Technical Report Documentation Page

1. REPORT No.
643449

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
K-Value-Deflection Relationship For AC Pavements

5. REPORT DATE
November 1969

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Zube, E.; Tueller, D.O.; and Hannon, J.B.

8. PERFORMING ORGANIZATION REPORT No.
643449

9. PERFORMING ORGANIZATION NAME AND ADDRESS
State of California
Department of Public Works
Division of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT & PERIOD COVERED
Final Report

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

An evaluation of a preliminary K-value versus deflection relationship for AC pavements is reported. By a limited amount of plate bearing and Benkelman beam deflection tests, the K-value versus deflection relationship was found to be valid with minor modification. a procedure is presented by which pavement deflection measurements may be utilized to predict the K-value of an existing AC roadway for PCC overlay thickness designs. It was concluded that the K-value of an existing AC roadway can be predicted from pavement deflection measurements which generally result in a reduction in PCC pavement thickness requirements.

17. KEYWORDS
Pavements, asphaltic concrete, pavement deflection, overlay thickness, design, K-value

18. No. OF PAGES:
24

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1969-1970/69-02.pdf

20. FILE NAME
69-02.pdf

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

Final Report
M&R No. 643449
90117 Research
November, 1969

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

K-VALUE-DEFLECTION RELATIONSHIP FOR AC PAVEMENTS

ERNEST ZUBE
Principal Investigator

DON O. TUELLER
AND JOSEPH B. HANNON
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

69-02

REFERENCE: Zube, E., Tueller, D. O., and Hannon, J. B., "K-value-Deflection Relationship for AC Pavements", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 643449, November, 1969.

ABSTRACT: An evaluation of a preliminary K-value versus deflection relationship for AC pavements is reported. By a limited amount of plate bearing and Benkelman beam deflection tests, the K-value versus deflection relationship was found to be valid with minor modification. A procedure is presented by which pavement deflection measurements may be utilized to predict the K-value of an existing AC roadway for PCC overlay thickness design. PCC overlay design thicknesses determined by transient pavement deflection measurements are compared with arbitrary PCC overlay thickness designs. It was concluded that the K-value of an existing AC roadway can be predicted from pavement deflection measurements which generally result in a reduction in PCC pavement thickness requirements.

KEY WORDS: Pavements, asphaltic concrete, pavement deflection, overlay thickness, design, K-value.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the personnel involved with data collection and testing, particularly Mr. Bob Page and Mr. Orvis Box. We would also like to thank the Department of the Army, Sacramento District Corps of Engineers, for their cooperation in making available their trailer unit and deflection beam for holding gages.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

It is the present practice of the California Division of Highways to design portland cement concrete (PCC) pavements for new construction utilizing the R-value of the basement soil to predict the subgrade modulus K[1,2,3]. However, no simple procedure is available for evaluating an existing asphalt concrete (AC) roadway for purposes of designing a PCC overlay. Here a problem arises because pavements which were constructed ten or more years ago may still have adequate alignment for today's traffic needs but the pavement wearing surfaces on some of these facilities are beginning to show distress. Corrective measures may now be required to either reduce maintenance or upgrade and extend the life of these facilities.

Since about 1960, the Materials and Research Department of the California Division of Highways has utilized transient pavement deflection measurements to evaluate the in-place strength of existing AC pavements, the purpose being to determine the amount of corrective treatment or thickness of AC overlay required[4,5]. Test Method No. Calif. 356-A, "Methods of Test to Determine Overlay and Maintenance Requirements by Pavement Deflection Measurements" describes the procedure used for correcting distress on existing AC pavements. However, this test method in its present form is not applicable to designing PCC overlays. At present, PCC overlay thicknesses varying from 0.55' to 0.70' are selected on an arbitrary basis only. If the present method of PCC design was to be used for determining the necessary PCC overlay for an existing AC roadway, no benefit would be derived from the residual strength of the existing pavement section which had developed over the years through traffic compaction. This factor has been of concern to some of our highway districts as questions have been asked as to whether a correlation existed between K-value and transient pavement deflection.

A considerable amount of research has been done by the Canadian Good Roads Association in the area of pavement deflection by Benkelman Beam and the subgrade support under a loaded bearing plate.

The McLeod procedure of flexible pavement design was developed based on data collected by the Canadian Department of Transport from studies of the load carrying capacities of runways at Canadian Airports using plate bearing tests[6,7,8,9]. The Materials and Research Department of the California Division of Highways has utilized the McLeod procedure to evaluate pavement deflection measurements which were obtained at seven different airport facilities in California. The use of this procedure to determine AC overlay thickness requirements was possible since the Canadian Good Roads Association had established a correlation between Benkelman beam deflection under an 18,000 pound single axle load and subgrade support under a loaded 30 inch diameter steel bearing plate at 0.500 inch deflection[10].

The research study that is reported herein, was undertaken because the authors surmised that perhaps a relationship between K-value and deflection could be developed from the Canadian data. By a series of simple calculations involving this data, a tentative K-value versus Benkelman beam deflection relationship was established for flexible pavements. The main purpose of this study was to evaluate this relationship by a minimal amount of plate bearing and Benkelman beam tests. If this relationship proved valid, PCC overlays could be designed from pavement deflection measurements which would greatly simplify this task. Also, the load supporting ability of airport flexible pavements could be evaluated with confidence from pavement deflection measurements. The results of this study, along with a proposed test method for predicting K-value for PCC overlay design based on deflection measurements, are presented herein.

CONCLUSIONS

The following conclusions are drawn from the results of this study:

1. The K-value of an existing roadway can be predicted from pavement deflection measurements.

2. Pavement deflection measurements can be utilized to design PCC overlays.

3. When compared to an arbitrary PCC overlay design thickness, a reduction in PCC thickness requirement may result from the use of the proposed pavement deflection method to design a PCC overlay on an existing AC pavement.

4. It is possible to predict the support load on a 30 inch diameter plate at a given plate settlement from pavement deflection measurements.

5. Since the K-value versus deflection relationship is valid, pavement deflection measurements can be utilized in conjunction with the McLeod procedure to design flexible overlay thicknesses for airport pavements having limited service use.

RECOMMENDATION

The following procedure is recommended for use in predicting the K-value of an existing AC roadway for the purpose of designing a PCC overlay:

Proposed Test Method

"Method of Test to Predict the K-value of an Existing AC Roadway from Pavement Deflection Measurements"

Scope

This test method describes the use of pavement deflection measurements to predict the K-value of an existing AC roadway.

Procedure

1. Determine the 80th percentile pavement deflection level by Test Method No. Calif. 356-A.

2. Predict the K-value using Figure 1.

Reference

Test Method No. Calif. 356-A

PRELIMINARY CORRELATION

Utilizing data obtained by the Canadian Good Roads Association, the tentative curve presented on Figure 2 was established.

Since the California Division of Highways uses a 15,000 pound single axle load for determining Benkelman beam deflection, a factor of 0.83 had to be applied to the Canadian deflection data which was established under an 18,000 pound single axle load. Also the loading on a 30 inch diameter plate to obtain a 0.050 inch settlement had to be found by multiplying the load required for 0.500 inch settlement by a factor of 0.25. The subgrade support under a 30 inch diameter bearing plate was based on ten repetitions of load rather than one repetition and required that a conversion factor of 1.2 be applied. This resulted in the following calculation for K-value, that was used at various levels of known Benkelman beam deflection to establish the tentative K-value versus Benkelman beam deflection curve:

$$\text{K-value} = \frac{0.25\ L_{0.5}(1.2)}{(d)(A)} = \text{lb./in.}^3$$

Where:

$L_{0.5}$ = load on 30 inch diameter bearing plate in pounds at various levels of measured deflection (Reference 10)

d = 0.050 inch deflection on 30 inch diameter bearing plate

A = surface area of 30 inch diameter bearing plate

Note: With the exception of the 0.83 factor for Benkelman beam loading, all other factors were obtained from References 6 and 7.

EVALUATION PROCEDURE

To verify the above relationship so that it could be used in conjunction with our present design procedure for PCC pavement, a series of plate bearing and pavement deflection tests had to be performed. This operation was simplified by selected test locations on the AC hardstand areas of the Headquarters Materials and Research Laboratory and the Service and Supply Warehouse Yard in Sacramento, California. These pavements have structural sections which consist of from 0.17' to 0.33' AC over an aggregate base. It was felt that this sampling, although of the same basic structural section, would be sufficient to verify the preliminary correlation curve relating pavement deflection to K-value (Figure 2).

Six test locations were selected by scanning the hardstand areas for different levels of deflection using the Lane-Wells Dynaflect (Figure 3). The range in deflection levels for these test areas were found to vary from 0.020 inch to 0.050 inch in terms of Benkelman beam deflection.

In order to perform plate bearing tests, a nest of four 1-inch thick steel plates 12, 18, 24 and 30 inches in diameter were fabricated. To provide the loading for the plate bearing tests, a large foundation drilling rig was selected. Two preliminary tests (Test Series 1) were made during the summer of 1968 at approximately the same location using this unit. For these tests the front bumper and all of the vehicles wheels were blocked and the load was applied by jacking against a drillrod locked in the chuck. This method proved to some extent, unsatisfactory, as most of the jack travel was used in taking up the springs of the vehicle. Also the rear wheels of the vehicle were only 5 feet from the center of loading but a minimum distance of 8 feet is required by ASTM. However, this factor was disregarded in these preliminary tests. Further use of this drilling rig was abandoned as it was needed on other projects.

To complete this study, it was then necessary to lease an 18 ton trailer unit from the U. S. Army Corps of Engineers for a one week period in May 1969. This trailer (Figure 4) was selected because it was modified for this type of operation and would provide for the plate loading at a distance greater than 8 feet from the wheels. Six individual plate bearing tests were conducted under Test Series 2 using this trailer loaded with approximately 26,000 pounds of steel snow plow bits.

All plate bearing tests were performed directly on the AC surfacing according to ASTM D1196-64, "Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, For Use in Evaluation and Design of Airport and Highway Pavements." The K-values which were derived by this method were corrected for bending of the plates using a correction curve presented in Mil-STD-621A, Method 104, "Modulus of Soil Reaction" dated 22 December 1964.

A hydraulic jack was used in conjunction with a load cell for applying and recording the load on the plates. The movement of the plates was recorded on three dial gages at each increment of load. This test arrangement is shown on Figure 5.

Pavement deflection measurements were obtained at the completion of all plate bearing tests. The manually operated Benkelman beam was utilized with the California Traveling Deflectometer (Figure 6) which carries a 15,000 pound single axle load. A series of five measurements were obtained at each plate bearing test location. The average of these five values was then compared to the K-value which was determined at each location.

ANALYSIS OF DATA

Discussion

Table 1 presents the compiled results of all plate bearing and pavement deflection tests. Figure 7 presents a graphical presentation of this data and illustrates how well it correlates to the tentative K-value versus deflection relationship. A proposed design curve is also presented here and on Figure 1 which can be utilized in predicting the K-value of an existing AC roadway by means of pavement deflection measurements. This design curve is constructed parallel to the preliminary curve on the lower limit of the test data.

Figure 1 presents an upper design limit for K-value of 600 psi/in. which is the maximum value shown in the stress charts contained in Reference 1. Some agencies suggest a maximum K-value of 500 psi/in. for a PCC overlay design for a flexible pavement, however, this appears to be an arbitrary limitation. Also, the incremental difference between 500 and 600 K-value has little effect on the final PCC design thickness.

As discussed in an earlier section of this report, there is some economical advantage in designing a PCC overlay thickness by a K-value determined from pavement deflection measurements rather than an arbitrary PCC thickness selection. To illustrate this point, Table 2 presents a comparison of two isolated cases of PCC overlay thickness designs. Here two projects that were subject to pavement deflection investigation are presented. A discussion of these comparisons is as follows:

<u>Project 03-Yol-505-13.8/22.8</u>

This project presently has two-lane alignment which the district has proposed to incorporate in a four-lane divided freeway section utilizing PCC in the structural section. An arbitrary PCC overlay thickness of 0.70' was selected for the existing AC facility because considerable maintenance problems had developed over the years. This section also matched the PCC section required for the new construction.

Pavement deflection measurements were originally obtained on the existing roadway in May 1966 and rechecked again in February 1967. These deflection investigations produced a maximum evaluated 80th percentile deflection level of 0.038 inch. From this level of deflection, a K-value of 370 can be predicted from Figure 1. This is only slightly lower than the K-value of 400 which was predicted from the preliminary curve. Using the PCC fatigue calculations for the new construction, a savings could have been derived from the 0.05' reduction in PCC overlay thickness.

<u>Project 07-Ven-101-9.0/23.1</u>

This project presently has four-lane alignment for which overlays of both flexible and rigid type pavement construction have been proposed as alternates. For the PCC overlay design, a preliminary K-value of 500 was assigned to the existing structural section based on the pavement deflection results of a 1963 study made by the Materials and Research Department. This deflection survey included 47 different test sections varying from 100 to 3000 feet in length. The existing design method requires a 0.75' thickness of PCC for the new construction on this project.

The assigned K-value of 500 was determined from the preliminary K-value versus deflection relationship. However, final analysis with the proposed design curve suggests that possibly a K-value of around 400 is more in order.

The evaluated 80th percentile deflection levels on this facility ranged from a low of 0.005 inch to a high of 0.057 inch. These deflections may appear excessive, however, only 5 of the 47 test sections produced levels above 0.034 inch deflection which is equal to a predicted K-value of 400. This K-value would require a 0.65 ft. PCC thickness which does not alter the proposed design. The maximum deflection level of 0.057 inch, if used, would require a 0.70 ft. PCC thickness. Since this deflection study was made six years ago, some maintenance has probably been done to correct the short areas of distress which contribute to the higher deflection levels.

Again, as with the District 03 project, a savings can be derived from the use of pavement deflection measurements to predict the K-value of an existing AC roadway for a PCC overlay design. Here a reduction of 0.05 ft. to 0.10 ft. from the 0.75 ft. PCC thickness requirement for new construction can be determined.

BIBLIOGRAPHY

1. State of California, Department of Public Works, Division of Highways, Planning Manual of Instructions, Part 7, Design, Figures 7-605.4 to 7-605.4J.

2. Estep, A. C. and Wagner, P. I., "A Thickness Design Method for Concrete Pavements", Highway Research Record Number 239, Highway Research Board, Washington, D. C., 1968.

3. Packard, R. G., "New Portland Cement Concrete Design Procedures", Proceedings, Ninth Annual Highway and Public Works Conference, University of the Pacific, March, 1966.

4. Zube, E. and Forsyth, R. A., "Flexible Pavement Maintenance Requirements as Determined by Deflection Measurements," Proceedings, 45th Annual Meeting of the Highway Research Board, January, 1966.

5. Zube, E., "Pavement Overlay Design By Deflection Measurements", Proceedings, Third Annual Nevada Street and Highway Conference, Reno, Nevada, March, 1968.

6. McLeod, N. W., "Airport Runway Evaluation in Canada", Research Report No. 4B, Highway Research Board, Washington, D. C., 1947.

7. McLeod, N. W., "Airport Runway Evaluation in Canada", Research Report No. 4B-1948 Supplement, Highway Research Board, Washington, D. C., 1948.

8. McLeod, N. W., "Flexible Pavement Thickness Requirements", Proceedings of the Association of Asphalt Paving Technologists, Cleveland, Ohio, Vol. 25, February 1956, pp. 199-291.

9. Yoder, E. J., "Principles of Pavement Design", John Wiley & Sons, Inc., New York, 1959, pp. 345-353.

10. Canadian Good Roads Association, Special Committee on Pavement Design and Evaluation, "Pavement Evaluation Studies in Canada", Proceedings, International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1962, pp. 181-182.

Figure 1

K-VALUE VS. DEFLECTION FOR AC PAVEMENT

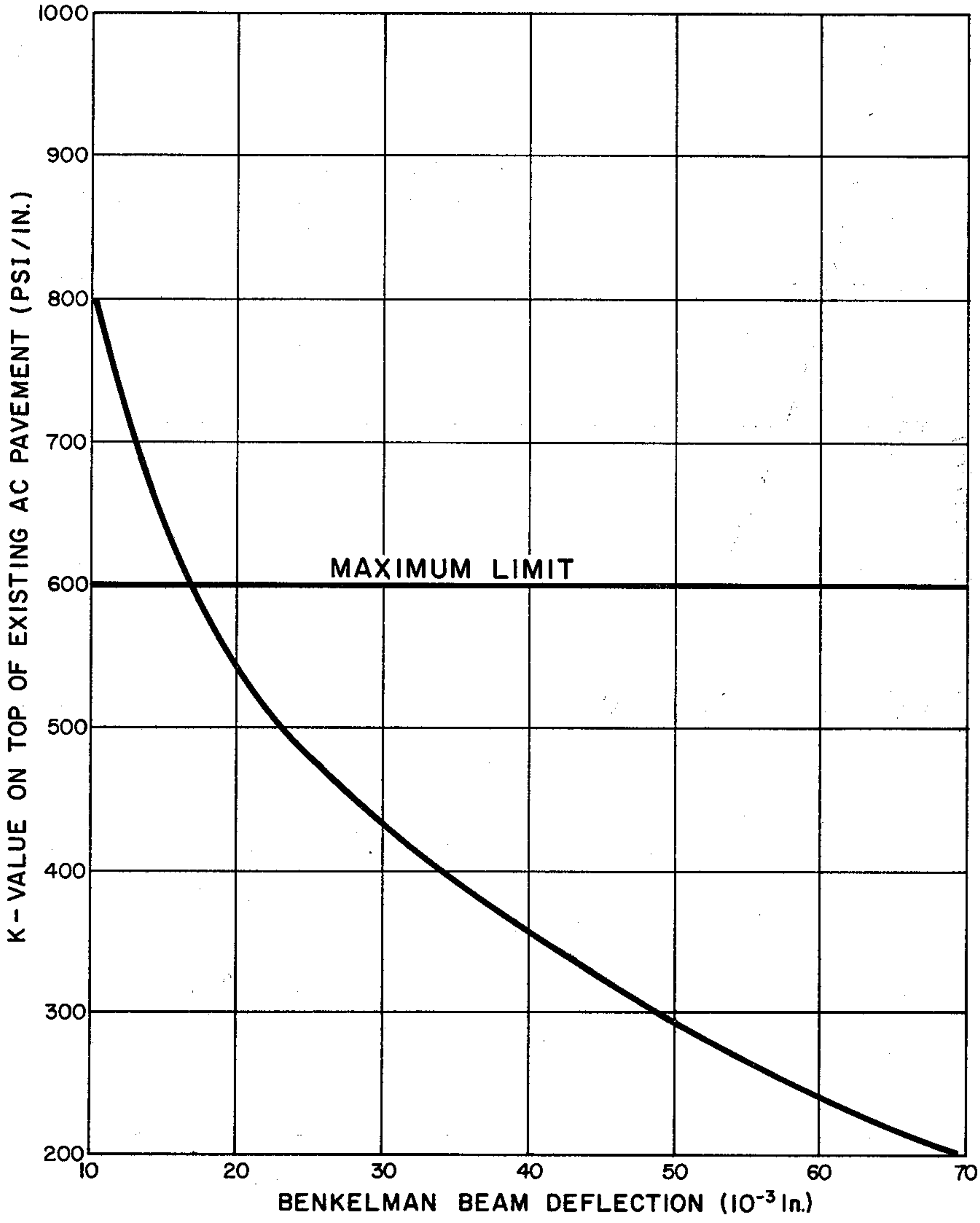


Figure 2

TENTATIVE K-VALUE VS. DEFLECTION RELATIONSHIP

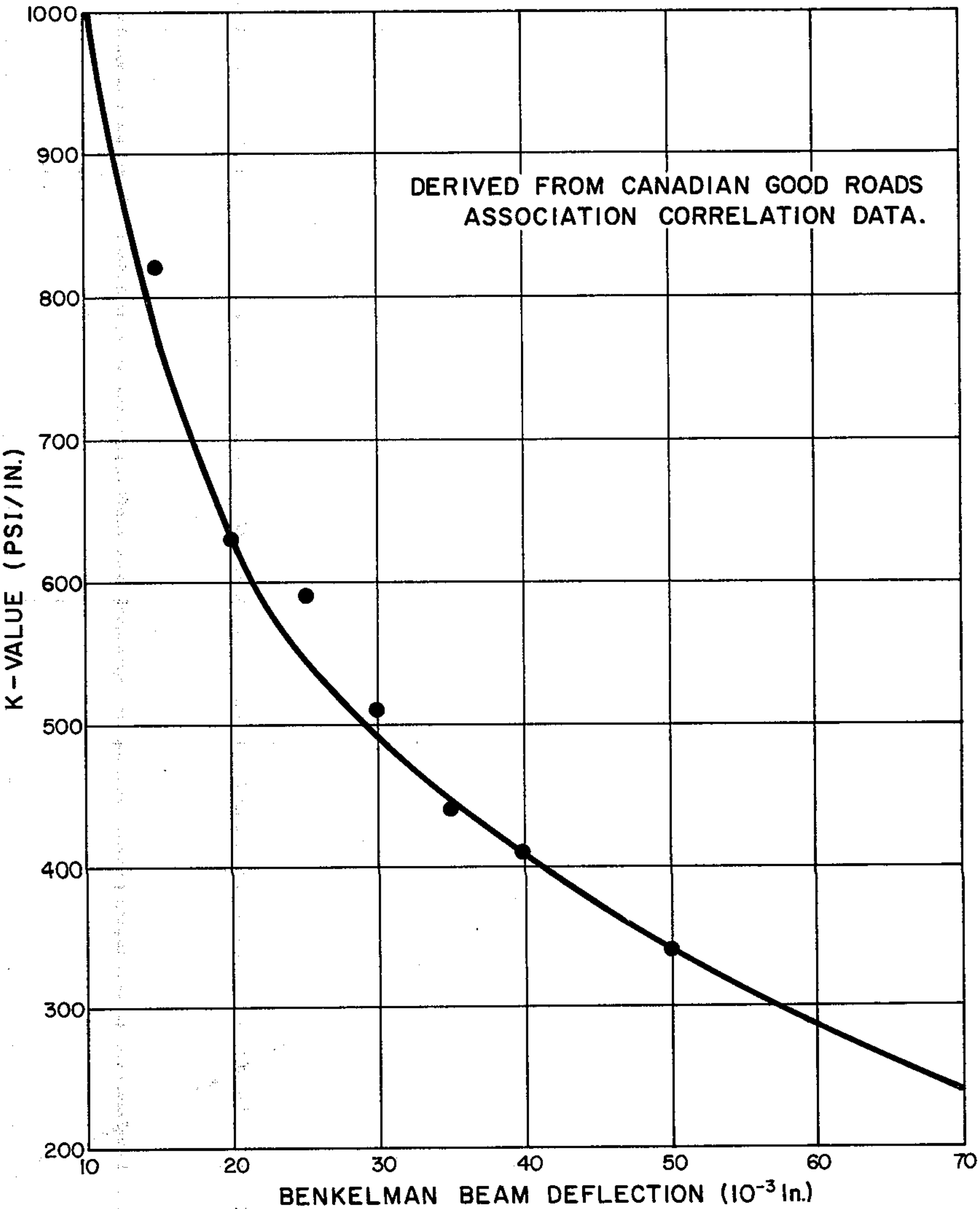
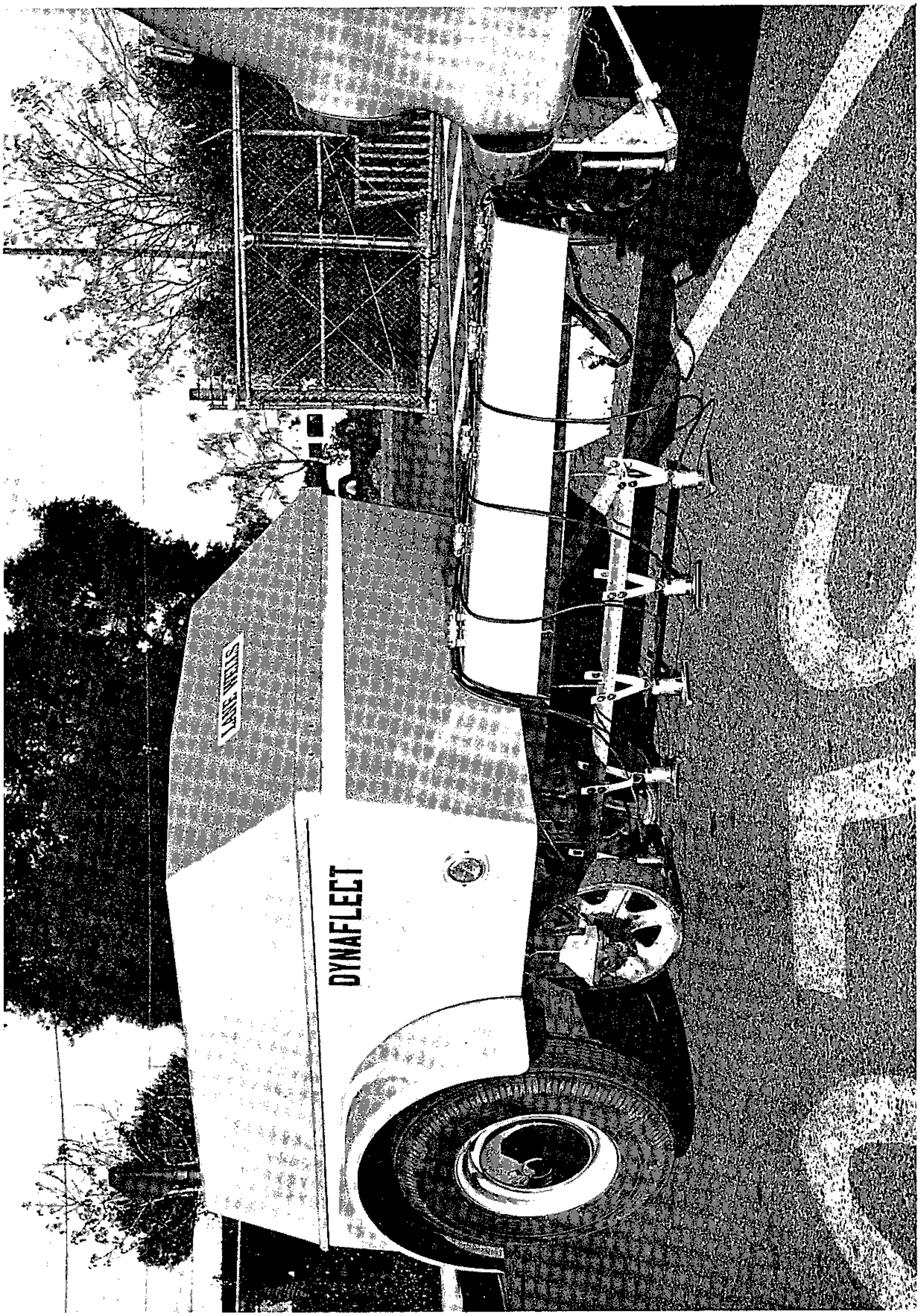
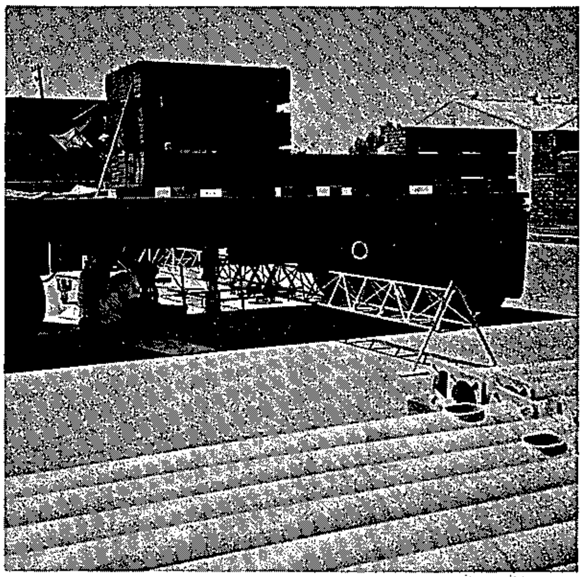


Figure 3



DYNAFLECT IN TEST POSITION WITH FORCE WHEELS AND GEOPHONES DOWN

Figure 4



CORPS OF ENGINEERS TEST TRAILER

Figure 5

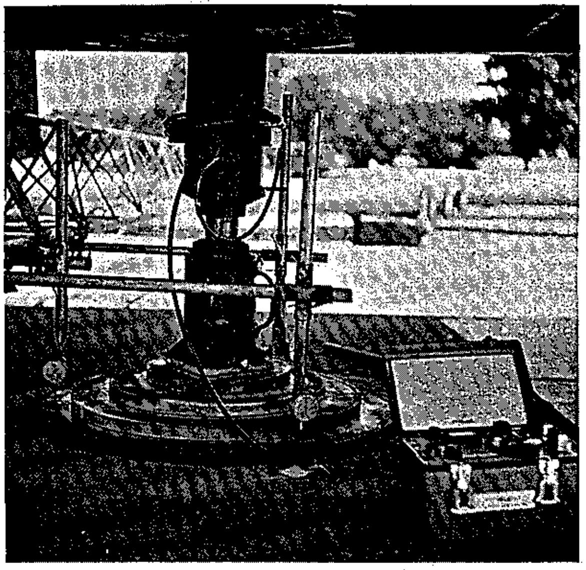
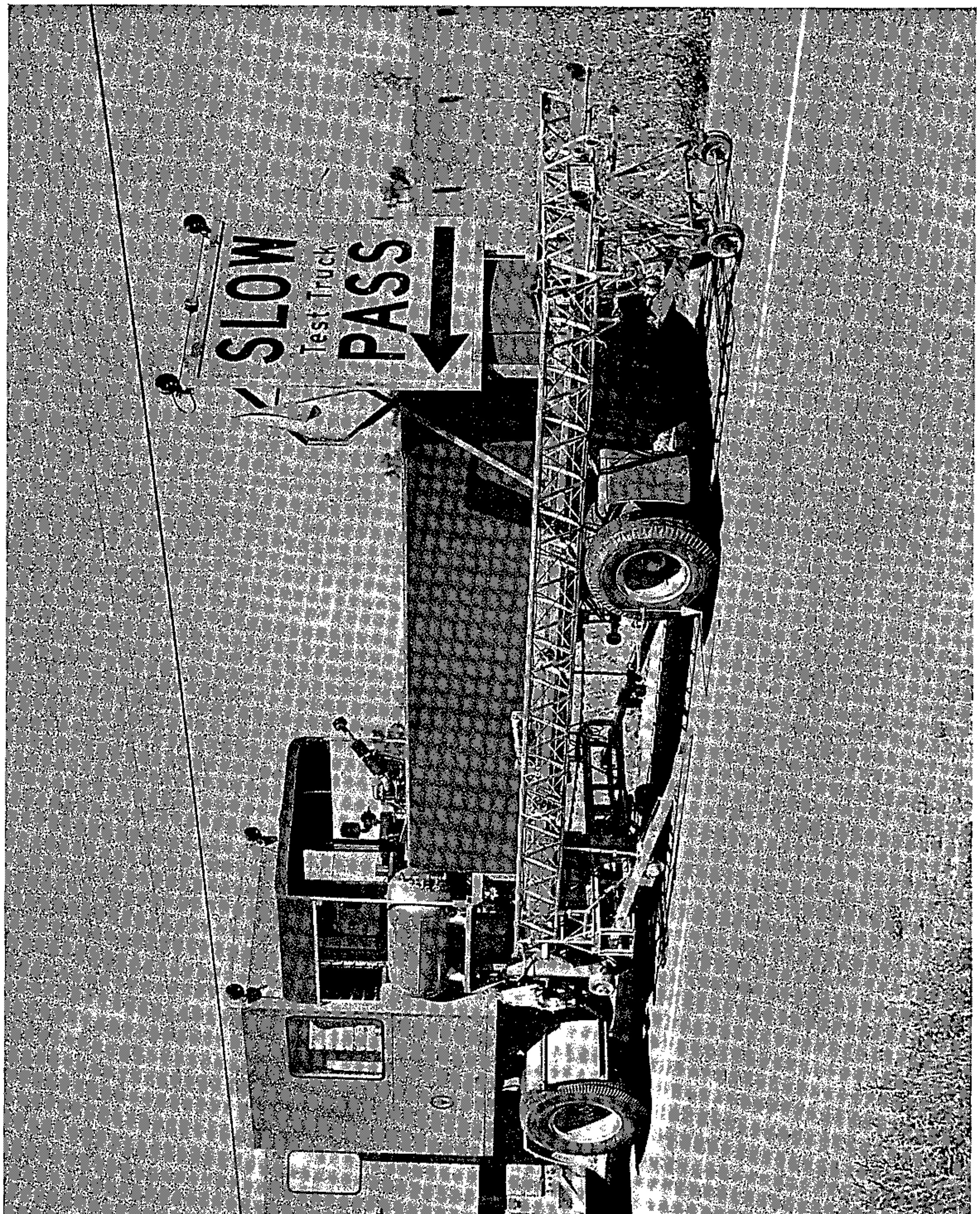


PLATE BEARING TEST ARRANGEMENT

Figure 6



TRAVELING DEFLECTOMETER

Figure 7

DATA CORRELATION

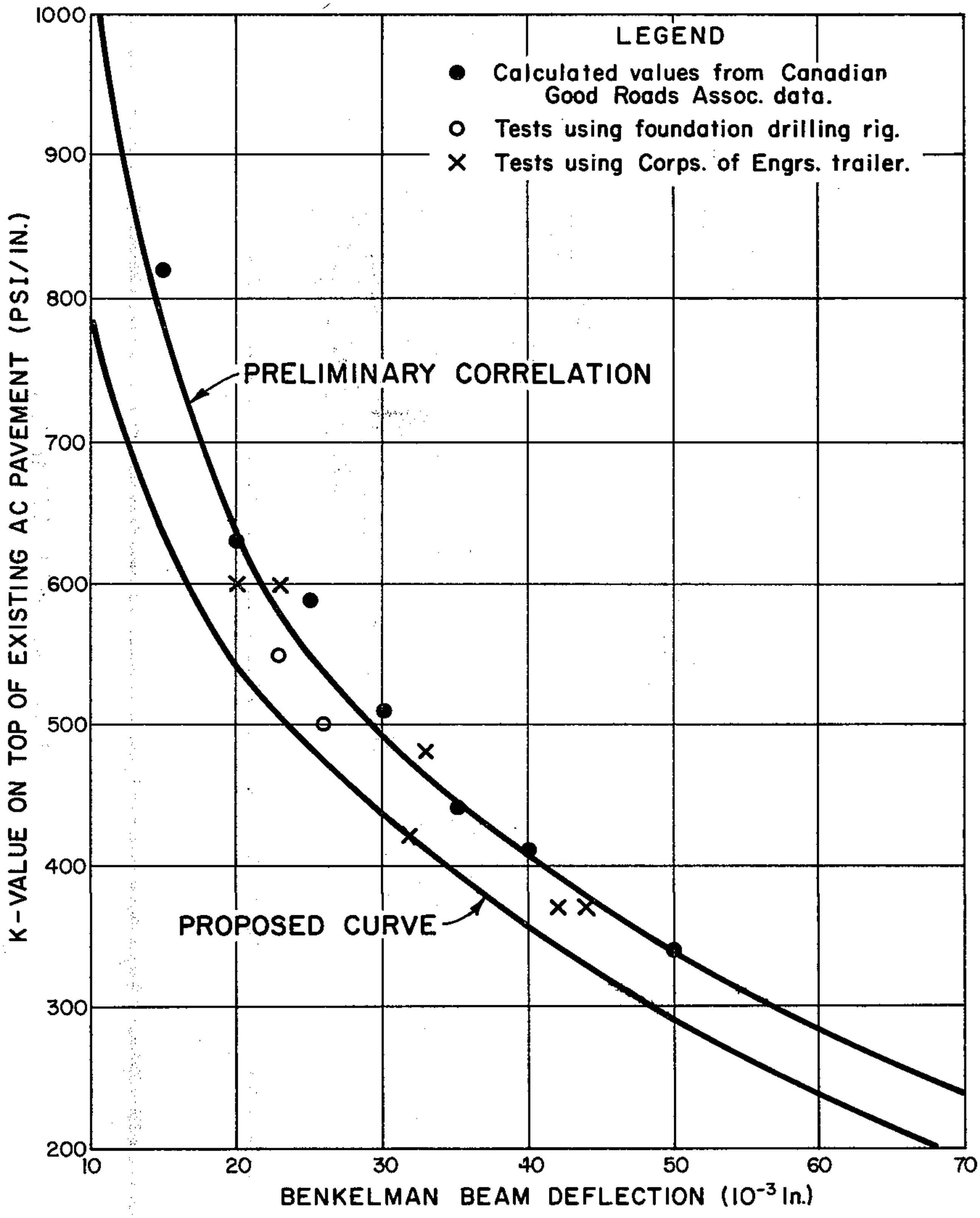


TABLE 1

TEST DATA

Test Series	Test No.	Existing Structural Section	Pavement Condition	Predicted K-value (lbs./in.^{3})	Air Temperature (°F)	Dynaflect Deflection (10^{-3} in.)	Benkelman Beam Deflection (Inches)
1	1	0.33' AC over original ground	Uncracked	550	81	1.34	0.023
"	2	"	"	500	90	1.34	0.026
2	1	0.17' AC 0.75' AB	Uncracked but in vicinity of longitudinal and "alligator" cracking	370	79	2.20	0.044
"	2	0.25' AC 0.83' AB	Uncracked	600	66	1.09	0.020
"	3	"	"	600	72	1.48	0.023
"	4	0.33' AC Over original ground	"	420	76	1.58	0.032
"	5	0.17' AC 0.75' AB	Uncracked but in vicinity of longitudinal and "alligator" cracking	370	84	2.15	0.042
"	6	"	Uncracked	480	76	1.53	0.033

TABLE 2

PCC THICKNESS COMPARISON

Project	Highest Evaluated Benkelman Beam Deflection Level (Inches)	Predicted K-value ($lbs./in.^3$)	PCC Overlay Thickness (ft.)	
			Designed by deflection	Proposed by District Design
1) 03-Yol-505-13.8/22.8	0.038	400 370 (4)	0.65 "	0.70 (1)
2) 07-Ven-101-9.0/23.1	0.034 0.057	400 (4) 260	0.65 0.70	0.65 (2) 0.75 (3)

(1) Selected to match new construction

(2) Based on an assumed K-value of 500

(3) Design thickness of new construction

(4) Determined from final K-value versus deflection relationship