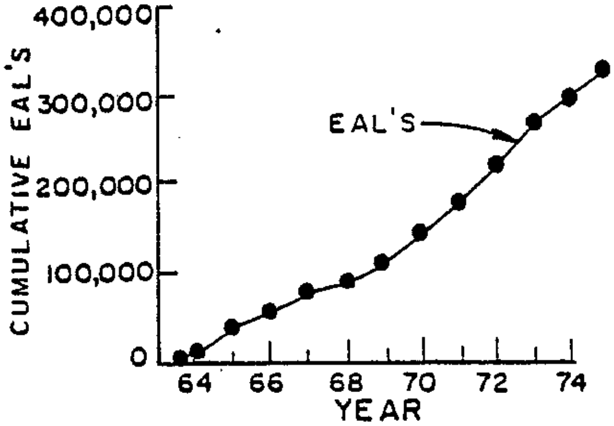
□ Based on 1976 pavement condition survey from Maintenance Rating System.

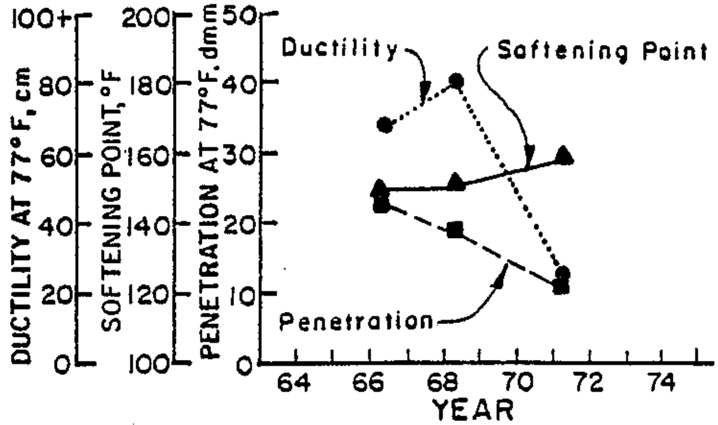
TABLE 16

PROJECT: 13 (05-SLO-1, 56 C,D)
CONTRACT NO: 61-5V13C12
TEST SECTION: P.M. 28.5± to P.M. 37.0±
STRUCTURAL SECTION: 0.06' OGAC, 0.21' AC, 0.67' AB, 1.00' AS
COMPLETION DATE: 8-15-63









NOTES

T.I. ≈ 7.0 (1969 Data)
Tolerable deflection = 0.031".

☐ Based on 1976 pavement condition survey from Maintenance Rating System.

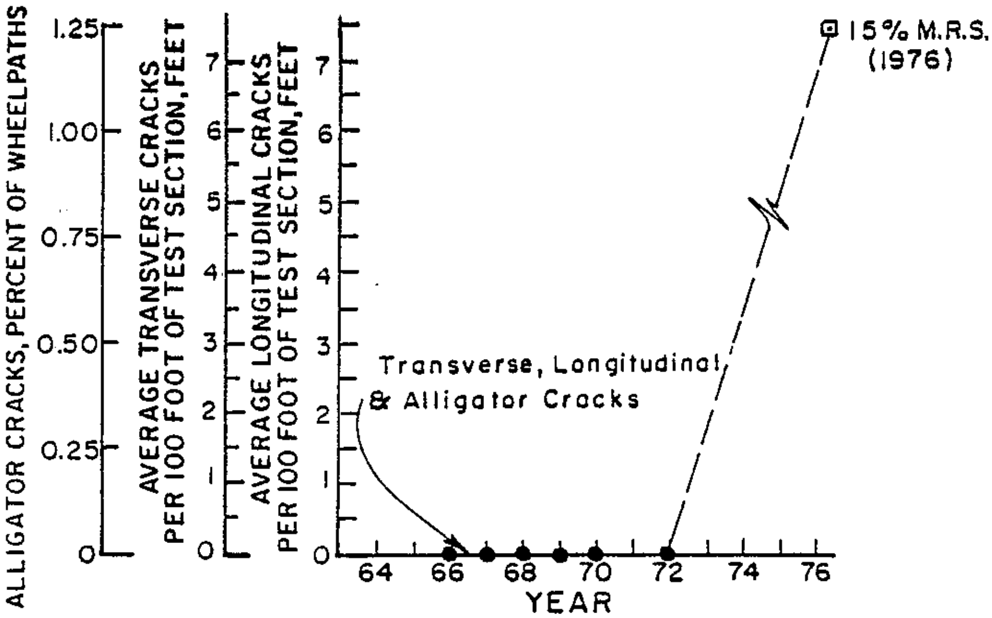


TABLE 17

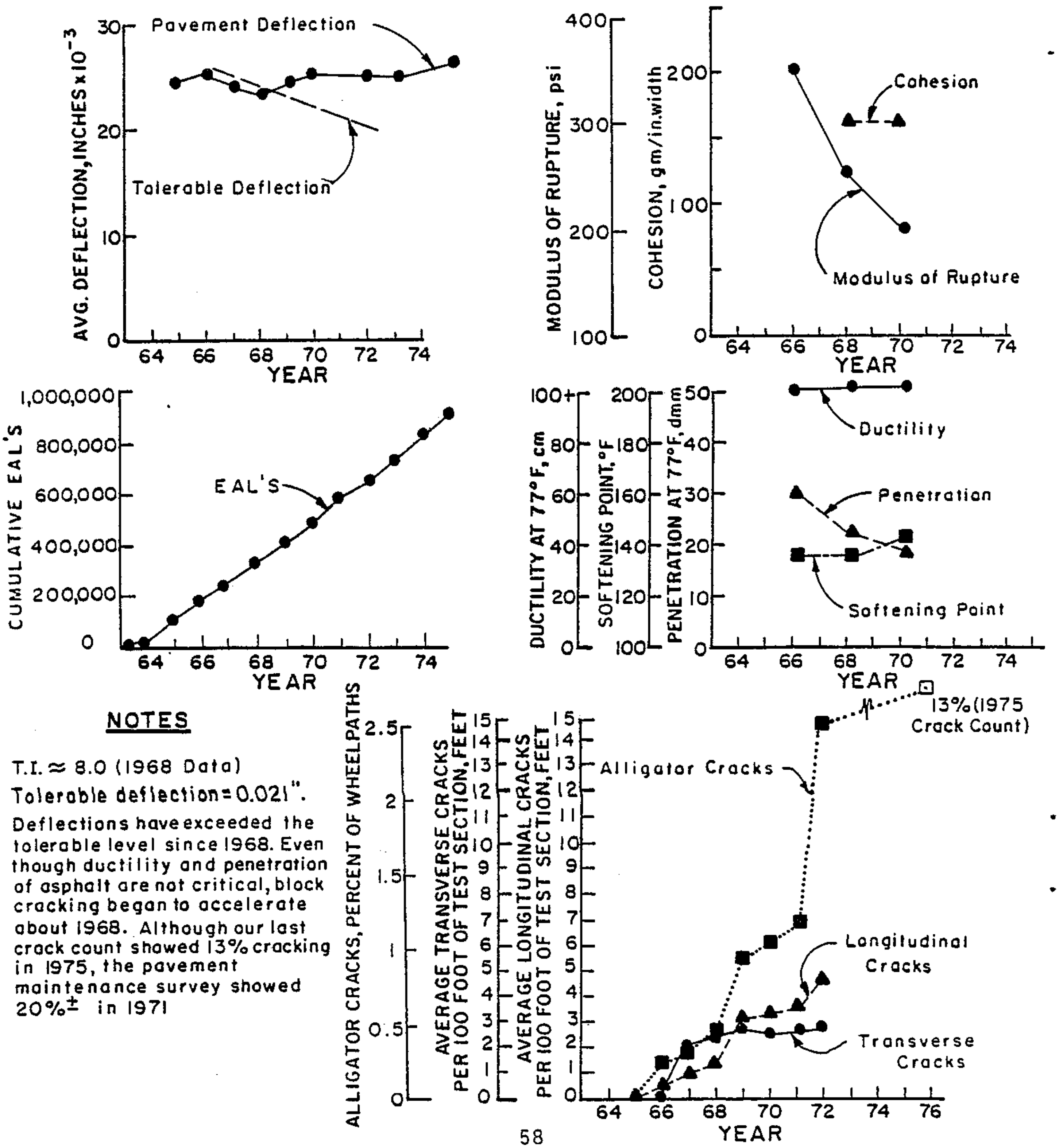
PROJECT: 14(06-Ker-204, 141 A)

CONTRACT NO: 64-6V13C2-F

TEST SECTION: P.M. 0.0± to P.M. 1.9±

STRUCTURAL SECTION: 0.29' A C , 0.67' A B , 0.83' to 1.04' A S

COMPLETION DATE: 5-5-64



NOTES

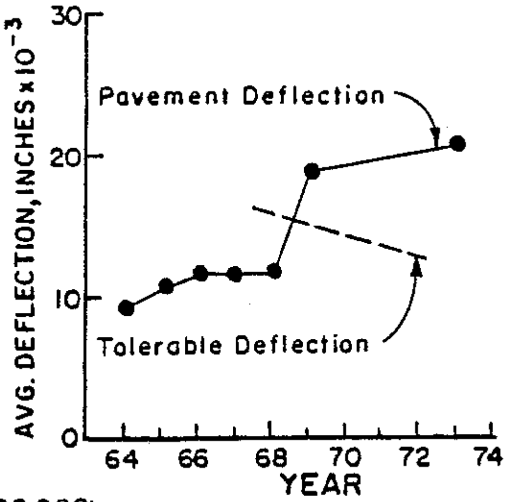
T.I. ≈ 8.0 (1968 Data)

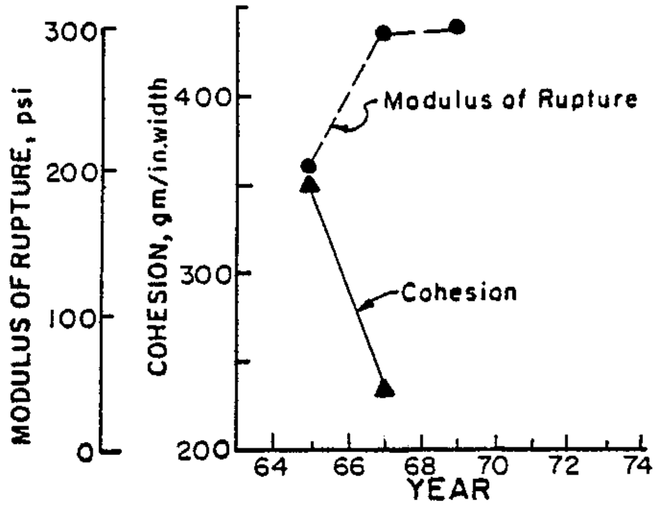
Tolerable deflection = 0.021".

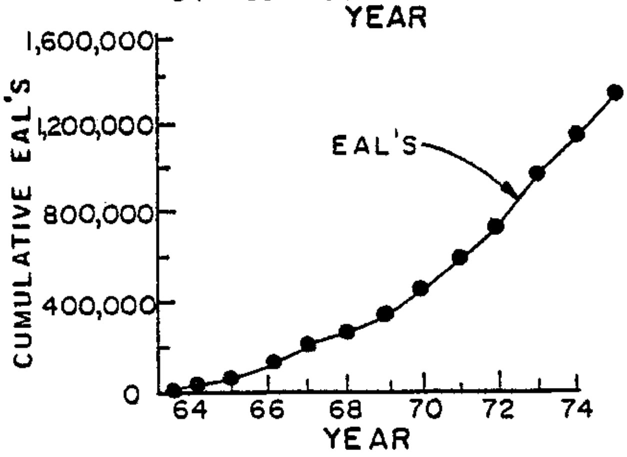
Deflections have exceeded the tolerable level since 1968. Even though ductility and penetration of asphalt are not critical, block cracking began to accelerate about 1968. Although our last crack count showed 13% cracking in 1975, the pavement maintenance survey showed 20%± in 1971

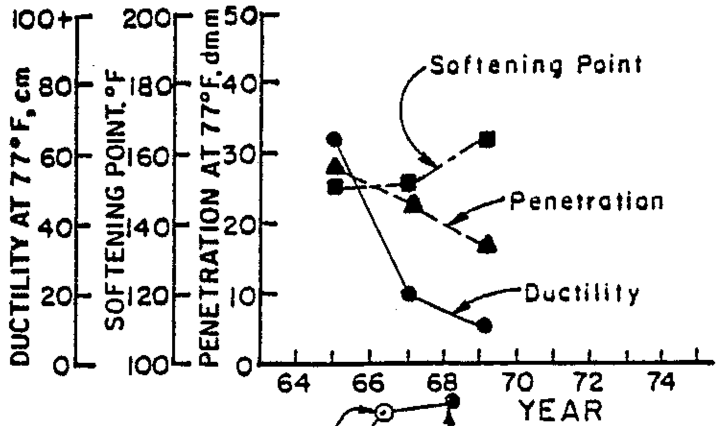
TABLE 18

PROJECT: 15(06-Kin-198.10B)
CONTRACT NO: 62-6T13 C4)
TEST SECTION: P.M.0.0± to P.M.8.9±
STRUCTURAL SECTION: 0.25'A C, 0.50'CTB, 0.67'A S, 0.33'I B
COMPLETION DATE: 6-26-63









NOTES

T.I. ≈ 9.0 (1973 Data)

Tolerable deflection = 0.020". Measured deflection approached tolerable about 1969. Ductility is critical (<10). Maintenance rating data shows 15% in 1969 and 30% in 1971. The last crack count was 1973 with 40% alligator cracking.

⊙ Based on 1969 & 1971 pavement condition survey from Maintenance Rating System.

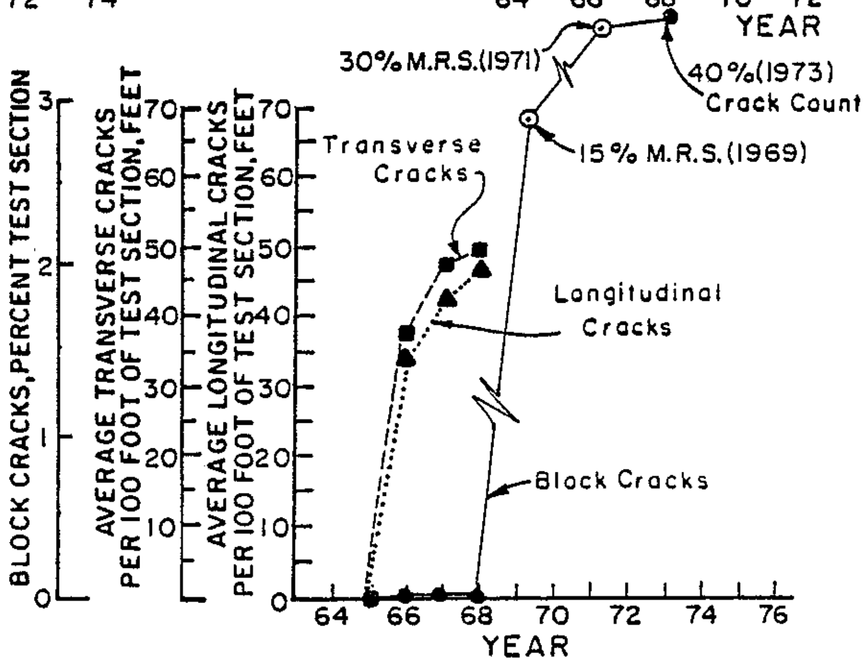
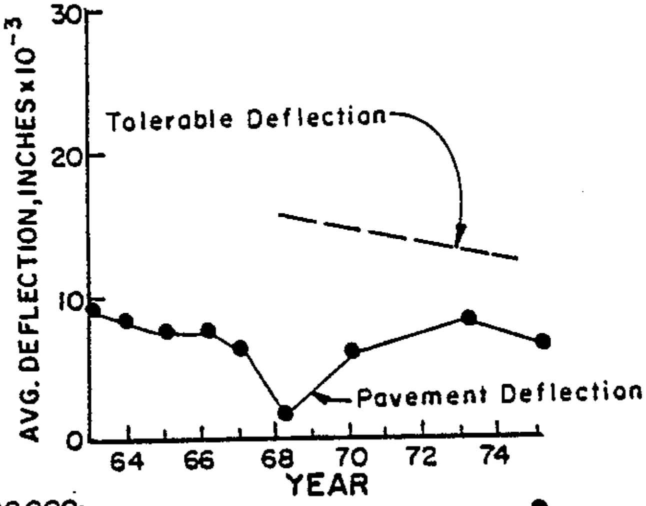
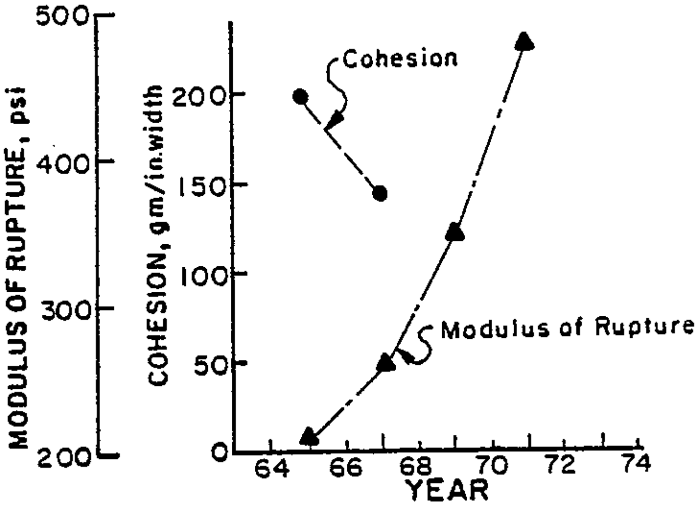
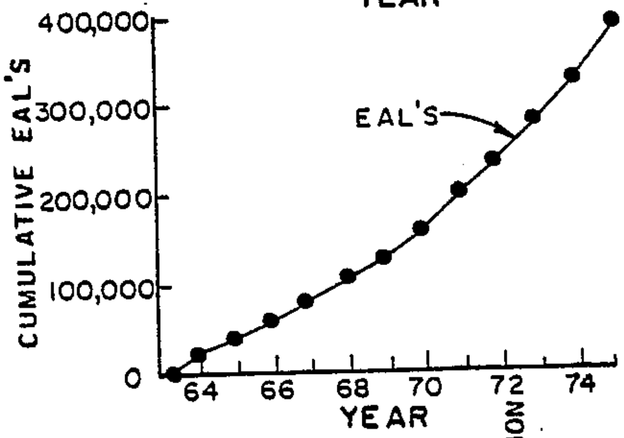


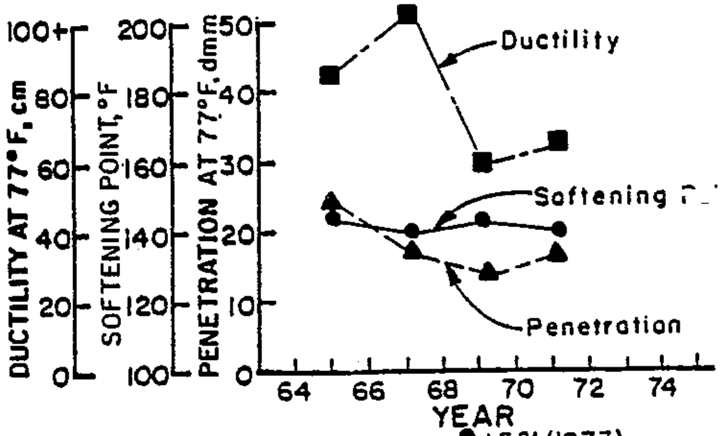
TABLE 19

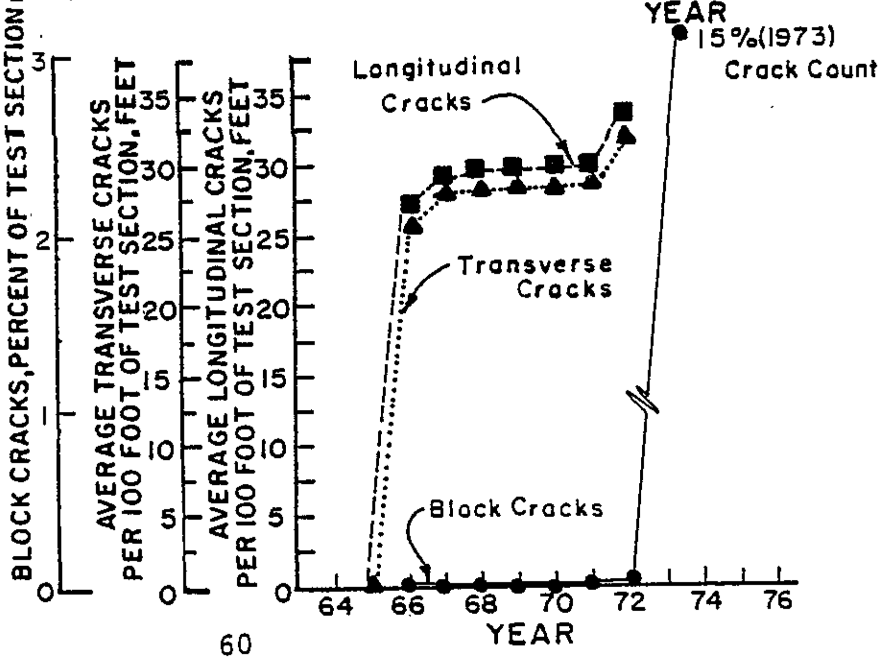
PROJECT: 16 (06-Kin, Tul-43, 135 BA)
CONTRACT NO: 63-6T 13C2-P
TEST SECTION: P.M. 0.0± to P.M. 3.3±, P.M. 21.7± to P.M. 22.7±
STRUCTURAL SECTION: 0.25'AC, 0.50'CTB, Exist. Pav't.
COMPLETION DATE: 2-4-63









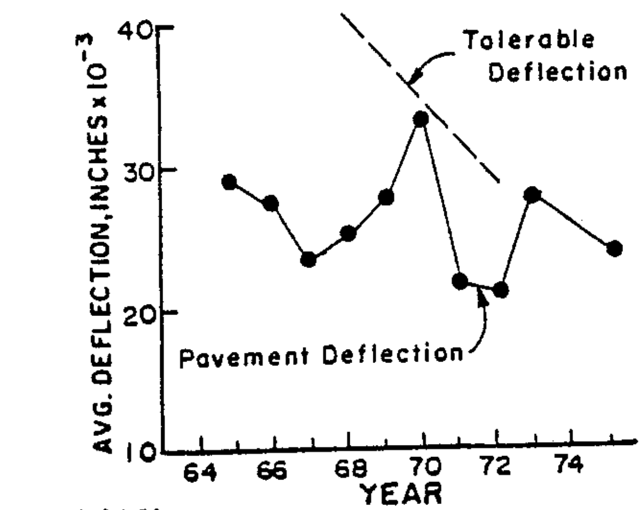


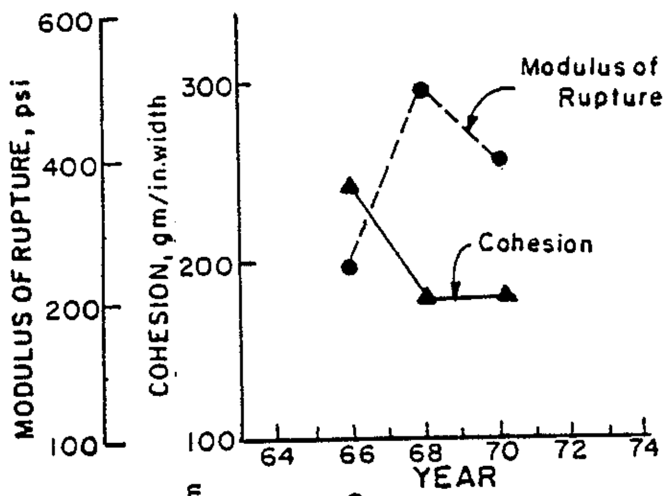
NOTES

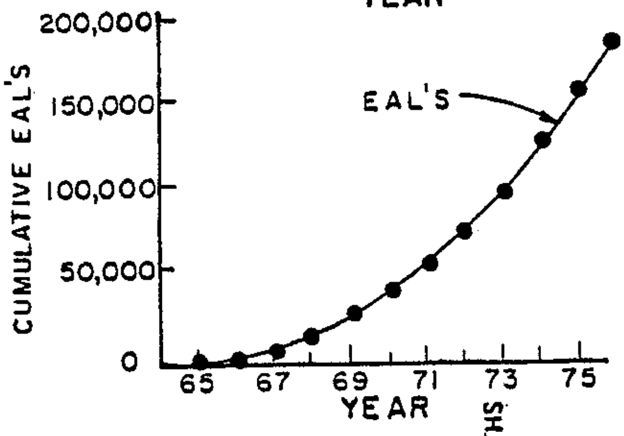
T.I. ≈ 8.0 (1975 Data)
Tolerable deflection = 0.014".
Measured deflections have not exceeded tolerable level. No significant block cracking shown in Maintenance Rating System for 1974 and 1976.

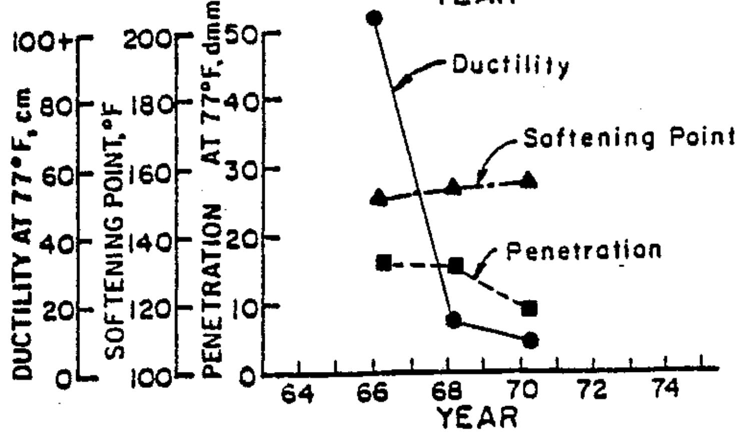
TABLE 20

PROJECT: 17 (06-Fre -811 FAS)
CONTRACT NO: 64-6Y24 C19-P
TEST SECTION: STA. 375 To STA. 639
STRUCTURAL SECTION: 0.25'AC, 0.50'AB, 1.17'AS
COMPLETION DATE: 9-29-64









NOTES

T.I. ≈ 6.0 (1970 Data)

Tolerable deflection = 0.036".
This road had light truck traffic.
Both penetration and ductility values were extremely low (1970)

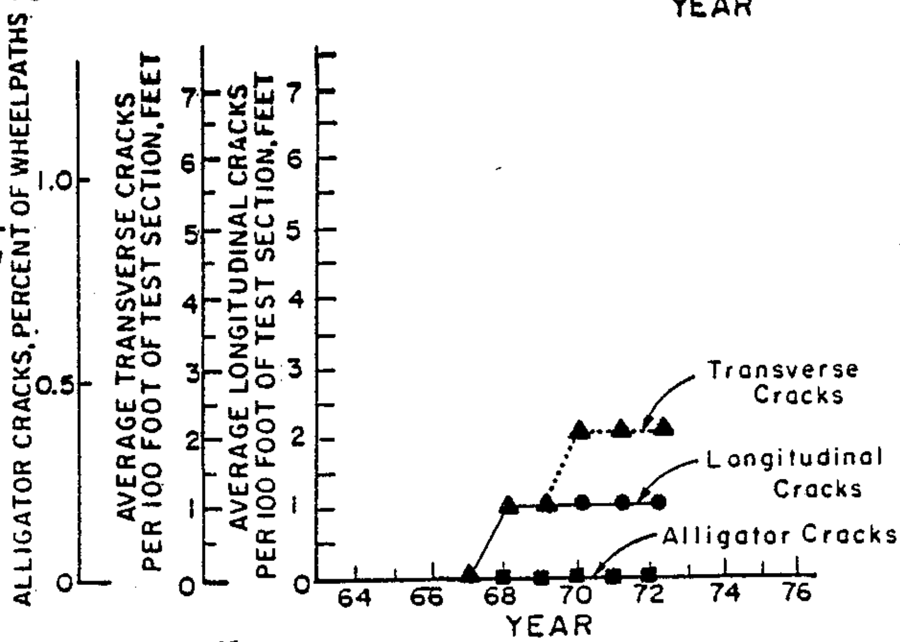
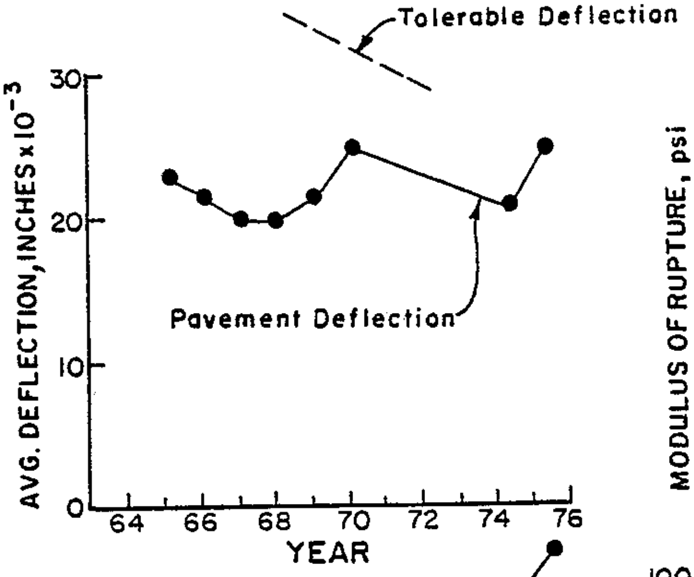
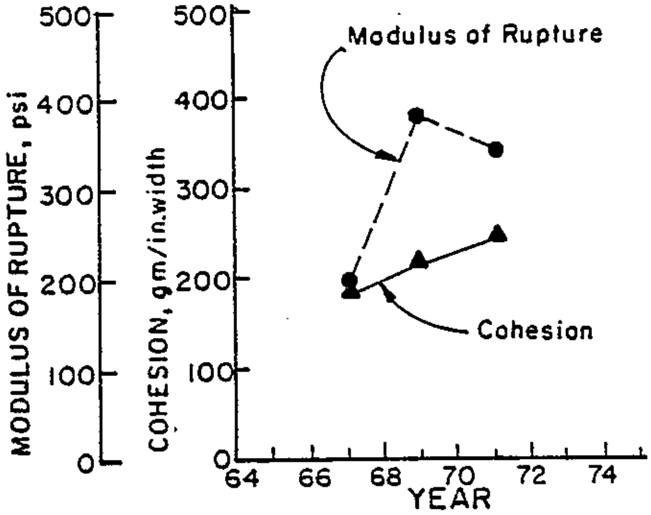
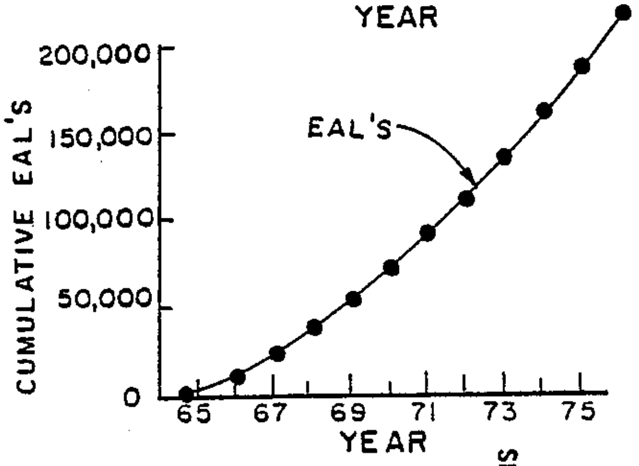


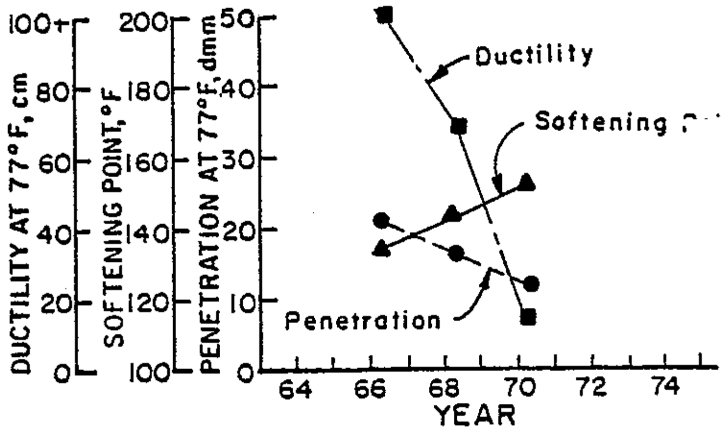
TABLE 21

PROJECT: 18 (06-Fre-1329-CR)
CONTRACT NO: 64-6Y24C20-P
TEST SECTION: STA.499 to STA.663+50
STRUCTURAL SECTION: 0.25'AC, 0.50'AB, 0.92' to 1.00'AS
COMPLETION DATE: 10-7-64









NOTES

T.I.≈6.5 (1970 Data)
Tolerable deflection = 0.032".
This road had light truck traffic in 1970; the pavement maintenance rating showed insignificant alligator cracking. In 1975, pavement deflections were below critical values.

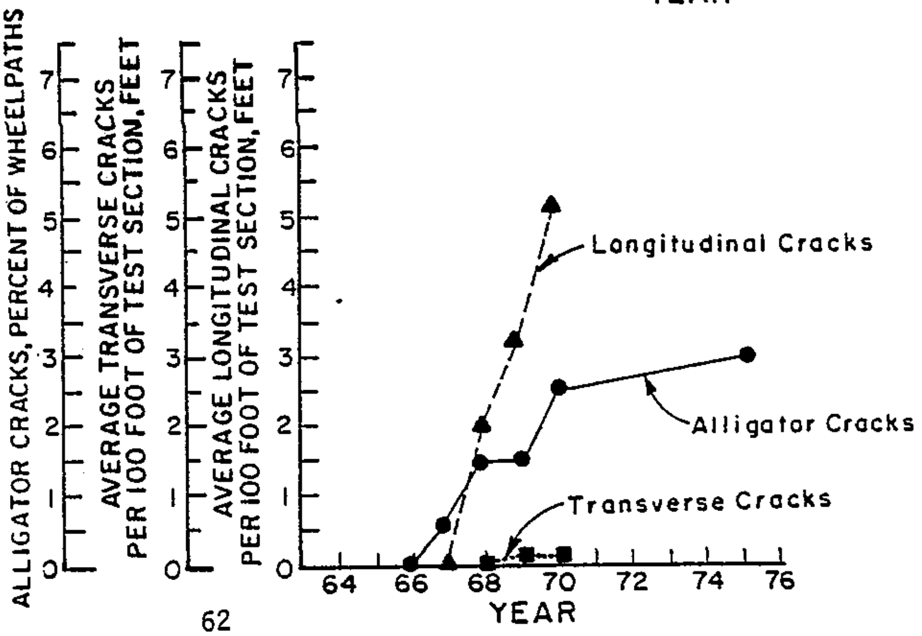
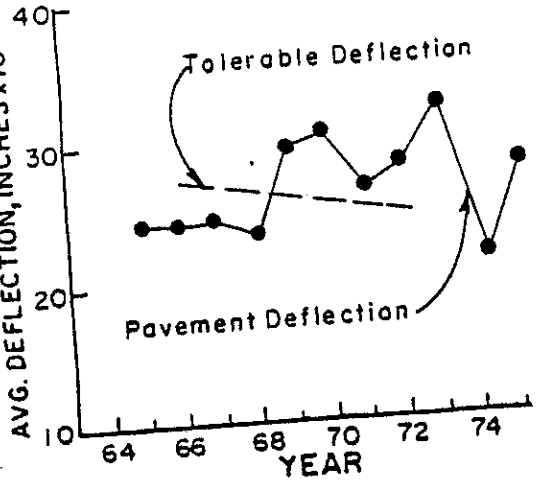
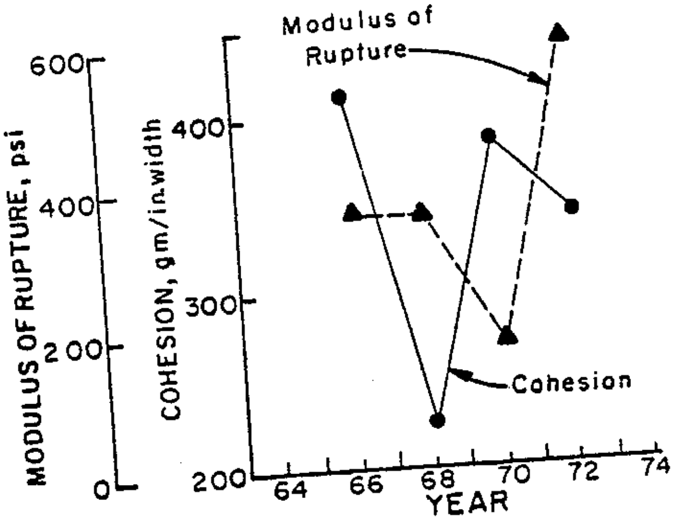
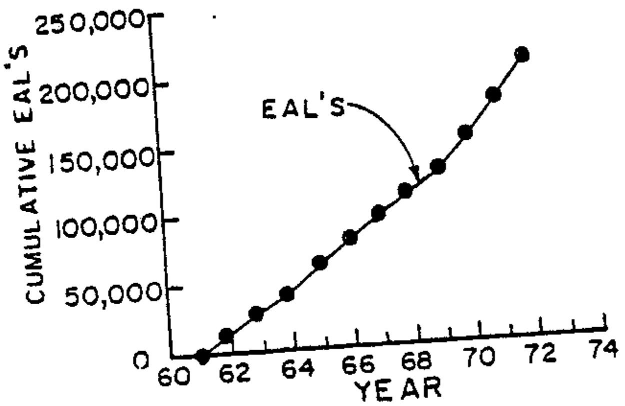


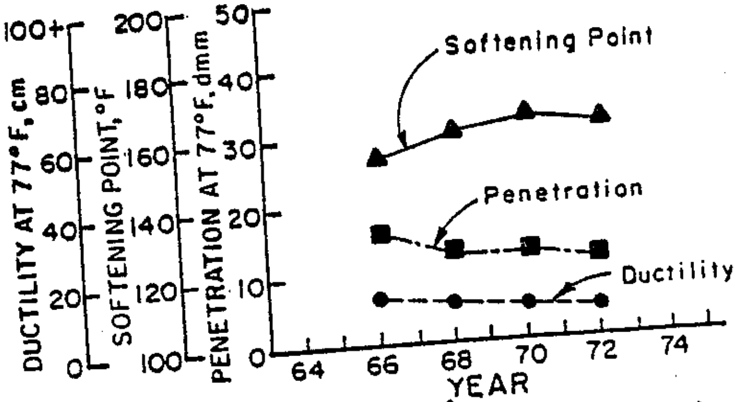
TABLE 22

PROJECT: 19 (06-Fre-33, 138 D)
CONTRACT NO: 60-6TC13-FP
TEST SECTION: P.M. 58.8± to P.M. 61.1±
STRUCTURAL SECTION: 0.29'AC, 0.50'AB, 1.17'AS
COMPLETION DATE: 3-18-61



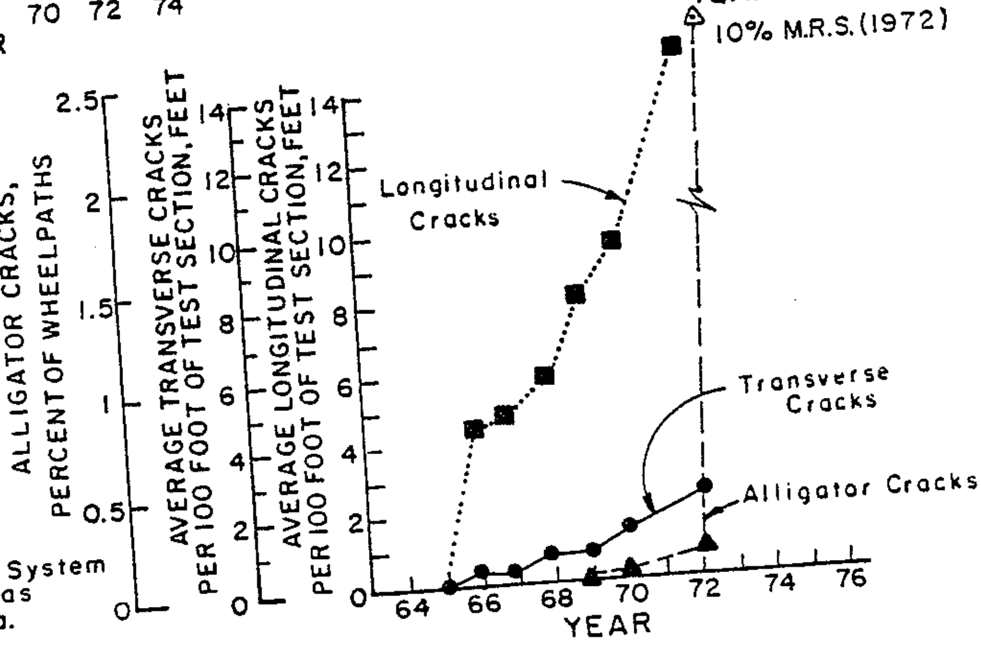






NOTES

T.I. ≈ 7.0 (1969 Data)
Tolerable deflection = 0.027".
In 1969 measured deflections were above the tolerable level. Block cracking started in 1969. Pavement condition survey showed 10% cracking in 1979. In 1973 this roadway was resurfaced.



△ 1972 pavement condition from Maintenance Rating System shows alligator cracking has developed in 10% of area.

TABLE 23

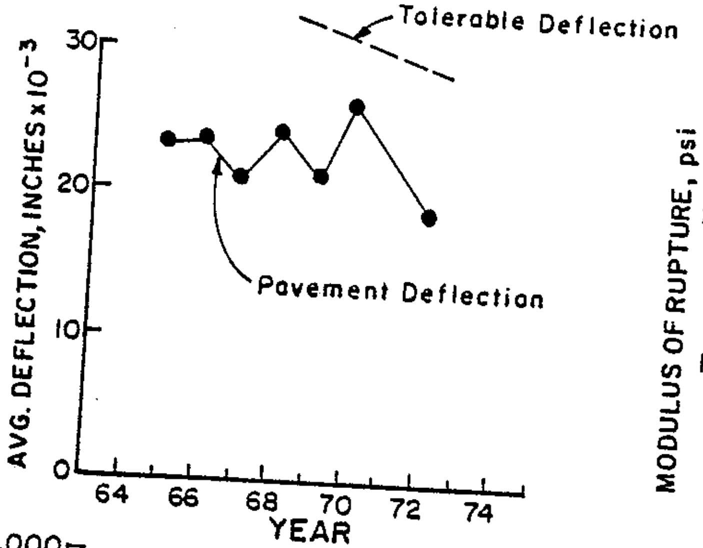
PROJECT: 20(10-Cal-49, 65A)

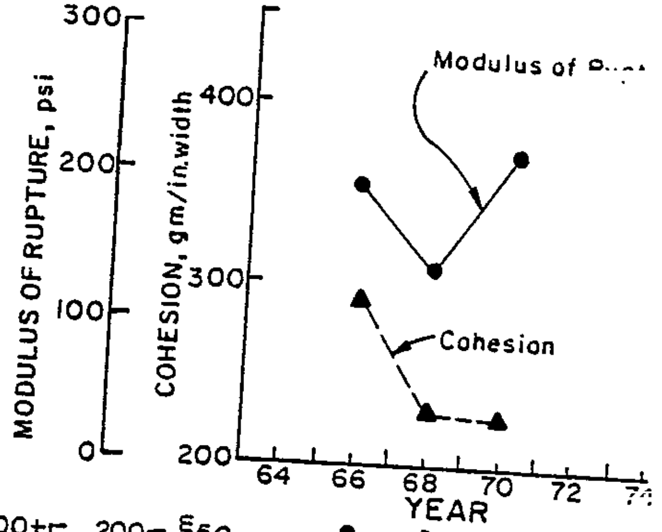
CONTRACT NO: 64-10-T13C 14

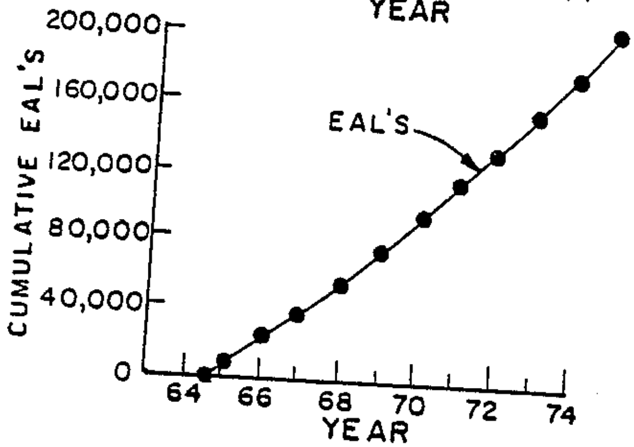
TEST SECTION: P.M. 20.5± to P.M. 27.6±

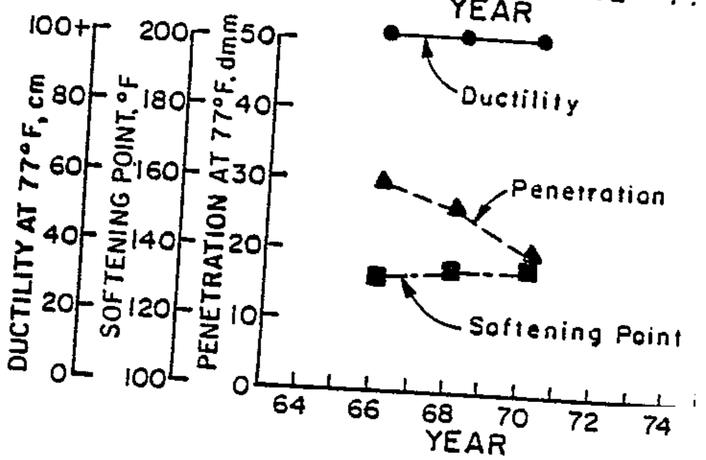
STRUCTURAL SECTION: 0.25'A C, 0.50'A B, 1.00'A S

COMPLETION DATE: 8-12-64









NOTES

T.I. ≈ 7.0 (1970 Data)

Tolerable deflection = 0.028". Measured deflections have not exceeded the critical value. Pavement condition surveys from maintenance ratings show no alligator cracking 1972 or 1976.

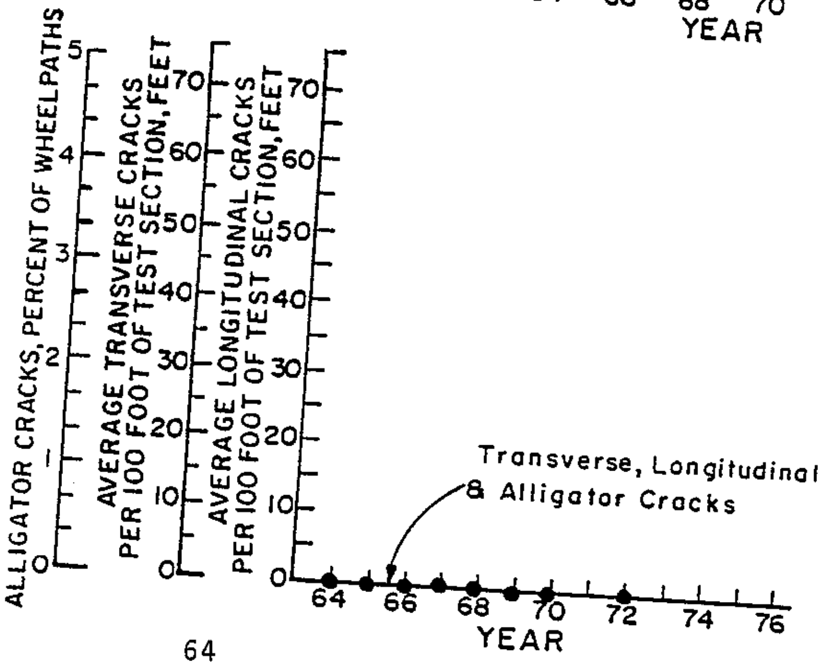
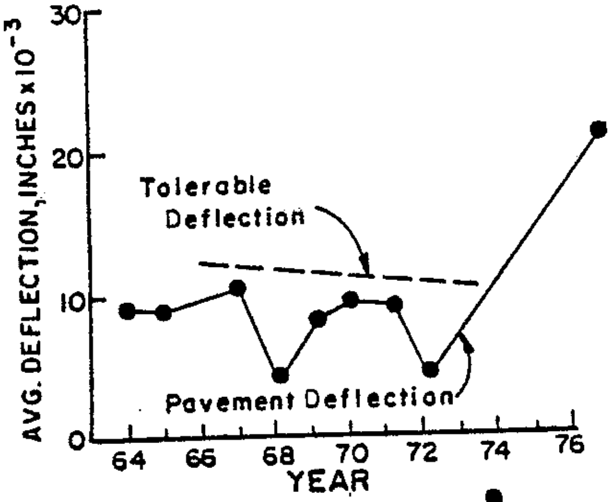
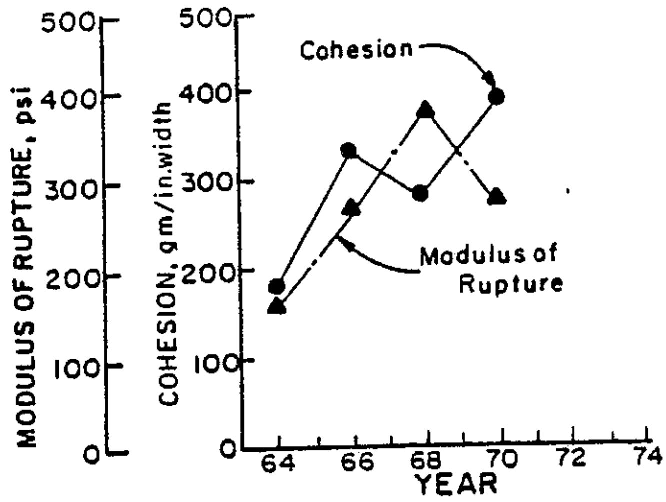
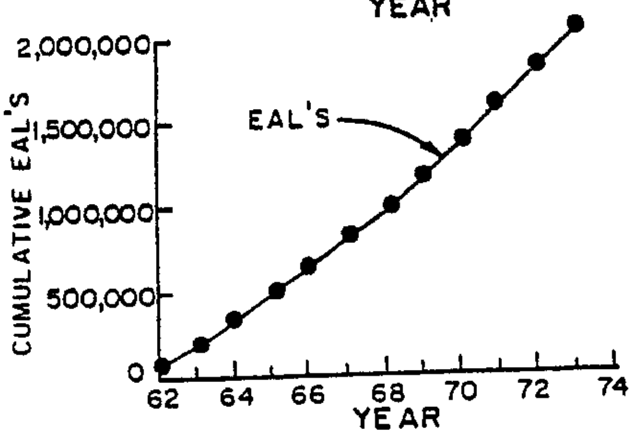


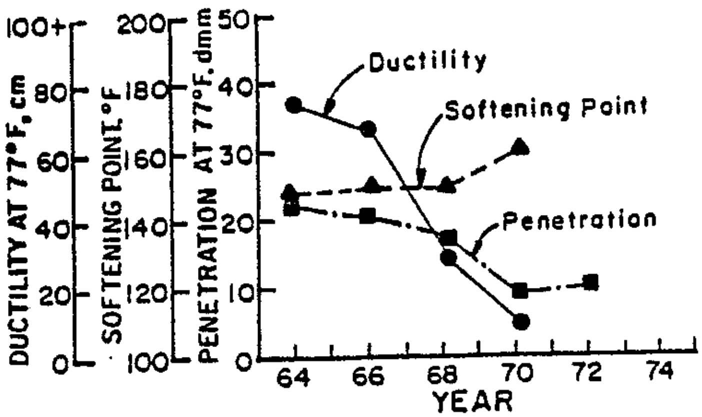
TABLE 24

PROJECT: 21 (10-Sol-680, 74 B)
CONTRACT NO: 60-10TC 18-FI
TEST SECTION: P.M. 0.0± to P.M. 7.4±
STRUCTURAL SECTION: 0.06' OGAC, 0.33' AC, 0.67' CTB, 1.00' ISM, 1.00' per mat'l.
COMPLETION DATE: 6-14-61



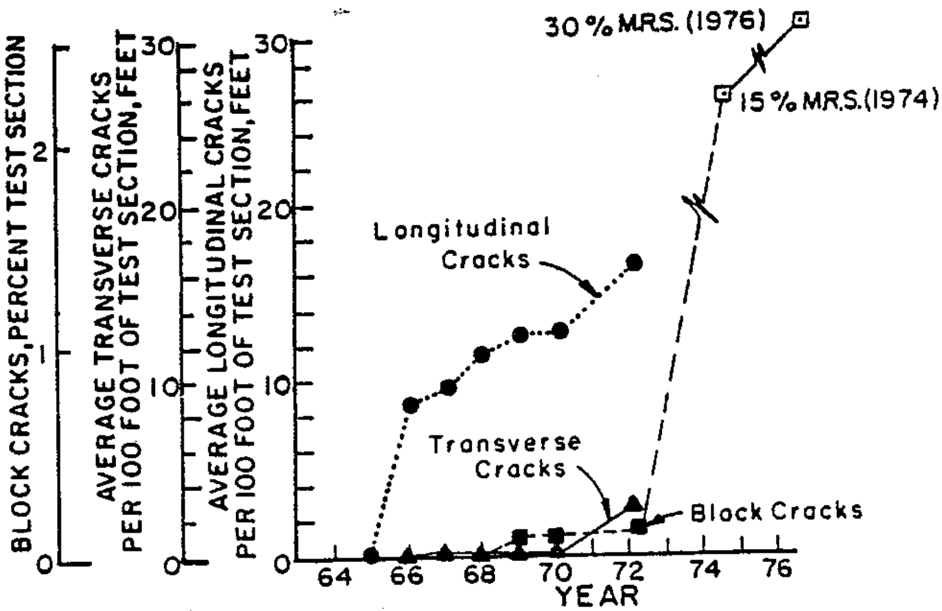






NOTES

T.I. ≈ 10.0 (1971 data)
Tolerable deflection = 0.011". Deflections have not exceeded tolerable levels. No significant block cracking in spite of low penetration and ductility.



⊡ Based on pavement condition survey from Maintenance Rating System

TABLE 25

(Column 1) Yes — Projects Where Deflections Did Exceed Tolerable Levels and Greater Than 10% Cracks Developed				(Column 2) Yes — Projects Where Deflections Below Tolerable Level and Less Than 10% Cracks Developed				(Column 3) No — Projects Where Deflections Exceed Tolerable Level, But Cracking Did Not Develop				(Column 4) No — Projects Where Deflections Did Not Exceed Tolerable Levels, But Cracks Did Develop			
Project No.	Dist-Co-Rt	Year Const.	Years Service	Project No.	Dist-Co-Rt	Year Const.	Years Service	Project No.	Dist-Co-Rt	Year Const.	Years Service	Project No.	Dist-Co-Rt	Year Const.	Years Service
1	03-Col-45	1961	12	2	03-Gle-162	1961	14					12B	05-SBt-156	1961	14
4C	03-Sac-99	1960	14	4A	03-Sac-99	1959	12+					13	05-SLO-1	1963	12
6	04-Nap-121 (29)	1962	11	4B	03-Sac-99	1960	14					16	06-Kin,Tul-43	1963	10
7	05-Mon-101	1963	12	17	06-Fre-811	1964	14+					8	05-Mon-101	1960	14
11	05-SBt-156	1962	13	18	06-Fre-1329	1964	14+					10	05-SB-246	1961	8
12A	05-SBt-156	1967	7	20	10-Cal-49	1964	14+					5	03-Yol-99,84	1961	10
14	06-Ker-204	1964	11												
15	06-Kin-198	1963	6												
19	06-Fre-33	1961	11												
21	10-Sol-680	1961	12												

16/22 = 73% Supports the theory

6/22 = 27% Does not support theory

Combining Variables to Evaluate Pavement Performance

Our analysis thus far has been a comparison of pavement performance to deflection and asphalt properties on an individual basis. It is obvious that both factors, in combinations, contribute significantly to the overall pavement performance. Highter and Harr (8) have found in their analysis of fatigue-type failures on the AASHO Road Test and certain airport investigations that there is a good relationship between cumulative deflections and pavement performance. The cumulative deflection is a measure of the destructive factor of a pavement and is calculated by multiplying the number of equivalent wheel loads (EWL's) by the average deflection of the pavement over the same time period. In order to analyze the pavement performance by a system more closely related to the actual physical behavior of the pavement during its life cycle, asphalt properties should be incorporated into the analysis.

In reviewing the data from Tables 3 to 24, it was noted that the asphalt property data after the 1970-72 period was limited. It was therefore decided to approach this phase of the study by using the test data compiled from the Zaca-Wigmore Test Road which was more complete (9). The enormous amount of test data obtained from this study contains the needed deflections, traffic loadings, asphalt property information and recorded alligator-type cracking to evaluate the "destructive factor" concept incorporating modifications for asphalt properties.

During the early stages of construction on the Zaca-Wigmore Test Road a series of asphalts were incorporated into individual test sections on new alignment with a common structural section (9). An important aspect of the project was that all of the test sections had equivalent amounts of loading during service life. However, deflection measurements showed there were differences between test sections.

The destructive factor was calculated by multiplying the number of EWL's for a given observation period by the average deflection of the travel lane (outer wheel track) for the same period to produce the cumulative damage factor in feet. An example of calculations for the destructive factor is shown below:

Given:

Time Period: May 1956 to March 1957

Average Deflection: 0.011 inch

EWL's: 61,042 per month (May 1956 to December 1956)

101,625 per month (January 1957 to March 1957)

Destructive Factor (May 1956 to December 1956)

$$\frac{61,042(7)(0.011)}{12} = 392 \text{ feet}$$

Destructive Factor (January 1957 to March 1957)

$$\frac{101,625(3)(0.011)}{12} = 280 \text{ feet}$$

Total Destructive Factor = 280 feet + 392 feet = 672 feet
(May 1956 to March 1957)

Table 26 presents the cumulated destructive factor, percentage of alligator cracking, recovered core penetration and ductility for each observation period on nine test sections paved during Period I over new alignment.

In order to provide more information on the properties of the asphalt, the stiffness values at 77°F and 40°F were calculated by the method of van der Poel (10). A 0.1 second loading time was used in the calculations.

The data used in the computer analysis are shown in Table 27. This includes the percent of alligator cracking, the destructive factor as measured by the cumulative deflection in feet, the pavement age in months, and the recovered asphalt penetration and stiffness values at 77°F and 40°F.

The combined analysis is based on the following:

1. The destructive factor causing fatigue of the pavement as measured by the percent of alligator cracking is best estimated by the average amount of deflection during any given period and the number of times the pavement is subjected to this deflection.

2. The difference in performance of any given pavement for the same amount of cumulative deflection is caused by changes in asphalt properties during pavement service life.

On this basis, the environmental factors and pavement voids will influence the asphalt properties in a detrimental manner, and so will cause an influence on the rate of failure as measured by the percent of alligator cracking. However, it is not necessary to measure such factors since their overall effect is on the asphalt properties within the pavement.

On the basis of the above, a computer program involving a stepwise-multiple regression analysis was performed on the five variables shown in Table 27 using the following:

Dependent Variable

Col. (1) Percent Alligator Cracking

Independent Variables

Col. (2) Destructive Factor (Cumulative deflection in feet)

Col. (3) Penetration at 77°F of recovered asphalt

Col. (4) Stiffness at 77°F of recovered asphalt

Col. (5) Stiffness at 40°F of recovered asphalt

The results of the computer analyses are shown below:

Percent Alligator Cracking = -2.12 + 0.0013 (Cumulative Deflection)

Correlation Coefficient = 0.67

Percent Alligator Cracking = -8.25 + 0.0012 (Cumulative Deflection + 0.043 (Stiffness at 77°F)

Correlation Coefficient = 0.86

Percent Alligator Cracking = -21.32 + 0.0013 (Cumulative Deflection) + 0.32 (Penetration at 77°F) + 0.061 (Stiffness at 77°F)

Correlation Coefficient + 0.86

Percent Alligator Cracking = -20.95 + 0.0014 (Cumulative Deflection) + 0.36 (Penetration at 77°F) + 0.079 (Stiffness at 77°F) -0.0022 (Stiffness at 40°F)

Correlation Coefficient = 0.87

When the percent of alligator cracking is compared with only the destructive factor on a one-to-one basis a relatively poor correlation (0.67) is obtained. When stiffness of the recovered asphalt (77°F) is added to the analysis, the correlation is markedly improved (0.86). When penetration at 77°F and stiffness at 40°F are added to the analysis, the correlation improves a small amount (0.87). Ductility values were not included in this study as a separate independent variable. The inclusion of ductility is assumed to be indirectly accounted for in the stiffness calculations since Heukelum (11) found a relationship between ductility and stiffness. However, on the basis of other studies, there is no reason to doubt the importance of a drop in ductility with the hardening of the asphalt (7),(12).

This study confirms other studies that fatigue cracking is caused by the number of loadings and the magnitude of the strain (deflection) caused by these repeated loads. We note that such fatigue cracking can be induced in the laboratory by repeated loading or deflection of a specimen over a period of time that is so short that little change in asphalt properties will take place. A reduction in load or deflection would increase fatigue life. Therefore, it is possible to fatigue-fail any asphalt pavement by a high enough strain repeated often enough without a real material change in asphalt properties. This type of failure may explain the rapid breakup of the traveled lane (truck lane) of pavement sections subjected to high moisture contents in the subgrade over an initial loading period of one or two years. Rapid breakup of pavement has been reported to occur during the spring in some northern states when subgrade conditions create high deflection conditions. Weight restrictions in these states during the spring months are often imposed. An important consideration also is that the ability of a pavement to carry loads without fatigue failure decreases as the asphalt ages.

Longer term fatigue cracking is definitely influenced by the change in asphalt properties. This is confirmed by the presented analysis. Here a relationship is attained between the percentage of alligator cracking and the destructive factor plus the asphalt properties. These two dependent variables are definitely interrelated. A detrimental change in asphalt properties alone may not cause a serious fatigue failure if the destructive factor remains low, and in fact no fatigue failure may occur, although block cracking (caused by other forces) may become a common occurrence.

Our present method of overlay design is primarily based on reducing the deflection to a tolerable level that will result in a satisfactory fatigue life. Therefore, any modifications in mix design or in construction practices which would aid in preventing changes in original asphalt properties or the use of highly durable (stable) asphalts should definitely increase the service life of the overlay. Other research effort should and is being directed toward this end.

TABLE 26

RESULTS FOR VARIOUS TEST SECTIONS

Code	Source	Pvt. Per.	Age Interval Mo.	Destructive Factor Total - Ft.	Percent Alligator Cracking	Rec. Core Pen-77°F	Rec. Duct. 77°F
A	Shell	I	0-5	827	0	125	100+
			5-13	1995	0	81	100+
			13-18	2300	0	60	100+
			18-28	2972	0	46	100+
			28-36	3717	0	42	100+
			36-41	4302	0.2	40	100+
			41-48	5156	0.4	38	100+
			48-53	5828	0.9	36	100+
			53-65	8088	1.6	32	100+
			65-77	11170	4.7	28	100+
			77-88	13806	12.8	25	100+
			88-101	16674	18.0	22	100+
C	Stand.	I	0.5	535	0	125	100+
			5-13	1469	0	88	100+
			13-18	1736	0	70	100+
			18-28	2224	0	46	100+
			28-36	2732	0	43	100+
			36-41	3122	1.4	41	100+
			41-48	3843	1.0	38	100+
			48-53	4472	1.4	37	100+
			53-65	6434	3.7	33	100+
			65-77	9370	7.9	29	100+
			77-88	12292	11.1	27	100+
			88-101	15639	16.0	24	100+

TABLE 26 (con't.)

Code	Source	Pvt. Per.	Age Interval Mo.	Destructive Factor Total - Ft.	Percent Alligator Cracking	Rec. Core Pen-77°F	Rec. Duct. 77°F
D	Golden Bear	I	0-5	584	0	145	100+
			5-13	1549	0	91	100+
			13-18	1842	0	77	100+
			18-28	2483	0.4	56	100+
			28-36	3194	-	51	100+
			36-41	3759	1.4	48	100+
			41-48	4613	1.5	44	100+
			48-53	5263	2.7	42	100+
			53-65	7522	1.8	37	100+
			65-77	10663	10.1	33	100+
			77-88	13413	15.5	29	100+
			88-101	16213	22.0	25	100+
E	Western	I	0-5	535	0	75	100+
			5-13	1469	0	38	100+
			13-18	1787	0	24	100+
			18-28	2519	0.4	18	100+
			28-36	3264	8.0	15	100+
			36-41	3829	13.0	13	16
			41-48	4763	25.0	10	5
F	Sunray Sect.2	I	0-5	535	0	85	100+
			5-13	1401	0	57	100+
			13-18	1630	0.04	46	100+
			18-28	2210	0.1	39	100+
			28-36	2820	0.3	35	21
			36-41	3288	0.4	33	-
			41-48	3929	0.4	31	-
			48-53	4536	6.4	29	-

TABLE 26 (con't.)

Code	Source	Pvt. Per.	Age Interval Mo.	Destructive Factor Total - Ft.	Percent Alligator Cracking	Rec. Core Pen-77°F	Rec. Duct. 77°F
G	Douglas Santa Maria	I	0-5	486	0	84	82
			5-13	1187	0	54	-
			13-18	1390	0	42	7
			18-28	1848	0	36	-
			28-36	2458	1.8	32	12
			36-41	2965	2.9	29	-
			41-48	3632	1.1	26	-
			48-53	4174	9.4	25	8
H	Douglas Los Angeles	I	0-5	694	0	110	100+
			5-13	1862	0	62	100+
			13-18	2180	0	43	100+
			18-28	2882	0	34	100+
			28-36	3695	0	33	100+
			36-41	4377	0	32	100+
			41-48	5445	0	31	100+
			48-53	6312	0	30	100+
			53-65	9225	0.1	28	100+
			65-77	13117	0.5	26	100+
			77-88	16268	5.6	25	100+
			88-101	19751	26.0	24	100+
			101-113	23318	36.0	22	100+

TABLE 26 (con't.)

Code	Source	Pvt. Per.	Age Interval Mo.	Destructive Factor Total - Ft.	Percent Alligator Cracking	Rec. Core Pen-77°F	Rec. Duct. 77°F
J	Macmillan	I	0-5	486	0	155	100+
			5-13	1303	0	92	100+
			13-18	1570	0	66	100+
			18-28	2211	0	59	100+
			28-36	2990	0	56	100+
			36-41	3497	0	55	100+
			41-48	4218	0	52	100+
			48-53	4803	0	51	100+
			53-65	6587	0	48	100+
			65-77	8977	0	45	100+
			77-88	10868	0	42	100+
			88-101	12849	0	39	100+
			101-113	14665	2.4	37	100+
F	Sunray Sect.1	I	0-5	438	0	88	100+
			5-13	1177	0	57	100+
			13-18	1406	0	46	100+
			18-28	1894	0	39	21
			28-36	2334	0	35	-
			36-41	2646	0	33	-
			41-48	3180	0.1	31	-
			48-53	3527	-	29	-
			53-65	4538	1.5	25	-
			65-77	6245	4.5	22	-
			77-88	7906	8.3	19	-
			88-101	9955	21.0	17	-
			101-113	12030	44.0	14	-

TABLE 27

DATA FOR REGRESSION ANALYSIS

(1) Dependent % Alligator Cracking	(2) Indep. Cumulative Defl. Ft.	(3) Indep. Penetration 77°F	(4) Indep. Stiffness kg/cm^2 77°F Asphalt	(5) Indep. Stiffness kg/cm^2 40°F Asphalt
0.2	4302	40	41	1020
0.4	5156	38	51	1530
0.9	5828	36	61	1650
1.6	8088	32	102	2040
4.7	11170	28	143	2620
12.8	13806	25	184	2856
18.0	16674	22	204	4080
1.4	3122	41	69	1800
1.0	3843	38	77	2000
1.4	4472	37	82	2142
3.7	6434	33	102	2550
7.9	9370	29	112	2958
11.1	12292	27	153	3570
16.0	15639	24	173	4080
1.4	3759	48	41	1326
1.5	4613	44	51	1530
2.7	5263	42	57	1650
1.8	7522	37	92	2040
10.1	10663	33	105	2650
15.5	13413	29	130	3050
22.0	16213	25	153	3600
0.4	2519	18	306	4080
8.0	3264	15	408	4590
13.0	3829	13	510	5100
25.0	4763	10	612	6120
0.1	2210	39	71	1400
0.3	2820	35	96	1550
0.4	3288	33	110	1650
0.4	3929	31	130	1750
6.4	4536	29	150	1800
1.8	2438	32	92	1326
2.9	2965	29	102	1428
1.1	3632	26	135	1500
9.4	4174	25	153	1530
0.1	9225	28	143	2142
0.5	13117	26	153	2244
5.6	16268	25	163	2346
26.0	19751	24	184	2448
36.0	23318	22	204	2550
1.5	4538	25	173	1836
4.5	6245	22	194	2040
8.3	7906	19	235	2244
21.0	9955	17	306	2448
44.0	12030	14	490	4080

PHASE III - EVALUATION OF SYSTEMS TO MINIMIZE REFLECTION CRACKING

In 1976, an interim report was published on this study that investigated eight experimental overlay projects utilizing various systems to minimize reflection cracking (4). The construction of these projects occurred between the summers of 1972 and 1974. The projects, listed in Table 2, were reevaluated since the fall of 1976 and pertinent crack count summaries for the various projects are shown in Tables 28 through 30.

Project 02-Las-395-29.8/31.8

This project is located near Doyle, California between Reno, Nevada and Susanville, California. In 1972, prior to being overlaid, the asphalt concrete surface exhibited extensive map or block cracking throughout. Annual temperature variations for this region range from about 20°F to 100°F. Average rainfall is nearly 15 inches per year.

As shown in Table 28, the additional 0.12 foot in thickness of the AC section has performed better than any other system used on this project. As of August of 1978 (6 years after construction), only 2 percent reflection cracking had occurred. The stress-relieving interlayer systems, both the rubberized (SRI) and the emulsion slurry seal system (ESS), and the Petroset test section failed by the summer of 1975. The control sections adjacent to these test sections (Sta. 0+00 to Sta. 38+00) were also badly cracked and for convenience were chip sealed during the fall of 1975. It was concluded that no measurable benefits were obtained with the stress relieving interlayer systems or Petroset.

A surprising result was obtained with the additional tack coat section known as the Petrolastic test section. This section performed as well as the Petromat test section with the only difference in construction being that no fabric was placed over the heavy 0.30 gal/yd^2 tack coat of RS-2 emulsion prior to the overlay. However, both sections, although somewhat better than the adjacent control sections, would not be considered a success when compared to the additional thickness of AC section.

Our final evaluation after 6 years resulted in the followang findings: (1) The best performance was achieved with the additional thickness of AC. Reflection cracking was approximately 7 percent of the amount for the control sections. (2) The Petromat test section and the Petrolastic test section performed about the same and developed approximately 40 percent to 60 percent of the reflection cracking of the control sections. (3) No significant benefits were achieved using the SRI, ESS, and the Petroset systems to minimize reflection cracking.

Project 03-Pla-80-31.3/33.2

This project located near Colfax, California, is part of the Interstate Highway System. Annual temperature variations for this region range from 23°F to 106°F. Average rainfall is nearly 47 inches per year. This section of roadway was constructed in 1959 with a structural section consisting of 0.30 foot AC over 0.67 foot CTB over 0.67 foot subbase. In July of 1972, longitudinal and transverse cracks were visible throughout most of the project and secondary cracking existed in the outer wheel tracks. The transverse cracks were spaced at about 10 to 20 foot intervals primarily due to shrinkage/thermal cracking of the cement treated base. The experimental overlay systems were constructed during July of 1974 (see Table 29). Condition surveys on the various test sections were made after 35 and 49 months of service. To date, it is too early to tell if any significant benefits will be obtained from the various systems. Periodic inspection of these test sections will continue under a research project that was established to evaluate the various types of fabric reinforcement materials.

Project 08-Riv-15-28.09/28.53

This overlay project is located approximately 15 miles south of Riverside, California, on Interstate 15. Annual temperature variations for this region range from 23°F to 115°F. Average rainfall is about 11 inches per year.

This experimental overlay project consisting of: (1) one-inch AC (control), (2) one-inch AC over Petromat, (3) 0.35 foot AC over Petromat and (4) 0.35 foot AC (control) was constructed on September 25, 1972. Alligator cracks less than 1/8-inch wide were observed in the wheelpaths prior to placing the overlays (Table 30). Pumping was also noted.

Approximately two years after construction the one-inch AC control section showed 98 percent reflection alligator cracking. At the same time the one-inch AC overlay with Petromat section showed 31 percent reflection cracking. There was considerably less pumping of the fines in the Petromat test area where the cracks had reflected through than in the control section. This would tend to substantiate claims that Petromat improves the waterproofing qualities of the overlay. After nearly four years, the amount of reflection cracking showed the one-inch AC overlay control section to be in worse condition than it was prior to the overlay in 1972. At this time, the one-inch AC overlay with Petromat showed 43 percent reflection alligator cracking, (see Table 30). The one-inch AC control section was chip sealed during April of 1976. The last condition survey was made during February of 1977. Reflection alligator cracking for the one-inch AC overlay with Petromat section was 47 percent. A thin open-graded asphalt concrete overlay was placed over the entire project during the summer of 1978 as part of a maintenance resurfacing project on Route 15. It should be noted that the 0.35 foot AC sections (with and without Petromat) showed no reflection alligator cracking throughout the life of the project.

Based on the performance of the project, it was estimated that the use of Petromat extended the service life of the one-inch AC overlay approximately 3 to 4 years. However, a comparison of the performance of Petromat plus the one-inch AC overlay versus the one-inch AC plus additional AC (approximately equal to the cost of Petromat) was not made.

11-Imp-115-22.0/23.9

This project is located in the Imperial Valley near Brawley, California, where the climate is hot and dry. Annual temperature variations for this region range from 25°F to 120°F. Average rainfall is less than 3 inches per year. This experimental overlay project consisting of: 0.10 foot AC over Petromat, 0.20 foot AC over Petromat, 0.20 foot AC (control), 0.35 foot AC (control), and rubberized chip seal section was constructed during the fall of 1974. The condition of the roadway prior to the overlay was badly alligator cracked and appeared dry and brittle.

After four years of service, no reflection cracking was noted on either the Petromat or control sections. In the rubberized chip seal test section, intermittent to continuous alligator cracks were observed throughout the project. Even though alligator cracking was visible through the chip seal, the rubberized membrane appeared to seal the surface and hold the badly distressted roadway together.

It is too early to tell if any significant benefits will be obtained from the various systems on this project. Periodic inspection of these test sections will also continue under a research project that was established to evaluate the various types of fabric reinforcement materials.

07-LA-1-3.4/8.3

On this project, Petromat was placed during January of 1973 at various locations on the Pacific Coast Highway in the City of Long Beach, California. Annual temperature variations for this region range from 33°F to 111°F. Average rainfall is about 13 inches per year. The pavement prior to the overlay was old PCC, and AC over old PCC. The experimental sections on this project consisted of:

Test Section	Existing Pavement	Experimental System
1	AC over PCC	Petromat + 0.15' AC
2	AC over PCC	Petromat + 0.15' AC
3	PCC	Petromat + 0.20' AC
4	AC over PCC	Petromat + 0.15' AC
5	AC over PCC	Petromat + 0.15' AC
6	PCC	Petromat + 0.20' AC
7	PCC	Petromat + 0.10' AC

After five years, test sections 1, 2, 4 and 5 (existing pavement AC over PCC) had no significant reflection cracking, nor were cracks noted in the adjacent control sections. Test sections 3 and 6 which were Petromat and 0.20 foot AC over old PCC also had no significant cracking after 5 years. On test section 7, which was 0.10 foot AC over Petromat placed on PCC transverse and longitudinal joints, the transverse joints had reflected through after only one year on both the Petromat section and the control section. Five years after construction, longitudinal reflection cracking was 72 percent in the control section (no Petromat) and three percent in the Petromat section.

It is too early to tell if any significant benefit will be obtained from the Petromat throughout most of this project. Periodic inspection of these test sections will also continue under a research project established to evaluate the various types of fabric reinforcement materials.

<u>06-Ker-43-0.1/8.3</u>

This project located near Bakersfield, California, has a annual temperature range from 25°F to 112°F with an annual rainfall of about 6 inches. The existing AC pavement (in 1972) had continuous alligator cracking in both the inner and outer wheelpaths. Heater-remixing of the existing pavement plus a Reclamite treatment was performed on this project prior to the placement of a one-inch AC blanket in the fall of 1972. Two years later, Reclamite was again applied to the AC surface of the test sections (0.10 gal/yd^2). In 1976, a chip seal was placed over most of this project (P.M. 2.00$\pm$ to P.M. 9.16$\pm$) primarily due to the poor performance of the control section (P.M. 8.11$\pm$ to P.M. 9.16$\pm$). It was noted that the heater-remixing with Reclamite test section was in reasonably good condition prior to the placement of the chip seal. An inspection of this project during the fall of 1978 showed that the heater-remixing with Reclamite test section was performing well. Average alligator cracking in the wheelpaths was only five percent and patching was less than one percent on the entire roadway.

An adjacent segment of Route 43 from P.M. 9.50 to P.M. 10.00 (without the heater-remixing and Reclamite treatment prior to the one-inch AC blanket in 1972) exhibited average alligator cracking of 24 percent in the wheelpaths, and patching covered 36 percent of the roadway.

02-Las-36-25.2±/25.6±

During the fall of 1972, Reclamite was applied as a construction seal to a freshly paved one-inch AC overlay in the City of Susanville. The application rate was 0.06 gallons per square yard on the 10 feet wide by 2200 feet long test section. The annual temperature range for this region is from -20°F to 100°F with an annual rainfall of nearly 15 inches. After six years of service, approximately 75 percent of the original transverse cracks reflected through the one-inch AC overlay. Longitudinal reflection cracking was only about five percent. It was noted that the reflection cracking in the Reclamite test sections was similar in extent and severity to the control sections (no Reclamite). It was therefore concluded that Reclamite was not effective as a system to minimize reflection cracking. However, the surface texture of the Reclamite test sections appeared to have retained considerably more fines than the control sections. It was concluded on this project that Reclamite did effectively reduce ravelling of the asphalt concrete surface.

05-SLO-101-8.0/12.2

This project is located in a coastal region of the State, near Arroyo Grande, California.

During the summer of 1972, a 0.06 foot open-graded AC overlay was placed prior to placing 0.30 foot dense graded asphalt concrete (placement of a dense-graded AC over open-graded AC is termed an "inverted" overlay since open-graded mixes are generally placed as a surface course). The existing pavement prior to the overlays consisted of both AC and PCC surfaces. The PCC pavement was subsealed prior to resurfacing. Annual temperature variations for this areas range from 26°F to 104°F and average rainfall is about 16 inches per year.

An inspection in the fall of 1978 showed the roadway to be performing well. Few visible transverse and longitudinal cracks were noted throughout the project. No patching or alligator cracking was observed. To date, it appears too early to tell if any significant benefits will be obtained from the "inverted" system. Experience with overlay design has shown that 0.40 foot AC overlay has provided good performance over both AC and PCC pavements. This project will also continue to be evaluated on a regular basis.

11-SD-78-7.5/15.6

This project is located near Vista, California. Petromat, Petroset AT and Reclamite were placed in conjunction with an 0.08 foot maintenance blanket on December 4 and 5, 1972. The existing 0.33 foot AC surfacing was alligator cracked with fines pumping through the cracks, the cracks were generally less than 1/8-inch wide. The temperature variations for this region range from 26°F to 105°F and the rainfall is about 11 inches per year.

Reflection cracking in the control sections (one-inch AC without Petromat) first started during the spring of 1973. Sand seals were applied to the control sections in 1976 and 1977. Cracking first appeared in the six Petromat test sections during May of 1977. At that time, very fine isolated longitudinal cracks were observed. During January of 1978, another inspection of the project was made. Reflection cracking in the control sections was 100 percent. Some rutting and the pumping of fines were noted in both wheelpaths.

Longitudinal reflection cracking in the Petromat test sections averaged only 17 feet per 100 feet of test section. It was concluded that the use of Petromat on this project prolonged the life of the one-inch AC blanket a minimum of four years.

The use of Reclamite and Petroset AT on this project were shown to be ineffective as systems to minimize reflection cracking. Both products did however appear to be beneficial in retaining fines in the surface of the asphalt concrete pavement.

TABLE 28

Project 02-Las-395-29.8/31.8

Section	Station	Cracking (Lineal Ft/100 Feet) Before (8-30-72)	After (5-10-74)	After (1-23-75)	Afeer (12-4-75)	After (7-14-76)	After (8-28-78)	Percent Reflection Cracks to Date
Control	0+00 to 8+00	300	91	100	Chip Sealed (August 1975)	Chip Sealed* (August 1975)	Chip Sealed (August 1975)	
SRI	8+00 to 18+00	270	15	58	"	"	"	
Control	18+00 to 20+00	250	62	73	"	"	"	
ESS	20+00 to 30+00	235	75	88	"	"	"	
Control	30+00 to 38+00	130	61	73	"	"	"	
Petroset	38+00 to 48+00	220	50	66	67	"	"	
Additional 0.12' AC	50+00 to 60+00	260	1	2	2	2	5	2
Petrolastic with 0.20 gal/yd Tack Coat	62+00 to 72+00	290	11	15	18	18	37	13
Control	72+00 to 80+00	330	76	80	87	87	98	30
Petromat	80+00 to 90+00	250	9	16	23	29	44	18
Control	90+00 to 92+00	250	17	41	44	46	Maintenance Patch/ Chip Seal	

*No experimental materials, a total of 0.20' AC placed to compare with the one inch AC experiment.

TABLE 29

03-Pla-80-31.33/33.19

Date of construction of experimental overlay: July 1974

Section	Station	Cracking (Average lineal feet per 100 foot of test section)			
		(Before Overlay) July 1974	(After 35 Months) June 1977	(After 49 Months) August 1978	Percent Cracks Reflection to Date
0.2'AC Control	0+00 to 14+87	288	21	27	9
Petroset 0.1 gal/yd^2 over 0.2'AC	14+87 to 21+17	351	1	1	0.3
0.2'AC Control	21+17 to 35+00	288	6	8	3
0.2'AC over Petromat	35+00 to 45+00	220	0	0	0
0.2'AC Control	45+00 to 48+12	227	2	2	1
0.1'AC over 0.1'OGAC	48+12 to 59+00	190	0	5	3
0.1'to 0.2'AC over 0.1'OGAC	59+00 to 60+50	145	0	0	0
0.2'AC over 0.1'OGAC	60+50 to 70+95	240	2	2	1
0.3'AC Control	70+95 to 81+00	197	0	0	0
0.2'to 0.3'AC Control	81+00 to 82+00	158	0	0	0
0.20'AC Control	82+00 to 98+00	150	3	6	4

TABLE 30

Project 08-Riv-15-28.09/28.53

Overlay placed on roadway: Sept. 25, 1972

Section	Overlay Thickness	Station	Cracking: Before Overlay 6/26/72 (1) Alligator	Before Overlay 6/26/72 (2) Lineal	After Overlay 11/14/74 (1) Alligator	After Overlay 11/14/74 (2) Lineal	After Overlay 4/6/76 (1) Alligator	After Overlay 4/6/76 (2) Lineal	After Overlay 2/16/77 (1) Alligator	After Overlay 2/16/77 (2) Lineal
Control	1"	9+00 to 11+00	238	28	233	0	315	0	Chip Sealed (April 1976)	Chip Sealed (April 1976)
Petromat	1"	13+00 to 18+56	202	48	62	10	87	43	94	76
Petromat	0.35'	21+00 to 27+00	275	11	0	0	0	0	0	0
Control	0.35'	27+00 to 32+00	369	0	0	0	0	0	0	0

(1) Average square feet of alligator cracks (in wheelpaths) per 100 foot of test section.

(2) Average transverse and longitudinal cracks per 100 foot of test section.

A thin OGAC overlay was placed over the entire project during the summer of 1978.

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APPENDIX A

History of Pavement Deflection

The California Department of Transportaton has utilized deflection measurements for the evaluation of flexible pavements for nearly 40 years. 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 distressed flexible pavement sections.

During the WASHO Road Test (1952-1954), a device called the Benkelman beam was developed which greatly simplified the method of measuring pavement deflections under wheel loadings. The Benkelman beam (Figures 1 and 6, Appendix B) operates on a simple-lever arm principle and was first used by the California Department of Transportation in 1954. From 1954 to 1972, the standard test load used in conjunction with the Benkelman beam was a rear single axle load of 15,000 pounds. After 1972, the rear axle load was increased to 18,000 pounds. Between 300 and 400 individual deflection measurements can be made in an average work day with the Benkelman beam.

In 1960, an automatic deflection measuring device was developed by the Transportation Laboratory based on the Benkelman beam principle. The electromechanical device, called the Deflectometer, is a tractor-trailer unit with a standard single axle load on the rear tires and a carriage to support probes for measuring pavement deflections under both dual wheel assemblies simultaneously. During operation, pavement deflections are measured at approximately 20-foot intervals and are permanently recorded on chart paper within the trailer unit as the Deflectometer moves steadily along the pavement surface at about one-half mile per hour. A newer version Deflectometer was developed in 1967. This device (Figure 2, Appendix B) is currently the pavement deflection standard of the California Department of Transportation. From 1960 to 1972, the standard test load for the Deflectometer was 15,000 pounds; after 1972, it was increased to 18,000 pounds. Between 1,500 and 2,000 individual deflection measurements can be made during an average work day.

In 1965, a commercial manufacturer developed a device called the Dynaflect that is currently used by the California Department of Transportation (Figure 3, Appendix B). The Dynaflect is an electromechanical system for measuring the dynamic deflection of a pavement surface produced by an oscillatory load. The device consists of a dynamic force generator together with five motion sensing geophones mounted on a small trailer. In test position, the Dynaflect exerts a 1,000 pound peak to peak oscillatory load onto the pavement surface through two rubber covered steel test wheels. The resulting amplitude of deflection is picked up by the geophones and is read on a meter located in the tow vehicle. The Dynaflect must be in a stopped position to measure pavement deflections.

On occasion, the California Department of Transportation uses a Dehlen Curvature Meter to determine radius of curvature values and estimate pavement deflections. This device consists of a dial gage fixed at the center of a 13-inch aluminum bar (see Figure 5, Appendix B). By placing this device between the dual wheels of a loaded test vehicle, it is possible to measure the middle ordinate of a curve having a chord length of 12 inches in the deflection basin.

It should be reemphasized that the Deflectometer is the current deflection standard of the California Department of Transportation. The Dynaflect, Benkelman beam and Dehlen Curvature Meter have all been correlated to the Deflectometer for evaluation purposes. All deflection values in this study are in terms of equivalent Deflectometer (18,000 pound single axle test load).

As a point of interest, correlation studies have also been made between California's Deflectometer and other deflection equipment. The model 400 Road Rater, developed by the Foundation Mechanics, Inc., the Dynaflect owned by Testing Engineers, Inc., the Cox Deflection Device developed by Cox and Sons, Inc. and the WES Device developed by the U.S. Army Corps of Engineers have all been correlated with the California Deflectometer (13).

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

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California Test 356
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METHODS OF TEST TO DETERMINE OVERLAY REQUIREMENTS BY PAVEMENT DEFLECTION MEASUREMENTS

A. SCOPE

Five pavement deflection measuring devices and the procedures used for determining overlay requirements for existing asphalt concrete roadways by deflection analyses are described in this test method. Basically, the method consists of measuring the total pavement deflection resulting from the application of an 18,000 pound (8,200 kg) single axle load [9,000 pound (4,100 kg) dual wheel load]. The deflection readings are then compared to previously determined allowable limits for a similar structural section and traffic volume in terms of equivalent 18,000 pound (8,200 kg) axle loads. Corrective treatment is described as the cover required to reduce the deflection to a level at which the surface will be unlikely to fail due to fatigue.

B. EQUIPMENT

1. *Benkelman Beam.* This instrument (Figures 1 and 6) operates on a simple lever arm principle. An 8-foot-long (2.4 m) probe is inserted between the dual tires [11.00 x 22.5, 12-ply and 70 psi (483 kN/m^2) pressure] of the truck which carries an 18,000 pound (8,200 kg) single axle test load. As the pavement is depressed, the beam pivots around a point of rotation on the reference beam which rests on the pavement behind the area of influence, so that the back four-foot extension of the beam depresses an Ames dial which records maximum deflection to within 0.001 inch (0.025 mm). While this device is limited to measurements of total deflection only for test vehicles operating at creep speed, it has the very important advantages of simplicity, versatility, and rapidity of measurements. Between 300 and 400 individual deflection measurements can be made in a day with this device.

2. *Deflectometer.* This instrument (Figure 2) is an automatic deflection measuring device based upon the Benkelman beam principle. It combines a tractor-trailer unit which carries an 18,000 pound (8,200 kg) single axle test load on the rear tires [11.00 x 22.5, 12-Ply and 70 psi (483 kN/m^2) pressure] and probes for measuring pavement deflection under both wheels simultaneously. The Deflectometer is an electro-mechanical instrument capable of measuring pavement deflections at 20 foot (6.1 m) intervals uniformly and continuously as the vehicle moves steadily along the road at one half mile (0.8 km) per hour. The deflections are measured to the nearest 0.001 inch (0.025 mm) by means of a probe arm resting on the pavement and are permanently recorded on chart paper. Between 1,500 and 2,000 individual deflection measurements can be made during an average working day.

3. *Dynaflect.* This device (Figure 3) is an electromechanical system for measuring the dynamic deflection of a roadway surface produced by an oscillatory load. This device consists of a dynamic force generator together with a motion measuring instrument, a calibration unit and a series of five motion sensing geophones mounted on a small trailer. The trailer in a stopped position exerts a 1,000 pound (454 kg) peak to peak oscillatory load onto the pavement surface through two rubber covered steel test wheels. The resulting amplitude of deflection is picked up by the geophones and is read as a deflection measurement on a meter located in the tow vehicle.

4. *Road Rater (Model 400).* This device (Figure 4) is similar to the Dynaflect. When operated at 25 cps with a 550 psi (3.79 MN/m^2) hydraulic system pressure and 0.058 inch (1.47 mm) mass displacement, the Road Rater exerts about a 600 pound (272 kg) peak to peak oscillatory load onto the pavement surface through two steel pads. Motion induced to the pavement is measured by two transducers. One is located at the center of loading and the other is out a distance of 12 inches (0.305 m). Pavement deflections are read from a meter on the control panel located in the cab of the vehicle.

5. *Dehlen Curvature Meter.* This device (Figure 5) consists of a ½ inch (1.27 cm) thick aluminum bar 1½ inches (3.81 cm) wide by 13 inches (33.0 cm) long with supporting feet at 12 inch (30.5 cm) centers and a 0.0005 inch (0.013 mm) dial gage, with 0.05 inch (1.3 mm) travel, fixed at the center of the bar. By placing this device between the dual wheels of a loaded test vehicle [18,000 pound (8,200 kg) single axle load and 11.00 x 22.5, 12-ply tires with 70 psi (483 kN/m^2) pressure], it is possible to measure the middle ordi-

nate of a curve having a chord length of 12 inches (30.5 cm) in the deflected basin. A radius of curvature can then be calculated and a deflection measurement estimated.

C. BACKGROUND DATA AND SELECTION OF TEST SITES

1. Collection of pertinent data on road to be tested.

a. Determine the existing structural section from contract records or other sources and note all variations.

b. Select appropriate Traffic Index.

c. Study contract files to determine foundation and drainage conditions and unusual construction conditions which may have had an effect upon the performance of the roadway.

2. Preliminary Field Work.

a. Determine nature, extent and limits of the various distress levels along with any vertical controls that are present and record on field note sheets.

b. Select one or more representative test sections for each change in visual condition or known change in structural section.

Reference each test section to a known or easily identifiable point in field. All test sections should include sufficient sight distance in both directions. Therefore, if possible, the location of test sections on horizontal or vertical curves should be avoided. Each test section should normally vary from 800 to 1,000 feet (244 to 305 m) in length and represent a centerline lane mile of roadway.

c. Obtain representative photographs of each test section and all localized areas of major distress.

D. FOUR METHODS OF DATA COLLECTION

1. *Benkelman Beam*—WASHTO Method

a. Bring test vehicle to stopped position at beginning of test section.

b. Position the beam between the duals so that the probe is 4.5 feet (1.4 m) forward of and perpendicular to the rear axle as shown in Figure 6.

c. Activate the vibrator and adjust the Ames dial to read 0.000 inches.

d. Drive the test vehicle approximately 25 feet (7.6 m) forward at creep speed and record the maximum dial reading (D_i) to the nearest 0.001 inch (0.025 mm).

e. After the dial needle has stabilized, record the final dial reading (D_f) to the nearest 0.001 inch (0.025 mm).

f. Pavement deflection $= 2\ (D_i) - D_f$.

g. Repeat this process at 25 foot (7.6 m) intervals longitudinally along centerline, alternating between wheel tracks, obtaining two (2) measurements in the outer wheel track for every one (1) measurement in the inner wheel track throughout the test section.

h. Report the average (mean) and evaluated 80th percentile (20 percent higher than and 80 percent lower than) deflection level of each wheel track (refer to Figure 7).

2. *Deflectometer*

a. Prepare unit for deflection testing and calibrate to nearest 0.001 inch (0.025 mm).

b. Obtain pavement deflection traces for both wheel tracks at 20 foot (6.1 m) intervals throughout each test section on the continuous chart.

c. By use of an event marker and by handwritten notations, indicate on the deflection chart the beginning and ending of each test section, location of cut and fill, road connections, post mile markers, culvert locations, bridges and other vertical control features, and limits and the extent of surface distress.

d. Read the deflection measurements from the deflection traces (Figure 8) to the nearest 0.001 inch (0.025 mm) and tabulate on deflection data sheets along with any accompanying notes. Refer to Figure 9.

e. Calculate and report the average (mean) and the evaluated 80th percentile (20 percent higher than and 80 percent lower than) deflection levels for both wheel tracks.

f. For comparison purposes only refer to Figure 16 for Benkelman Beam and Deflectometer.

3. *Dynaflect*

a. Set up and prepare unit for deflection testing.

b. Calibrate unit.

c. Obtain one (1) deflection measurement every 0.01 mile [approximately 53 feet (16 m)] in the wheel track which exhibits the most distress. The single No. 1 geophone is sufficient for most work.

d. Obtain a minimum of twenty (20) measurements per test section if possible.

e. Record measurements on Dynaflect data sheet with appropriate multiplier (refer to Figure 10). Also, record information concerning visual observations of pavement condition, road or street intersections, locations of cut and fill sections, post mile markers, and vertical control features.

f. Calculate average (mean) and evaluated 80th percentile Dynaflect deflection levels and convert to equivalent Deflectometer deflections using Figure 11.

g. For comparison purposes only refer to Figure 12 for Dynaflect and Benkelman Beam.

4. *Road Rater Model (400)*

a. Prepare unit for deflection testing.
b. Calibrate unit.
c. Obtain one (1) deflection measurement every 50 to 200 feet (15 to 61 m) in the wheel track which exhibits the most distress. The No. 1 transducer, at center of loading, is sufficient for most work.
d. Obtain a minimum of twenty (20) measurements per test section if possible.
e. Record pavement deflections and locations of measurements. Also record information concerning visual observations of pavement condition, road or street intersections, locations of cut and fill sections, post mile markers and vertical control features.
f. Calculate average (mean) and evaluated 80th percentile Road Rater deflection levels and convert to equivalent Deflectometer deflections using Figure 14.

5. *Dehlen Curvature Meter*

a. Bring test vehicle [18,000 pound (8,200 kg) single axle load on dual wheels] to stopped position.
b. Insert and center Dehlen Curvature Meter between one set of dual wheels with bar parallel to wheels and directly under the axle.
c. Record initial Ames dial measurement (d_i) to nearest 0.0001 inch (0.0025 mm).
d. Move test vehicle forward approximately 25 feet (7.6 m) at creep speed and record the maximum Ames dial rebound measurement (d_f) to nearest 0.0001 inch (0.0025 mm).
e. Calculate the radius of curvature (R) under the influence of the dual wheel load as follows:
$R \text{ (feet)} = 1.5/[d_f(\text{in.}) - d_i\text{ (in.)}]$
f. Repeat process at 25 foot (7.6 m) intervals longitudinally along centerline alternating between wheel tracks, obtaining two (2) measurements in the outer wheel tract for every one (1) measurement in the inner wheel track throughout the test section.
g. Calculate average (mean) and evaluated 80th percentile radius of curvature measurements and convert to equivalent Deflectometer deflection levels using either Figure 15 or 16 depending on whether the existing structural section consists of untreated aggregate base (Figure 15) or cement treated base (Figure 16). This provides an estimate of the deflection levels.
h. Report equivalent average (mean) and evaluated 80th percentile Deflectometer deflection levels.

E. HAZARDS

Follow the Transportation Laboratory's "Signing and Traffic Control Procedures for Slow Moving Test Vehicles Operating on Highways Open to Public Use" dated June, 1972. This is a modification of the signing and traffic control provisions in Figures 5-5, 5-6, and 5-7 of the Traffic Manual.

F. ANALYSIS OF DATA AND SELECTION OF OVERLAY

Repair or Maintenance Treatment

1. For an effective overlay design the following factors must be considered.

a. Cause of pavement failure.
b. Existing structural section materials.
c. Deflection magnitude of existing section.
d. Reflection cracking potential.
e. Traffic Index.
f. Tolerable deflection level.

2. Compare the measured evaluated 80th percentile deflection to the tolerable deflection level determined from Figure 17 for the existing pavement thickness at the design Traffic Index (T.I.).

If the measured evaluated 80th percentile deflection is less than the tolerable deflection, and reflection cracking does not control, no corrective repair is necessary other than a seal coat or thin AC blanket to seal cracks or improve appearance and riding quality.

Figure 18 shows percentage reduction in deflection obtained with varying increases in gravel equivalent thickness. This is the basic overlay design curve which may also be used in conjunction with Figure 17, "Tolerable Deflection Chart", to determine overlay thickness requirements.

3. Use of Overlay Design Chart

a. Enter Figure 19 with the predicted T.I. and follow this value vertically to the initial deflection curve (actual or interpolated) corresponding to the 80th percentile initial deflection.
b. Read the thickness of AC overlay required off the vertical scale.

4. The existence of vertical control features such as curbs and gutters may restrict overlay construction. In these situations digout repairs may be necessary and the nature of the reconstruction would be governed by the existing structural section materials. Where no vertical controls exist, utilization should be

made of the residual strength of the existing pavement by placing a contact overlay.

5. For some pavements, the magnitude of the existing deflection level is not a governing criterion for design. At times the need to eliminate potential reflection cracking from the underlying pavement establishes the AC blanket thickness.

6. Examples

a. *Problem No. 1 (Deflections Control)*

T.I. = 9.0
Existing Structural Section:
0.25 ft (7.6 cm) AC
0.50 ft (15.2 cm) AB

Test Section	*80th Percentile Deflection*	*Appearance*
1	0.042 in. (1.1 mm)	Intermittent to continuous small "alligator" cracking with isolated rutting.

No vertical controls exist. It is obvious from Figure 17 that the existing deflection level is excessive and that a major repair is necessary. Enter the graph on Figure 19 with a T.I. of 9.0, following this value to an interpolated value of 0.042 in. (1.1 mm) initial deflection. The required thickness of AC overlay is 0.33 ft (10.1 cm).

Recommend 0.35 ft (10.7 cm) of AC Overlay.

b. *Problem No. 2 (Reflection Cracking Controls)*

T.I. = 11.0
Existing Structural Section:
0.25 ft (7.6 cm) AC
0.50 ft (15.2 cm) Cl "A" CTB
1.00 ft (30.4 cm) AS

Test Section	*80th Percentile Deflection*	*Appearance*
2	0.015 in. (0.38 mm)	Intermittent large block and "map" cracks.

No vertical controls exist. For a T.I. of 11.0, the graph on Figure 17 shows a tolerable deflection of 0.009 in. (0.23 mm) for 0.50 ft (15.2 cm) of CTB. The measured deflections as well as the appearance of the pavement is an indication that cracking in the CTB has progressed to the point where the structural section is in need of repair. The measured 80th percentile deflection value needs to be reduced by the following amount: (0.015–0.009/0.015) 100 = 40 percent to reach the tolerable level. Entering Figure 18, a 40 percent reduction in deflection indicates a need for a 0.40 ft. (12.2 cm) gravel equivalent increase. From Figure 20, for a T.I. of 11.0 a 0.20 ft. (6.1 cm) thickness of AC has a gravel equivalent of 0.34 ft. (10.4 cm) and a 0.25 ft. (7.6 cm) thickness of AC has a gravel equivalent of 0.43 ft. (13.1 cm). Therefore, a 0.25 ft. (7.6 cm) AC overlay is recommended for structural adequacy. However, experience has shown that 0.25 ft. (7.6 cm) would probably not be enough to prevent reflection cracking. To minimize reflection cracking for AC over CTB, a minimum thickness of 0.30 ft. (9.1 cm) should be used.

NOTE: At present there is no set method to determine overlay thicknesses to prevent reflection cracking; however, a rule of thumb generally used is as follows:

a. The new blanket thickness should be at least half the thickness of the existing AC pavement over untreated bases.

b. For PCC pavements or existing AC pavements over CTB, a minimum overlay thickness of 0.30 ft (9.1 cm) should be used. A lesser overlay thickness could provide a smooth riding surface, but will allow existing cracks to reflect through the overlay prematurely.

Recommended 0.30 ft (9.1 cm) AC Overlay.

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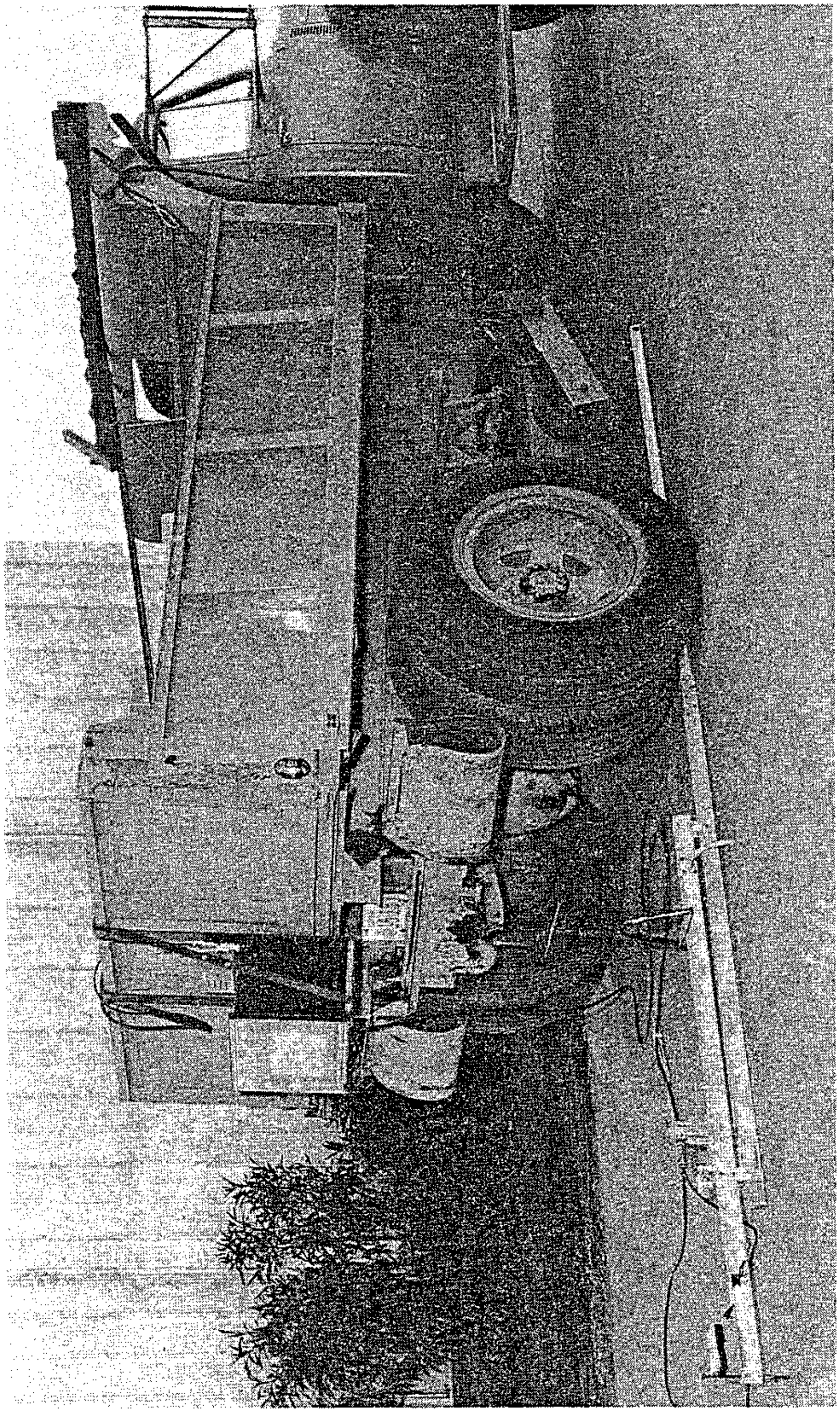

FIGURE 1
BENKELMAN BEAM WITH TEST TRUCK

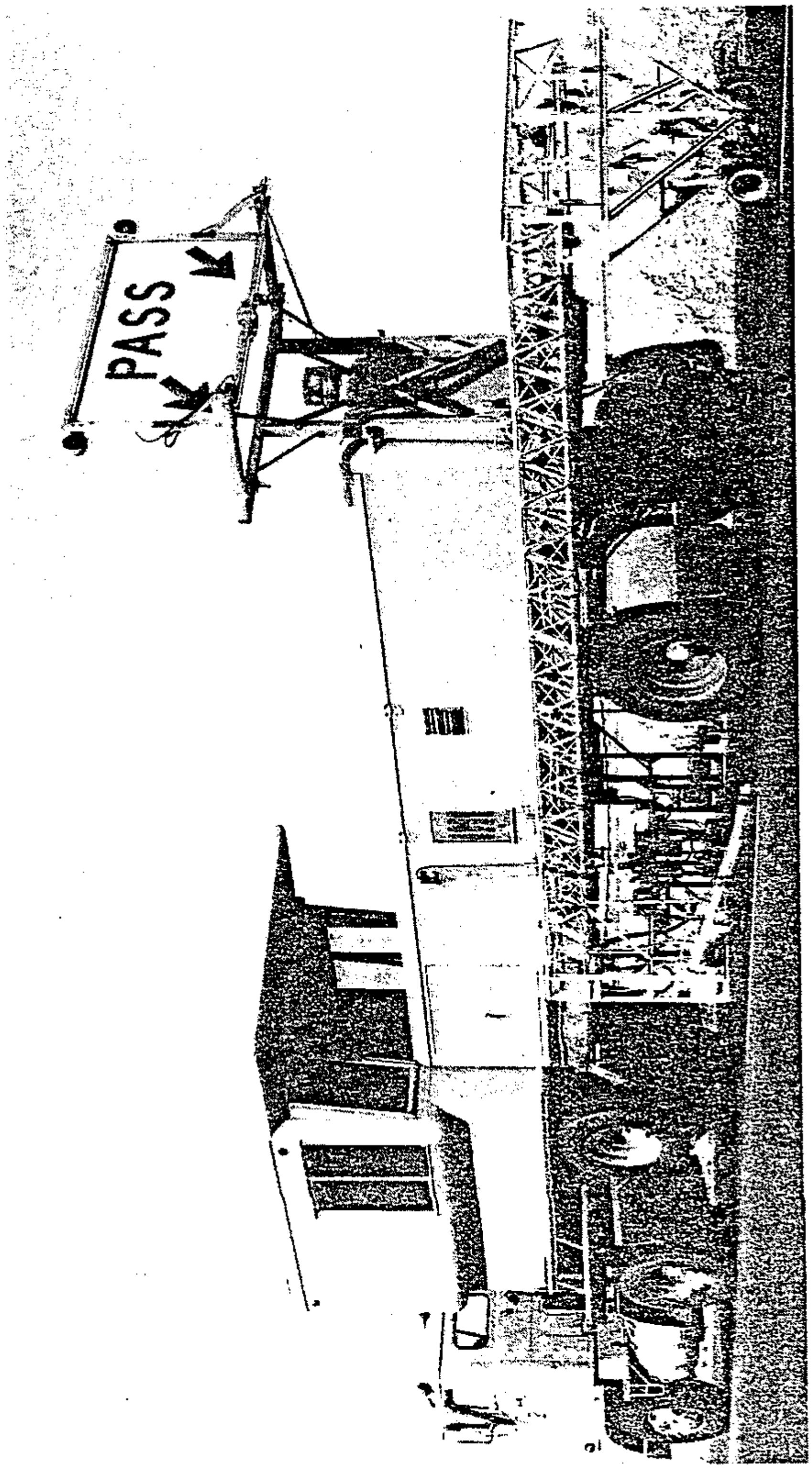

FIGURE 2
DEFLECTOMETER