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16. Abstract

The first phase of this study was undertaken to develop an inexpensive, easy-to-use non-destructive test procedure for evaluating the structural condition of transverse joints in concrete pavements. The test method consists of a load deflection measurement technique (18,000 pound single-axle load) in conjunction with a finite element model of the jointed slab system, called JSLAB. Time-deflection measurements were recorded over a variety of concrete pavement thicknesses, ages, and conditions. The process was determined to be very useful as an aid in making rehabilitation decisions for concrete joints. Deflection based guidelines are provided for concrete pavement rehabilitation decisions for joint replacement and for grinding and undersealing of faulted joints. The test method was sufficiently sensitive to characterize a roadbed soil conditioned with lime, and then treated with cement, as containing greater stiffness than soil (for the same pavement) that was lime conditioned only.

The second phase was conducted to investigate the effectiveness of adding a bonded concrete overlay and tied shoulder to an existing C.R.C. pavement with asphalt shoulder. In general, the addition of an overlay and tied shoulder reduced pavement deflections significantly. The test method used was similar to that in Phase I and included load deflection measurements in conjunction with the finite element program JSLAB.

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EVALUATION OF JOINT AND SUBBASE EFFICIENCY IN RIGID PAVEMENTS USING NONDESTRUCTIVE TESTINGS

FINAL REPORT

by

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ABSTRACT

The first phase of this study was undertaken to develop an inexpensive, easy-to-use non-destructive test procedure for evaluating the structural condition of transverse joints in concrete pavements. The test method consists of a load deflection measurement technique (18,000 pound single-axle load) in conjunction with a finite element model of the jointed slab system, called JSLAB. Time-deflection measurements were recorded over a variety of concrete pavement thicknesses, ages, and conditions. The process was determined to be very useful as an aid in making rehabilitation decisions for concrete joints. Deflection based guidelines are provided for concrete pavement rehabilitation decisions for joint replacement and for grinding and undersealing of faulted joints. The test method was sufficiently sensitive to characterize a roadbed soil conditioned with lime, and then treated with cement, as containing greater stiffness than soil (for the same pavement) that was lime conditioned only.

The second phase was conducted to investigate the effectiveness of adding a bonded concrete overlay and tied shoulder to an existing C.R.C. pavement with asphalt shoulder. In general, the addition of an overlay and tied shoulder reduced pavement deflections significantly. The test method used was similar to that in Phase I and included load deflection measurements in conjunction with the finite element program JSLAB.

IMPLEMENTATION STATEMENT

For Phase I, using the influence curves in Figure 1, the guidelines in Figure 2 and the test set up in conjunction with the finite element program JSLAB, decisions can be made on how and when to repair faulted joints.

Louisiana DOTD through LTRC has implemented this method of determining the proper type of rehabilitation. Figure 3 is a sample memorandum prepared by LTRC and sent to the District Construction Engineer with the recommended action necessary for the pavement in question. Several scheduled rehabilitation projects within Louisiana are included in appendix "A", recommending the proper method of rehabilitation.

Through Phase II it was shown that concrete overlays and tied jointed concrete shoulders are extremely effective reducing pavement deflections and, therefore, increasing structural capacity.

METRIC CONVERSION CHART

SI UNIT CONVERSION FACTORS*

To Convert from	To	Multiply by
	Length	
foot	meter (m)	0.3048
inch	meter (m)	0.0254
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
	Area	
square foot	square meter (m^2)	0.0929
square inch	square meter (m^2)	0.000645
square yard	square meter (m^2)	0.8361
	Volume (Capacity)	
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic meter (m^3)	0.03382
	Mass	
ounce-mass (avdp)	kilogram (kg)	0.0284
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
	Mass per Volume	
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
	Temperature	
deg Celsius (C)	Kelvin (K)	$t_k=(t_c+273.15)$
deg Fahrenheit (F)	Kelvin (K)	$t_k=(t_F+459.67)/1.8$
deg Fahrenheit (F)	Kelvin (K)	$t_c=((t_F-32)/1.8)$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

PAGE NO.

PHASE I
INTRODUCTION

The construction and performance of transverse joints in Portland cement concrete (PCC) pavements has been a source of problems for highway engineers since jointed pavements were first used in Louisiana in the 1920's. A transverse joint in a PCC pavement creates a discontinuity in the pavement, causing a weaker zone adjacent to the joint. The most common problems that can affect jointed concrete pavements are load transfer failure, joint faulting, pumping, sealant loss and general joint failure as a result of concrete crushing.

More than 50 percent of the major highway systems in Louisiana have been constructed as jointed PCC pavements. While the majority of these pavements are performing adequately, many pavements older than 20 years are in need of rehabilitation or reconstruction. Traffic demands on these pavement have been increasing significantly, although the procedures available to evaluate them are limited. In past years the Louisiana Department of Transportation and Development (LaDOTD) has not had a comprehensive joint evaluation and maintenance program. Where joint rehabilitation has been needed at a particular highway site, the choice of a repair procedure has usually been based upon visual observation of that site. Deflection testing to determine the need for joint rehabilitation has received limited use, but has not produced definitive results using existing equipment and techniques. For some time, it has been theorized, that a structural evaluation procedure which uses a slow-moving heavy load might have advantages over lighter loads in evaluating the condition of PCC pavements. In particular, a test procedure was needed to assist in the decisions among various rehabilitation strategies and reconstruction. Also, guidelines were needed to decide between grinding and undersealing operations or replacing the joints where joints are faulted and loss of load transfer in suspected.

Another factor that has contributed significantly to joint faulting on older concrete pavements (15 years or more) is the use of a cantilever type of load transfer device called the starlug (instead of using steel dowel bars). Pavements constructed with starlugs have been studied extensively in Louisiana (1) because of their use on many older concrete pavements both on and off the interstate system.

OBJECTIVE AND SCOPE

The objective of this research was to develop a fast, easy-to-use, non-destructive test method for evaluating the condition of transverse joints in concrete pavements. This non-destructive test method included an in-place deflection measurement technique in conjunction with a finite element model of the jointed slab system to evaluate joint conditions. Field measurements were made at 10 sites in Louisiana to illustrate the use of this test procedure and to test its validity. Jointed concrete pavements with starlug and dowel-type load transfer devices were studied.

METHOD OF PROCEDURE-EXPERIMENTAL

Corner deflections (vertical) and joint efficiencies have been extensively used to characterize the adequacy of a transverse joint (2,3,4). Therefore, an experimental testing procedure was developed to measure these factors under actual field conditions. Ten sites from projects that represent pavement and subbase conditions typical throughout Louisiana were evaluated to find corner deflections and joint efficiencies caused by a known load. At each of the 10 test sites, measurements were taken at a minimum of 10 randomly selected joints. Table 1 contains the location and main pavement characteristics of each test site. Each site had varying age, slab length, subbase type and load transfer device type that are representative of past and current construction practices in Louisiana and other parts of the country. All test sites had asphalt shoulders, which did not provide load transfer.

Besides representing a range of pavement and subbase conditions the 10 projects were chosen for the following reasons:

(1) Test projects Nos. 1 and 2 provide comparisons of dowel bars and starlugs in older pavements of the same thickness, slab length and subbase type. Both these pavements contain distressed transverse joints or moderate to heavy faulting (1/2 to 3/4 inch).

(2) Test projects Nos. 3 and 4 are new interstate pavements selected to provide support and load transfer characteristics of new pavements. Both projects contain a cement treated roadbed soil except in several locations on project No. 4 where lime treatment was substituted. This project was subdivided for testing to determine whether the procedure could detect any difference in support between the two types of soil treatments.

(3) Test projects Nos. 5 and 6 were selected to represent 8-and 9-inch concrete pavements that are relatively new and in good condition.

(4) Test project No. 7 is a 9-inch doweled pavement with a 4-inch bonded concrete overlay added in 1981 when the pavement was 20 years old. The project was selected because of its thickness.

(5) Test project No. 8 is a 15-year-old interstate pavement that contains starlugs and an asphaltic concrete subbase that has experienced moisture damage (stripping). The project was selected because joint faulting has become noticeable (approximately 1/8 to 1/4 inch).

(6) Test project No. 9 is an interstate rehabilitation project containing starlugs where approximately half of the joints were faulted above 1/4 inch and half of the joints were faulted below 1/4 inch. The project was selected to help define the relationship between joint faulting and remaining load transfer.

(7) Test project No. 10 is a 25-year-old doweled pavement that is being evaluated as a possible candidate for a bonded concrete overlay. The project was selected to evaluate the level of load transfer and slab support remaining.

Instrumentation

The instrumentation used to measure corner deflection and joint efficiencies consisted of two linear voltage displacement transducers (LVTDs) connected to a data acquisition system (Figure 4). The LVDT's were suspended over the joint from the untied asphalt shoulder.

The data acquisition system used was a Hewlett-Packard HH 9000 series 200 computer system with a HP98640 data acquisition card. A computer program was written in BASIC which enabled readings to be taken sequentially by each LVDT. Measurements were taken every 0.005 seconds continuously for 15 seconds in order to ensure that the maximum deflection was recorded. This test equipment proved to be especially fast and easy to use. Approximately 10 minutes were required at each joint to set up equipment and to record corner deflections.

To limit the effects of temperature change on deflection readings, readings were typically taken over a two hour period in the early morning. Also, especially hot or cold days were avoided. Both of these precautions should limit the effects of pavement slab curling on the deflection readings.

Measurements

Since the ideal responses for pavement evaluation have been shown to be surface deflection under slow moving loads (3, 5), corner deflections were measured continuously at six inches on both side of the joint and six inches from the 6 shoulder (Figure 4) as a truck traveled at creep speed over the joint and 24 inches from the shoulder. The truck was a standard LaDOTD dump truck (single axle and dual tires) loaded and weighed with a rear axle weight of 18,000 lbs. and a front axle weight of 5,000 lbs. Deflections were taken from the time the truck's front axle moved onto the approach pavement until the truck's rear axle moved off the leave pavement. Figure 5 shows the location of the dual rear tire contact areas with respect to the shoulder and joint.

The measurements recorded indicate deflection of the joint as a function of time. Figure 6 is a typical time vs. deflection curve showing the deflection of both the approach and leave pavements. Each curve contains two peaks, a small one corresponding to the front wheel passing over the joint and a much larger one corresponding to the rear wheel passing over the joint. Referring to Figure 6, A is the maximum measured deflection of the approach pavement with the load on the leave pavement. A′ and B′ are the deflection of the unloaded adjacent pavements at A and B. The ratio of A′/A is the joint efficiency when the load is on the approach pavement slab and the ratio B′/B is the joint efficiency when the load is on the leave pavement slab.

Field Evaluation

To help evaluate the stage of pavement deterioration at the time the measurements were made, a summary of the pavement condition of all joints tested were recorded. Every joint measured for corner deflection was rated using Chong, Phang, and Wrong's Manual for Condition Rating of Rigid Pavements (14).

METHOD OF PROCEDURE-ANALYTICAL

Subgrade support and dowel/concrete interaction have been shown to be the primary subbase, slab and joint properties affecting joint behavior under moving loads. Because of the significance of these pavement properties, a parametric study was conducted using the modulus of subgrade reaction (K), dowel/concrete interaction (G), corner deflection and joint efficiency as the variables. A family of influence charts representing each pavement thickness studied (8,9,10,13 inches) was developed indicating the relationships among these parameters. Once these charts were produced, corner deflection and joint efficiency were measured for a specific joint in the field, and K and G were determined from the influence charts. By knowing K and G, the quality of subgrade support and load transfer device system could then be determined.

Modulus of Subgrade Reaction (K)

Modulus of subgrade reaction (K) is a measure of the stiffness of the subgrade support expressed in terms of pressure in pounds per square inch per inch of deflection, or simply pounds per cubic inch (pci) (6). In analysis, the use of a single value for K for the entire pavement slab implies elasticity for the subgrade (the support the subgrade supplies is directly proportional to the deflection). However, since joints cause non-uniform deflections, elastic layer theory may be used only at the center of the pavement slab and cannot be used at or close to a joint or corner edge.

Westergard (7) made an important simplification as compared to elasticity. He assumed that the subgrade cannot transfer shear stresses (that it is a Winkler foundation) (8). This means that the reaction of the subbase on the pavement slab, the vertical pressure, is a constant, K, times the deflection.

The numerical value of K depends not only on factors that affect soil behavior, such as soil texture, density and moisture, but also on factors such as pavement slab rigidity and size of loaded area. If untreated or treated subbases are placed between the subgrade and the pavement slab, values of K can be substantially increased. K can range from about 50 pci for very poor subgrades to 1,000 pci or more for extremely firm soils (9). Any value less than 200 pci is generally classified as a poor subgrade in need of rehabilitation.

Modulus of Dowel/Concrete Interaction (G)

The modulus of dowel/concrete interaction describes the stress between a load transfer device and its surrounding concrete. It is a measure of the resisting pressure exerted from the concrete on the load transfer device and is stated in terms of pounds per square inch per inch of dowel deflection or simply pci.

Typical values of G range from 25,000 pci up to 5,000,000 pci (9). Looseness that develops in the load transfer embedment under the action of repeated loads reduces this load transfer capability. Ozbeki, Kilareski, and Anderson (4) found that corner deflection and joint efficiency change significantly for values of G less than 200,000 pci and selected this value as a minimum limit for an acceptable G value. Modulus values less than 200,000 pci are considered to represent conditions when the load transfer device had failed and are an indication that joint rehabilitation is needed.

A Description of the Finite Element Model

Numerous analytical models exist that can approximate a pavement-subgrade system. Recently, use has been made of the finite element technique to model jointed concrete pavements. A finite element model called JSLAB was recently developed by Tayabji and Colley (10) for the Portland Cement Association. The program is based on the Winkler foundation theory (8), with the following assumptions:

1. Any plane section before bending remains plane after bending.

2. The pavement slab is homogeneous, isotropic and elastic.

3. The subgrade cannot transfer horizontal shear stresses.

4. The reaction of the subbase on the pavement slab (the vertical pressure) is a constant, K, times the deflection.

JSLAB can analyze concrete pavement sections consisting of up to nine slabs and can allow for the analysis of a two-layer system (a layer of concrete placed over either a stabilized layer or another concrete layer). In the case of this research the concrete slab was modeled as one layer and the subgrade and/or subbase was modeled as the other layer. The resulting K value is a composite K for both subgrade and subbase. Load transfer devices can be modeled as dowels or aggregate interlock and keyways. Dowel bars are modeled as short thick beams, and aggregate interlock and keyways are modeled as linear-elastic spring elements. Load input is in terms of wheel loads at any location on the pavement. The significant input variables are: subgrade modulus of dowel/concrete interaction (G), dowel diameter and spacing, concrete modulus of elasticity (E), and Poisson's ratio of concrete. The accuracy of the model for the prediction of stresses and deflection has been verified with closed-form solutions and results of experimental studies.

Development of Influence Charts

Pavement variables included concrete properties such as modulus of elasticity and Poisson's ratio as well as dowel properties. For concrete, Poisson's ratio is not a constant but varies as a function of a number of different factors such as temperature, moisture content and stress conditions. Based on the result of many tests (11), it has been determined that the range to be expected for pavement slabs lies between 0.10 and 0.20. The average figure of 0.15 is usually adopted and was used in this study.

A summary of many tests (6) indicates that the modulus of elasticity for concrete (E) is roughly 1,000 times its compressive strength and ranges from 2 to 6 million psi. The modulus varies not only with strength, but also with pavement age, moisture state, stress conditions and other factors. Since ACI (12) has stated that the compressive strength of concrete for the design of rigid pavement should not be less that 4,000 psi (28-day strength), 4 million psi is frequently used (25, 27) as an approximation for E. The compressive strength of concrete for pavements in this study was approximately 3,600 psi at 28 days. Therefore, 4 million psi is the value chosen to be used in this parametric study.

For simplicity, starlugs were modeled as dowel bars on 12-inch spacings, even though the starlug were spaced at 14-inch increments. The resulting load transfer characteristics therefore represent those that a dowel bar system would exhibit given the measured deflection characteristics of a joint containing starlugs. It was thought that this procedure would provide the best comparison between projects with different load transfer devices. Standard dowel properties used for the pavements tested were:

(1) dowel modulus of elasticity = 29,000,000 psi
(2) dowel spacing = 12 inches
(3) Poisson's ratio of dowel material = 0.29
(4) joint opening = 0.1 inch
(5) diameter of dowel = 1 inch

Loading Configuration

A total tire load equal to 18,000 pounds was applied on four equivalent 7-inch by 8-inch rectangular areas corresponding to the four tire contact areas for the rear axle at the edge of the approach pavement slab. This loading is in agreement with the actual weight and type of truck used in the test procedure. Front-axle tires were neglected in the analysis because they have been shown in previous studies to have an insignificant effect on deflections caused by rear-axle loading (4, 9, 13). Results from this study were in agreement with these previous findings.

Results

Using the loading configurations and pavement input variables discussed in the previous sections, along with specific K and G values, JSLAB can determine a corner deflection and a joint efficiency. If K and G are varied, a unique pair of values for deflection and efficiency can be produced for each specific K and G. By varying K from 50 pci to 2,000 pci in increments of 50 and G from 50,000 pci and 5,000,000 pci in increments of 100,000, the results can be plotted as lines of K and G with corner deflection and joint efficiency as the independent and dependent variables, respectively. A graph of influence curves for a 10-inch concrete pavement is depicted in Figure 1.

DISCUSSION OF RESULTS

The measured corner deflection and joint efficiencies were plotted on the previously generated influence charts as shown in Figure 4 for a 10-inch concrete slab. Since the deflection and efficiency of a specific slab joint was known, an effective K and G for each joint could be determined.

Pavements older than 15 years (project nos. 1, 2, 8, 9, 10) had a significant scattering of estimated K and G values. Since the deterioration process can vary from joint to joint depending on such factors as subbase or load transfer loss, one joint may perform adequately while the adjacent joint performs unacceptably. This process leads to a higher standard deviation of results in the older pavements. It should be noted, however, that the following sections use average values of K and G to draw several conclusions.

Comparison of Data with Project Characteristics

Table 2 contains average values of K, G, joint efficiency, and absolute deflection for each test site. The following observations can be made from this information:

(1) Projects Nos. 1 and 2 represent a dowel bar and a starlug project at end of life and both projects contain G-values of approximately 200,000 psi. Cores obtained over doweled joints contained broken concrete above the bars indicating a concrete bearing failure. The starlugs exhibited metal and concrete wear sufficient to allow faulting between 1/2 and 3/4 inch. K values were relatively low for both projects (400-500 pci) indicating possible voids under the slab near the joints.

(2) Projects Nos. 3 and 4 represent new 10-inch jointed concrete pavement with dowel bars. G values exceeded 5,000,000 psi and K values exceeded 2,000 pci on project No. 3 where the 2-inch asphaltic concrete subbase was constructed over a

working table of soil cement. In fact, the average deflection under the 18,000-pound load was only .0012 inches. Project No. 4 is identical except that the roadbed soil contained intermittent lime or cement treatment depending on soil characteristics. G values were also high, however, K values in the cement-treated section exceeded 2,000 pci whereas K values in the lime-treated section ranged between 600 and 1,000 pci. Average deflections were 0.0002 inches and .0029 inches respectively.

(3) Projects Nos. 5 and 6 represent recent concrete paving construction and contained K values in excess of 1000 psi.

(4) Project No. 7, a 4-inch bonded pcc overlay over 9-inch plain doweled jointed concrete pavement (JCP), exhibited excellent load transfer and slab support after 7 years of service.

(5) Project No. 8, a 15-year-old 10-inch (Interstate 10) plain jointed concrete pavement with starlugs, has lost load transfer (G = 200,000 pci) and is experiencing faulting. The K values are somewhat lower than on new pavements of this type and cores indicate some stripping of the asphaltic concrete base.

(6) Project No. 9 indicates the reduction in load transfer caused by faulting on an older interstate project with starlugs. Joints faulted more than 1/4 inch (No. 9b in Table 2) contained significantly less load transfer than joints faulted less than 1/4 inch (No. 9a).

(7) Project No. 10 indicates the possibility of voids in the transverse joint area as evidenced by relatively low K values (300 to 500 pci). The 30-year-old doweled JCP contained very little joint faulting. However, because the dowels resist faulting the slabs tend to bridge over voids rather than fault as with starlug pavements, hence the low

K values. Since this project is a candidate for a bonded-concrete overlay, undersealing will be scheduled to restore slab support before overlay.

The Effect of Faulting on Joint Performance

Faulting plays a significant role in joint performance. To evaluate the effects of faulting, results for joints were grouped together according to their severity level and compared with one another. Table 3 shows the severity level of joint faulting compared with average joint efficiencies and K and G values. Observation of the table reveals:

1. When severe faulting (1/2 to 3/4 inch) is present, average G values are significantly below the minimum acceptable value of 200,000 pci recommended by Ozebki, Kilareski, and Anderson (4).
2. Regardless of severity level, average K values are above the minimum recommended lower limit value of 200 pci.
3. A severe level of faulting corresponds to joint efficiencies below the acceptable limit of 50 percent recommended by many sources (6,11).
4. A moderate level of faulting (1/2 to 1/4 inch) produces joint efficiencies which are near the 50 percent limit.

Evaluation of Joint Efficiencies

Corner deflections and joint efficiencies have previously been shown to be directly related to load transfer and subbase properties. Results presented in Table 2 and Table 3 indicate that slabs with negligible joint faulting produced higher joint efficiencies on the approach slabs than those on the leave slabs. This is in agreement with other research (4, 6, 11) because the amount of pumping and loss of subgrade support is greater under the leave pavement slab, causing lower joint efficiencies on the leave slab.

Nevertheless, the results show the opposite effect on pavements that contain higher levels of joint faulting and distress. The joint efficiency of the approach pavement slab is considerably lower than that of the leave pavement slab. As pavement age increases, pumping from underneath the leave slab causes water and subbase particles to be ejected from under the leave slab and deposited under the approach slab. As joint load transfer diminishes and faulting occurs, the leave slab "bottoms out" or is seated on subbase. This results in larger joint efficiency on the leave than approach slab.

Summary of Results

From the data and analyses presented in this section, it has been shown that low joint efficiencies and low values of the modulus of dowel/concrete interaction (G) are associated with the severity of joint faulting. Values of G tend to range near unacceptable levels (less than 300,000 pci) for severe or moderate faulting but increase substantially (to greater than 3,000,000 pci) when only slight or very slight faulting is present. Results indicate that high G values are maintained at greater than 2,000,000 pci until they drop suddenly, indicating some form of brittle failure of the concrete surrounding the load transfer device. This was supported by cores taken over load transfer devices on joints which exhibited very low load transfer efficiencies (less than 20 percent). Once this failure has taken place, the slab has the ability to move vertically, resulting in increased faulting and rapid deterioration of the entire pavement system.

Values for the modulus of subgrade reaction (K) indicated that all joints exhibited good subbase support, according to the criterion of Ozebki, Kilareski, Anderson, and others. However, joints on pavements older than 15 years showed several signs of decreased subbase support. It is suggested here that the minimum value of K be raised to 500 pci when using this test method, which is the average value of K for these older pavement slabs. Below this level it is thought that voids are probable, and that the pavement should be scheduled for undersealing.

It should be noted that in approximately 10 percent of the joints evaluated, analytical results showed indications of poor load transfer capability or subbase support, while visual observations showed no signs of pavement distresses. By using only a visual observation, these joints would have been evaluated as satisfactory and would not have been selected for rehabilitation. This non-destructive test procedure can effectively determine the performance of a joint without solely relying on visual observations this procedure would identify poor joints that a visual inspection would not.

Recommended Joints for Repair

It has been shown that corner deflections and joint efficiencies, along with a visual observation of the site, can be used to predict the performance of a joint. Joints that are severely deteriorated because of concrete breakage are usually scheduled for full-depth patching. Through this process load transfer is restored, pavement stresses are relieved, and a sealed joint is provided. However, in the case of a joint which is faulted but not otherwise deteriorated, the decision to grind and underseal (but not restore load transfer) or to replace the joint because of loss of load transfer is not always an obvious choice. It is in this situation that corner deflection and joint efficiency determination can provide the information needed to make these "fix it" or "replace it" types of decisions. The guidelines such as those depicted in Figure 2 can be used for deciding how to rehabilitate faulted joints.

7. Guidelines for concrete pavement rehabilitation decisions were developed to aid in the determination of whether to replace faulted joints caused by a loss of load transfer, or whether to grind and underseal based on the modulus of dowel-concrete interaction. Joint replacement is recommended when G is less than 300,000 pci.

OBJECTIVES AND SCOPE

The deflection readings and JSLAB finite element program were used to determine the following:

(1) Suitability of JSLAB as an analytical modeling tool of pavements with a concrete overlay and tied concrete shoulder and

(2) The implied benefit of adding tied concrete shoulders.

The deflection readings during the four stages of construction were repeated at six sites along Interstate 10 in Baton Rouge and these results were compared with the results from the JSLAB model of the four stages of construction.

Sample plots of deflection readings are shown in Figure 7 and 8. In Figure 7 is a pre-construction plot and Figure 8 is a post-construction plot. A notable decrease in pavement deflection is noticed when comparing Figures 7 and 8, from the pre-construction to post-construction phases.

The results from the deflection readings are shown in Table 4. The results shown are the average of the six readings taken at each stage of construction with the second column being the maximum pavement deflection and the third the maximum shoulder deflection.

Analytical Model

Using the finite element program JSLAB (described in detail in Phase I), computer models of each phase of construction were generated.

Table 4 contains the results from the four finite element models in its last two columns. To obtain the most accurate results from the finite element models, the finite element mesh size was decreased until deflection results remained consistent. For the post-construction phase, the combination of tied shoulder and concrete overlay with the mesh size necessary to insure accurate results created a computer overflow that precluded obtaining any results for the post-construction phase.

The following were input data for the JSLAB program:

1. Modulus of Elasticity: 4000 ksi for existing pavement and 6000 ksi for concrete overlay and new shoulder.

2. Poisson's Ration: 0.15 for all concrete.

3. Full composite action between existing pavement and overlay.

4. Subgrade Modulus: 300 pci.

CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis of the experimental and analytical results, the following conclusion and recommendations can be made:

1. The addition of the overlay and tied shoulder were effective in reducing pavement deflections.

2. Addition of a 4-inch fiber reinforced concrete overlay to an existing 8-inch CRC pavement reduced edge deflection by approximately 50 percent.

3. Construction of a 9-inch tied concrete shoulder further reduced the edge deflection by 25 percent.

4. The combined overlay and shoulder construction reduced edge deflections by 60 percent under a 22-Kip single axle load.

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TABLE 1

PROJECT LOCATION AND PAVEMENT CHARACTERISTICS

TEST NO.	STATE ROUTE	LOCATION	THICKNESS (IN.)	LOAD TRANSFER DEVICE	SLAB LENGTH (FT.)	AGE (YRS.)	TYPE OF SUBBASE
1	I-10 West	West of LA 415 interchange (Port Allen)	10	dowels	58.5	17	soil-cement
2	I-12 East	Livingston-Tangipahoa parish line (near Hammond)	10	starlugs	58.5	20	soil-cement
3	1-49 North	North of LA 181 interchange (Cheneyville)	10	dowels	20	new	hot mix asphalt
4	I-49 North	North of LA 920 interchange (near Natchitoches)	10	dowels	20	new	hot mix asphalt
5	LA-42 South	1.0 mile South of LA42-LA30 intersection (near Baton Rouge)	9	dowels	20	6	soil-cement
6	LA-408 East	just West of Comite River Bridge (near Baton Rouge)	8	dowels	20	6	soil-cement
7	US-61 South	32. miles North of I-10 - US-61 interchange (near Zachary)	13**	dowels	20	7	soil-cement
8	I-10 West	Lafayette-St. Martin parish line (near Breaux Bridge)	10	starlugs	20	15	hot mix asphalt
9	I-55 North	Independence - Amite	10	starlugs	58.5	19	soil-cement
10	US-90 East	Airport - Broussard	10	dowels	20	30	soil-cement

** - Original 9" thick pavement with 4" thick overlay

TABLE 2

AVERAGE DEFLECTIONS AND PREDICTED K AND G VALUE FOR EACH TEST SITE

Test Site	A (in)	A'/A (%)	$K_{approach}$ (pci)	G (pci x 1000)	B (in)	B'/B (%)	K_{leave} (pci)
1	.0059	41	637	178	.0064	65	456
2	.0058	39	686	208	.0047	56	423
3	.0012	97	2,000	5,000	.0012	97	2,000
4(a)	.0002	97	2,000	5,000	.0002	97	2,000
(b)	.0029	97	800	5,000	.0027	97	800
5	.0030	88	1,120	3,250	.0030	82	1.186
6	.0022	89	1.350	2,830	.0022	83	1,445
7	.0007	95	2,860	4,420	.0011	81	3,300
8	.0033	47	1,120	220	.0027	68	1.047
9(a)	.0027	82	1,400	2,040	.0025	79	1,000
(b)	.0021	64	1,720	410	.0022	67	1,650
10	.0065	59	515	440	.0069	69	375

Note: 4(a) Subbase Type: 2-inch asphaltic concrete/6-in. cement treated soil
4(b) Subbase Type: 2-inch asphaltic concrete/6-in. lime treated soil

Note: 9(a) joint faulting < 1/4"
9(b) joint faulting > 1/4"

TABLE 3

SEVERITY OF JOINT FAULTING VERSUS AVERAGE VALUES OF K, G AND JOINT EFFICIENCY

		Average Values				
Severity of Joint Faulting	No. of Joints	Joint Efficiency (%)		G	$K_{approach}$	K_{leave}
		Approach	Leave	(pci)	(pci)	(pci)
Severe	15	32	60	120,000	710	500
Moderate	14	55	66	330,000	1,000	890
Slight	4	88	74	3,000,000	1,270	1,370
Very Slight	22	96	82	3,700,000	1,470	1,390

NOTE: Severe Faulting 1/2 to 3/4 inch
Moderate: 1/4 to 1/2 inch
Slight: 1/8 to 1/4 inch
Very Slight 1/8 inch

TABLE 4. RESULTS

Stages	Average Experimental Results		Analytical Results[1]		
	Pavement Deflection (in)	Shoulder Deflection (in)	Pavement Deflection (in)	Shoulder Deflection (in)	Axle Load (kips)
Pre-Construction	0.0062	0.0048	0.0076	0	22.0
Shoulder Removed Pre-Overlay	0.0069	0.0060	0.0076	0	21.6
Shoulder Removed with Overlay	0.0033	0.0038	0.0055	0	22.5
Post-Construction	0.0025	0.0019	*	*	22.5

* No results available.

[1] K value assumed at 300 pci.

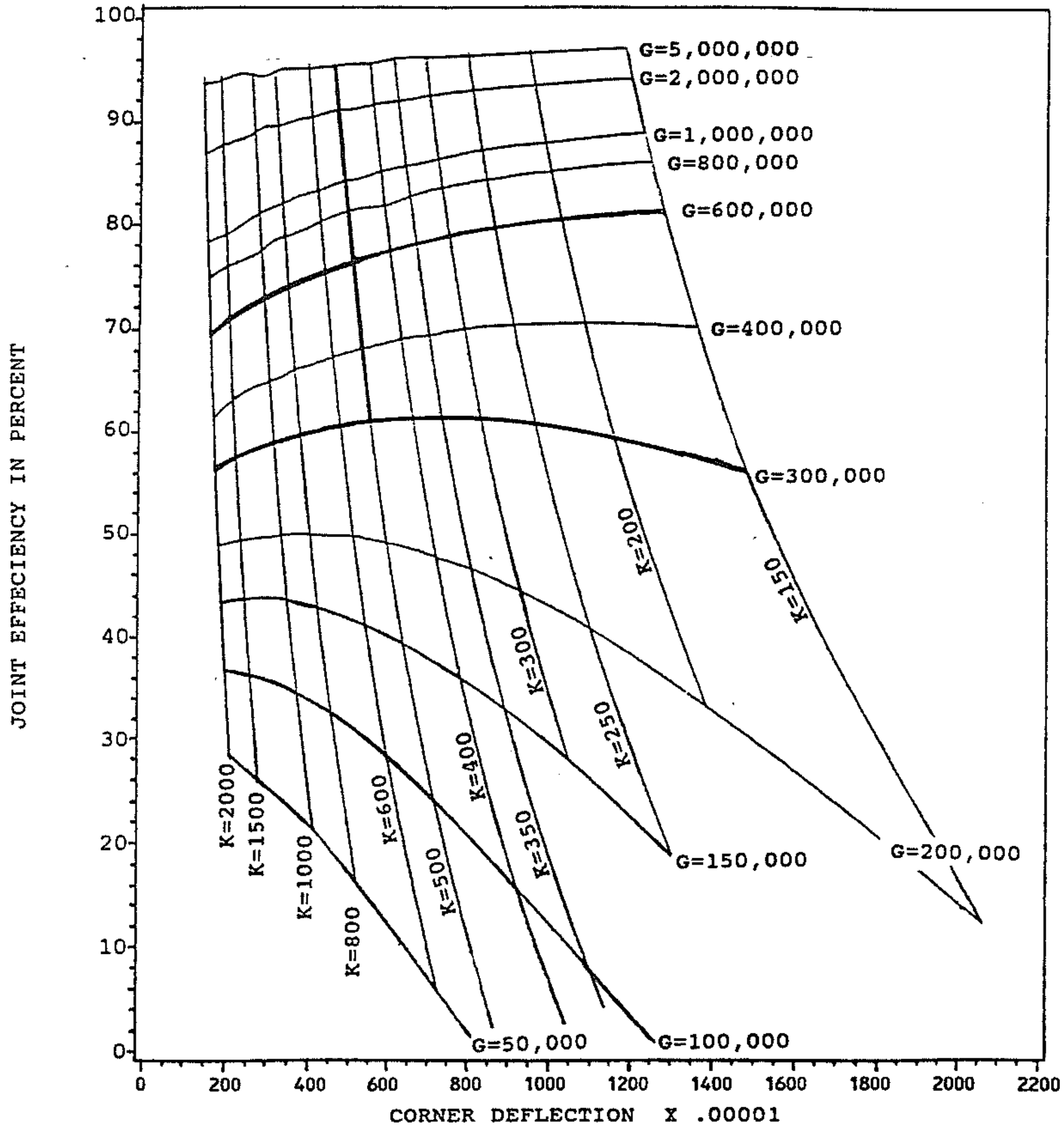
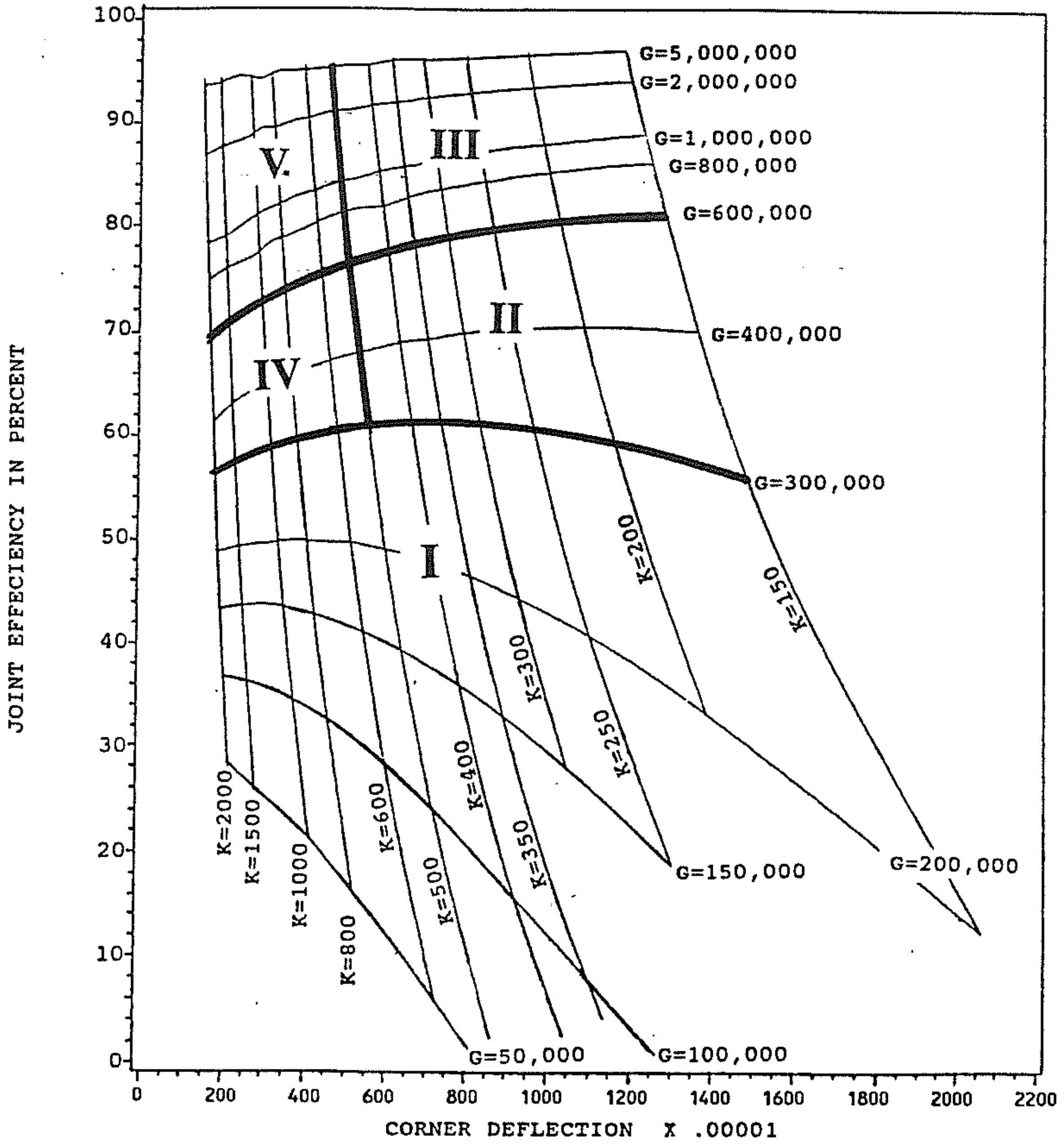


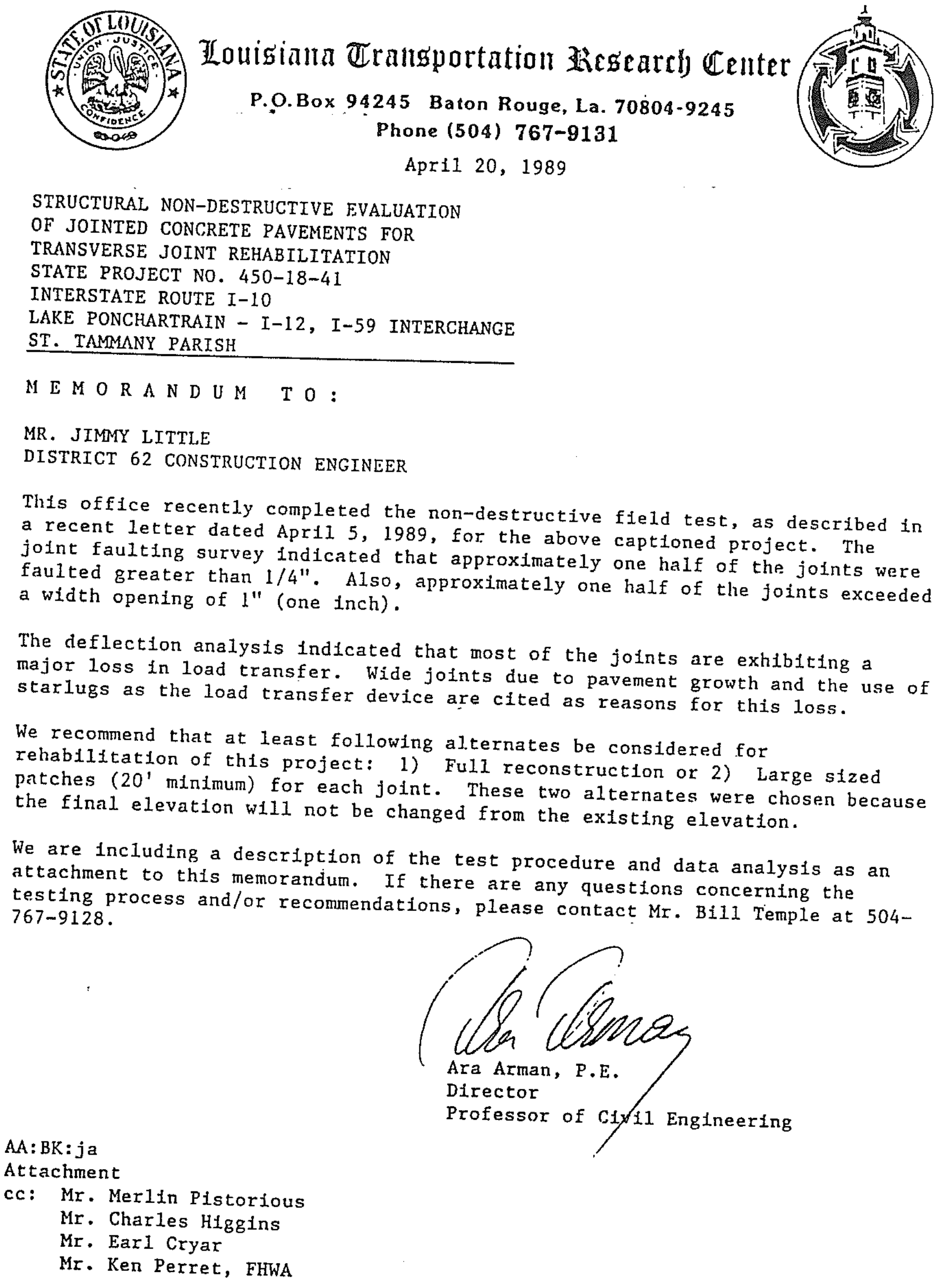
FIGURE 1. Influence curves of K and G for 10-inch jointed concrete pavements



CONDITION			REHABILITATION ACTION REQUIRED	
*	LOAD TRANSFER	VOIDS	JOINT FAULTING (OTHERWISE OK)	JOINTS BROKEN (SPALLS, CRUSHING)
I	UNACCEPTABLE	POSSIBLE	FULL DEPTH PATCH	FULL DEPTH PATCH (FDP)
II	MARGINAL	PROBABLE	FULL DEPTH PATCH/ GRIND & UNDERSEAL	FULL DEPTH PATCH
III	GOOD	PROBABLE	GRIND & UNDERSEAL	FULL DEPTH PATCH
IV	MARGINAL	DOUBTFUL	F.D.P. AND/OR GRIND	FULL DEPTH PATCH
V	GOOD	DOUBTFUL	NO ACTION	FULL DEPTH PATCH

* REGION

FIGURE 2. Guidelines for rehabilitation of jointed concrete.



Louisiana Transportation Research Center
P.O.Box 94245 Baton Rouge, La. 70804-9245
Phone (504) 767-9131

April 20, 1989

STRUCTURAL NON-DESTRUCTIVE EVALUATION
OF JOINTED CONCRETE PAVEMENTS FOR
TRANSVERSE JOINT REHABILITATION
STATE PROJECT NO. 450-18-41
INTERSTATE ROUTE I-10
LAKE PONCHARTRAIN - I-12, I-59 INTERCHANGE
ST. TAMMANY PARISH

MEMORANDUM TO:

MR. JIMMY LITTLE
DISTRICT 62 CONSTRUCTION ENGINEER

This office recently completed the non-destructive field test, as described in a recent letter dated April 5, 1989, for the above captioned project. The joint faulting survey indicated that approximately one half of the joints were faulted greater than 1/4". Also, approximately one half of the joints exceeded a width opening of 1" (one inch).

The deflection analysis indicated that most of the joints are exhibiting a major loss in load transfer. Wide joints due to pavement growth and the use of starlugs as the load transfer device are cited as reasons for this loss.

We recommend that at least following alternates be considered for rehabilitation of this project: 1) Full reconstruction or 2) Large sized patches (20' minimum) for each joint. These two alternates were chosen because the final elevation will not be changed from the existing elevation.

We are including a description of the test procedure and data analysis as an attachment to this memorandum. If there are any questions concerning the testing process and/or recommendations, please contact Mr. Bill Temple at 504-767-9128.

Ara Arman, P.E.
Director
Professor of Civil Engineering

AA:BK:ja
Attachment
cc: Mr. Merlin Pistorious
Mr. Charles Higgins
Mr. Earl Cryar
Mr. Ken Perret, FHWA

FIGURE 3. Sample Memorandum to the District.

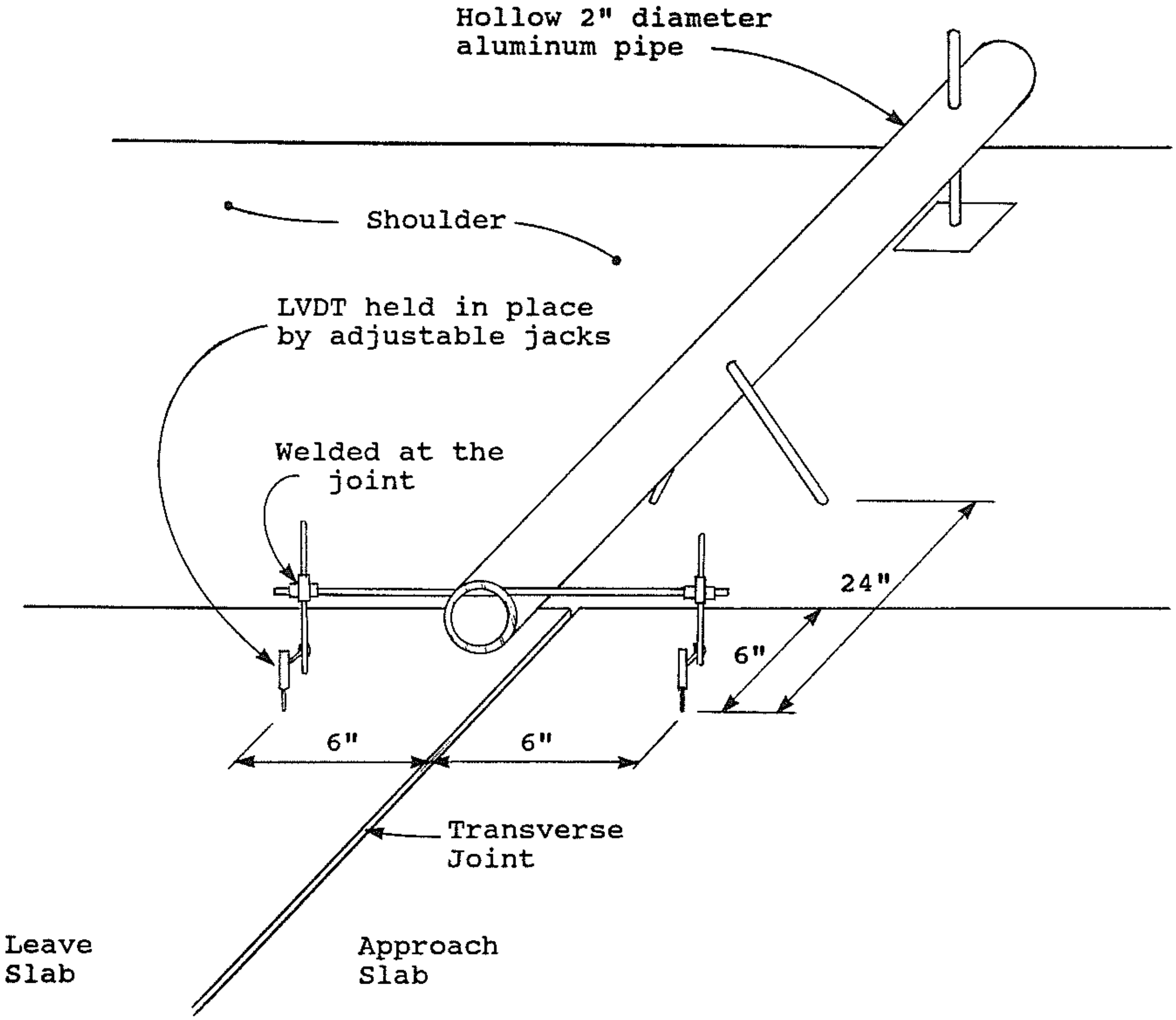
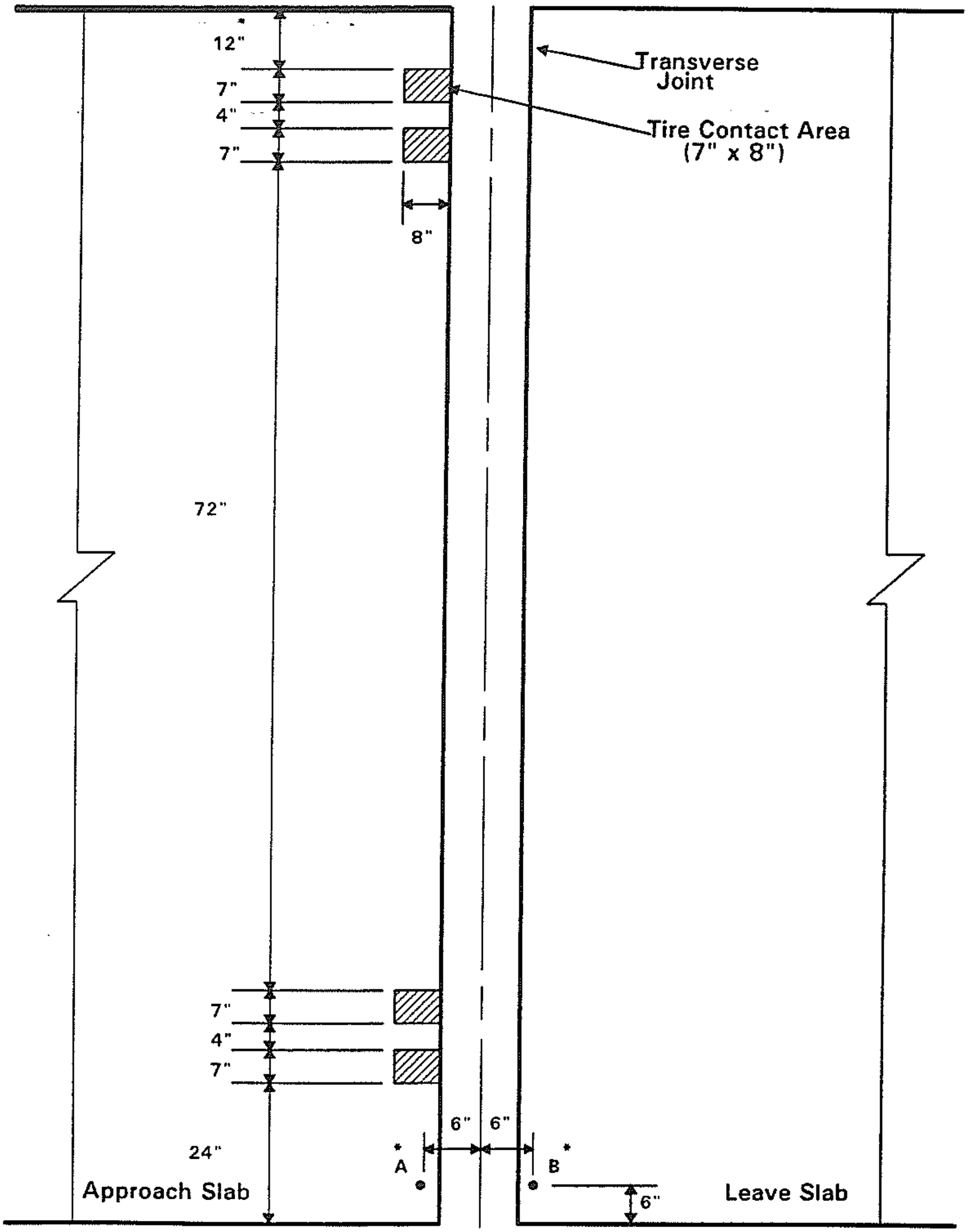
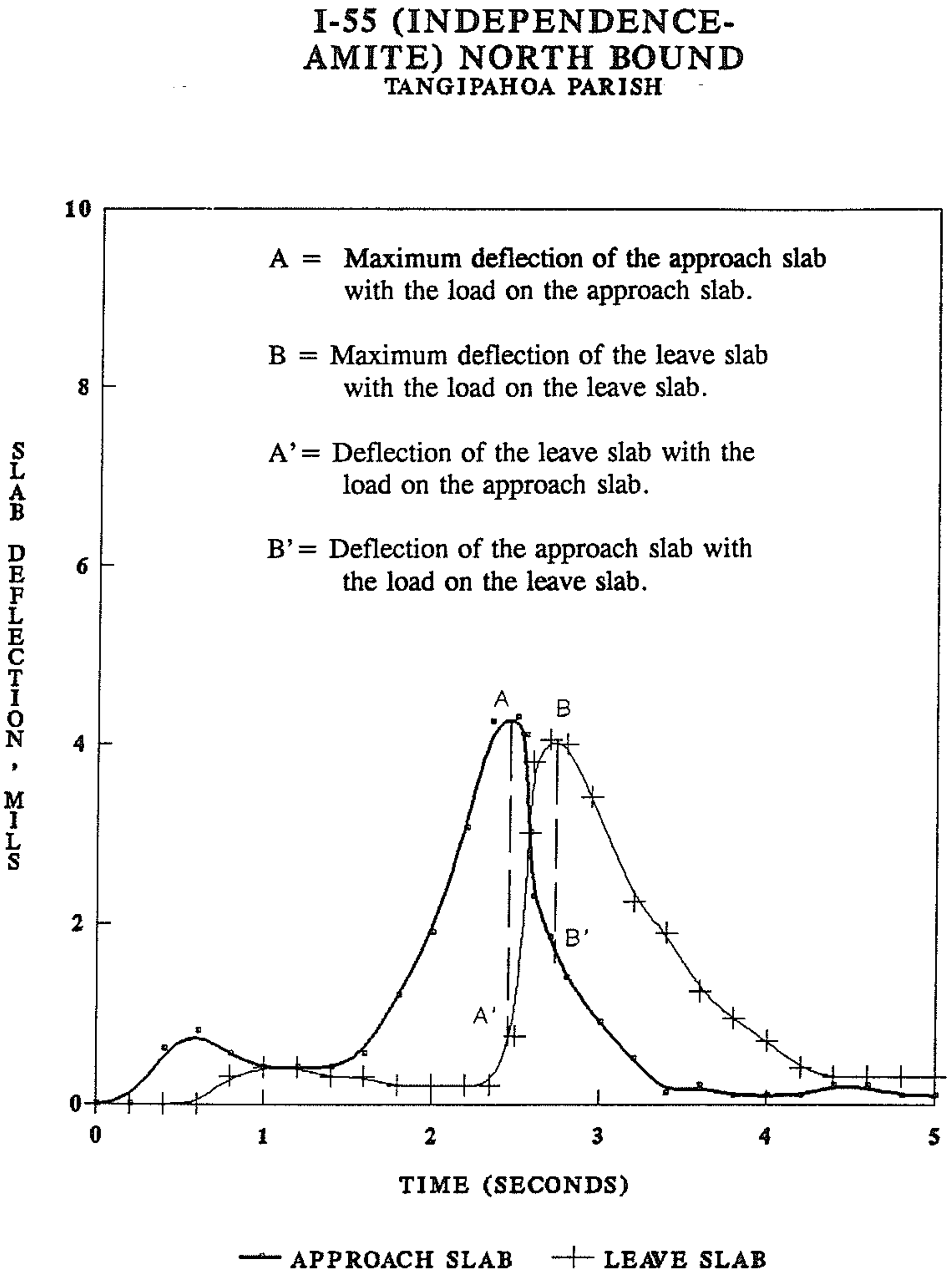


FIGURE 4. Schematic of Instrumentation



* Points A and B are locations of transducers.

FIGURE 5. Loading Configurations.



I-55 (INDEPENDENCE-AMITE) NORTH BOUND
TANGIPAHOA PARISH

A = Maximum deflection of the approach slab with the load on the approach slab.

B = Maximum deflection of the leave slab with the load on the leave slab.

A' = Deflection of the leave slab with the load on the approach slab.

B' = Deflection of the approach slab with the load on the leave slab.

FIGURE 6. A typical time-deflection curve.

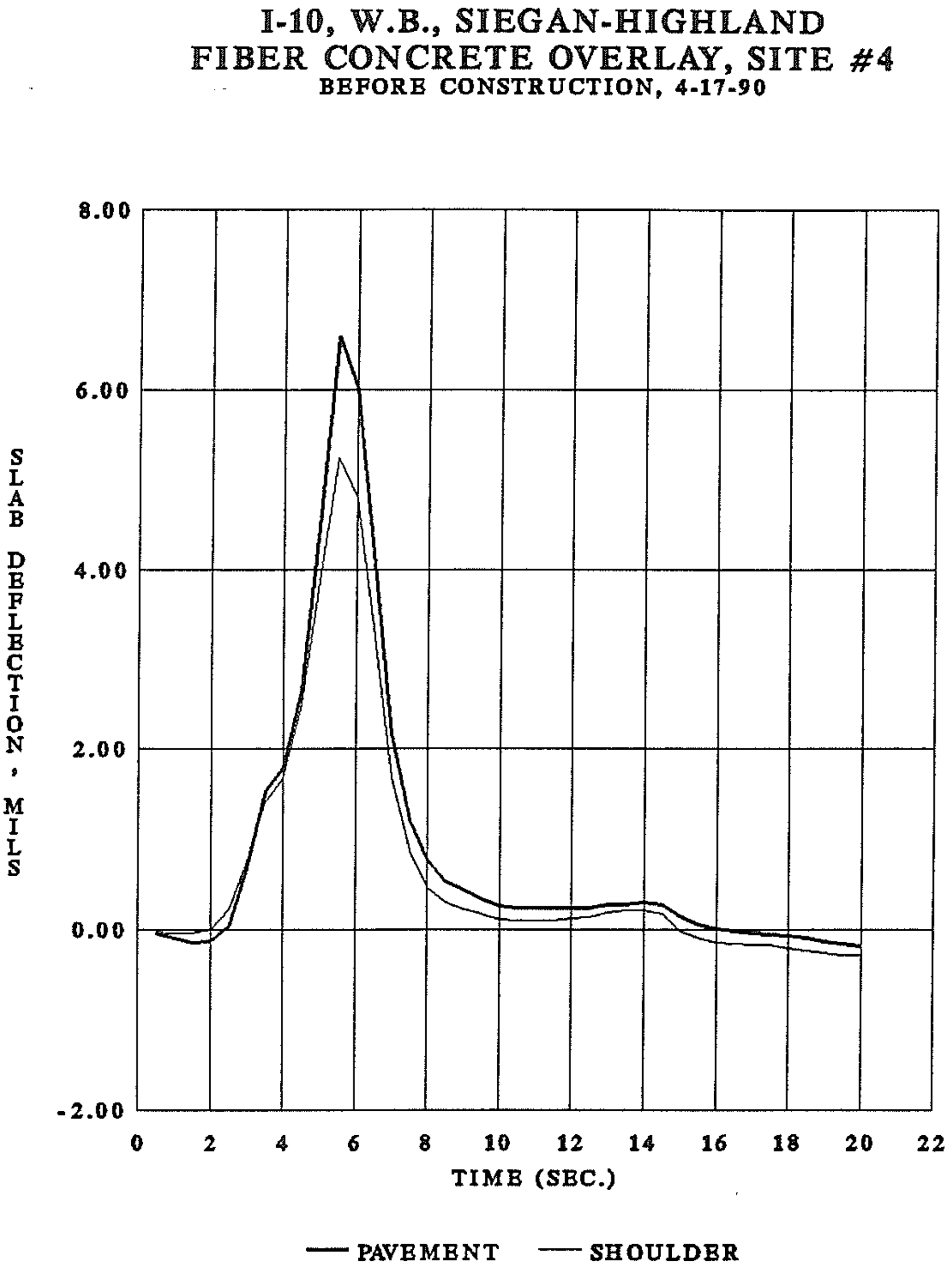


FIGURE 7. Sample plot of deflection readings - Before Construction

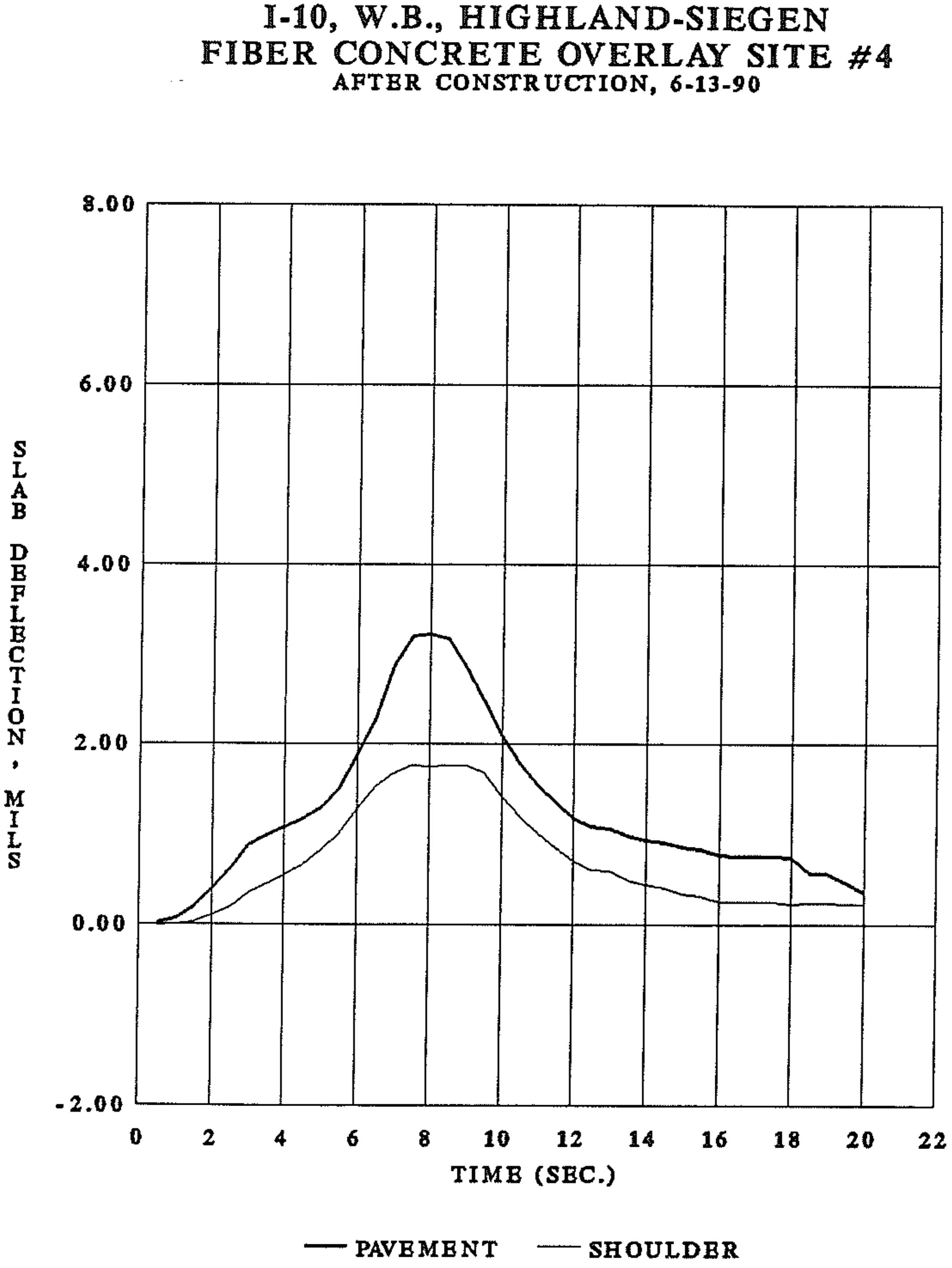


FIGURE 8. Sample plot of deflection readings - After Construction

I-12 (AT NATALBANY RIVER BRIDGE) EAST BOUND
LIVINGSTON/TANGIPAHOA PARISH LINE TO HAMMOND
TANGIPAHOA PARISH
10" CONCRETE

This project has developed extensive joint faulting throughout, with an average value of 0.40 inches. Cores taken over the starlugs indicate that the faulting is a result of metal and concrete wear. As indicated in Table 5, the typical joint is transferring less than 50% of the load. Figure 8 which contains the joint data plotted, indicates that on several joints, slab support is questionable and voids may be present under the slab.

RECOMMENDATIONS: It is recommended that a cost study be undertaken to evaluate at least the following alternatives: 1) Reconstruct; 2) Rubblize and rebuild; 3) Break, Seat and Overlay; 4) Extensive large patching; 5) Small 6 ft. patching with 3-inch to 4-inch asphaltic concrete overlay.

TABLE 5

JOINT NUMBER	JOINT FAULTING	JOINT WIDTH	CORNER DEFLECTION (MILS)	JOINT EFFICIENCY %	K	G x 1000
1	0.4"	0.85"	5.877	20	700	75
2	0.45"	0.75"	6.489	3	700	45
3	0.5"	0.50"	8.046	72	280	450
4	0.2"	0.50"	9.531	29	340	140
5	0.4"	0.60"	4.194	50	700	200
6	0.4"	0.60"	5.652	40	580	150

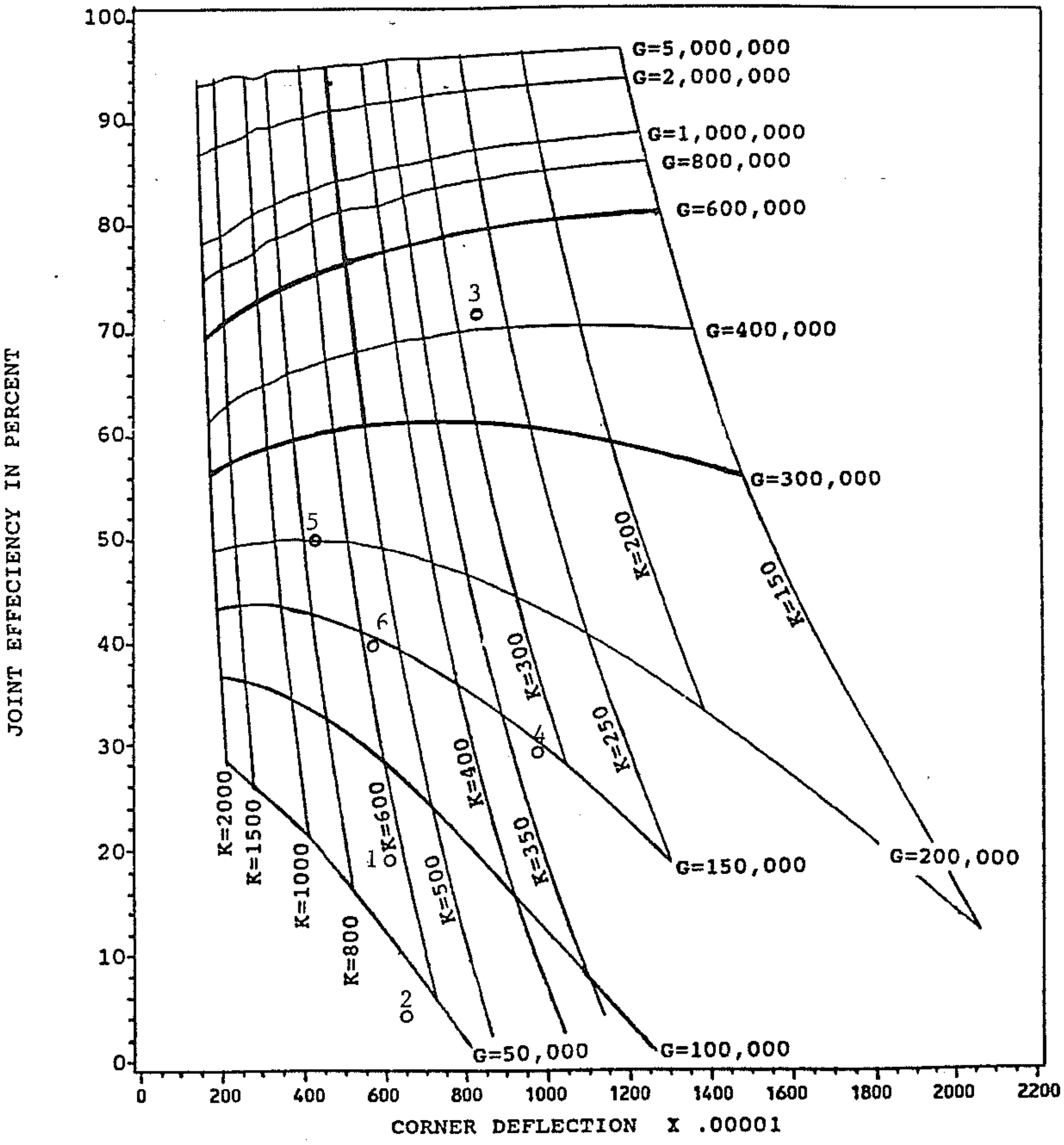

JOINT EFFECIENCY IN PERCENT
CORNER DEFLECTION X .00001
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FIGURE 9

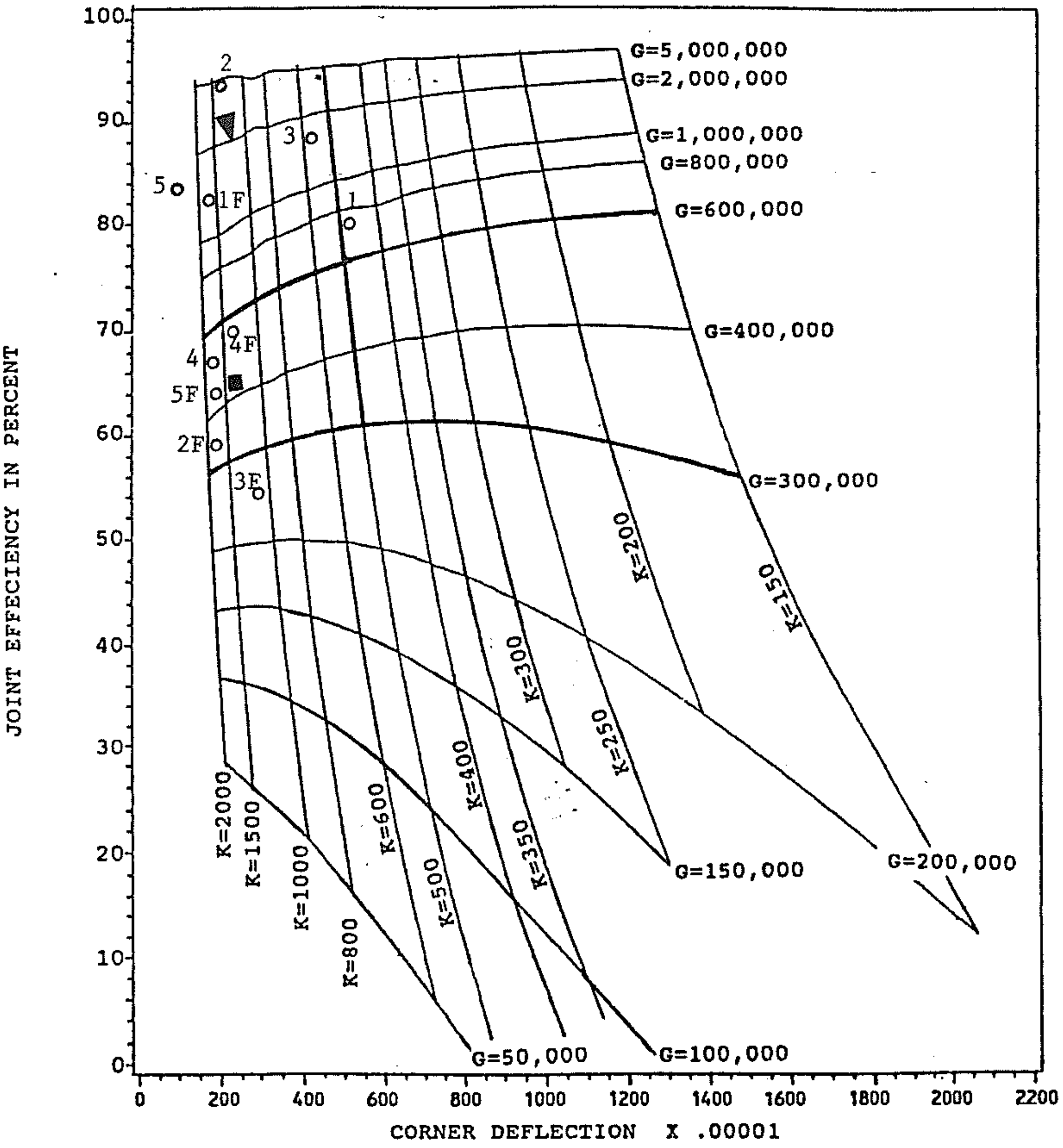
I-55 (INDEPENDENCE - AMITE) NORTH BOUND
TANGIPAHOA PARISH
10" CONCRETE

The district joint faulting survey indicated that approximately half of the joints in this project were faulted greater than 1/4-inch. The "G" and "K" values in Table 6 are grouped by joint faulting levels (above and below 1/4-inch) to determine if there should be a different treatment for the two conditions. As indicated in the table, the joints with greater than 1/4-inch faulting have significantly lower load transfer remaining. Figure 9 which contains the joint data plotted, indicates that slab support is adequate and therefore voids under the slab are not a consideration at this time. It was recommended that joints faulted greater than 1/4" be full depth patched to restore load transfer.

TABLE 6

JOINTS FAULTED < 1/4"						
JOINT NUMBER	JOINT FAULTING	JOINT WIDTH	CORNER DEFLECTION (MILS)	JOINT EFFICIENCY %	K	G x 1000
1	0.2"	0.95"	4.482	80	500	800
2	0.2"	1.00"	1.818	93	1500	5000
3	0.2"	0.50"	4.059	88	600	1500
4	0.2"	1.20"	1.620	67	2000	500
5	0.2"	1.75"	0.945	83	2500	1400

JOINTS FAULTED > 1/4"						
JOINT NUMBER	JOINT FAULTING	JOINT WIDTH	CORNER DEFLECTION (MILS)	JOINT EFFICIENCY %	K	G x 1000
1F	0.4"	0.75"	1.611	75	2000	500
2F	0.4"	0.80"	1.800	59	2000	325
3F	0.3"	0.60"	2.907	54	1200	250
4F	0.5"	0.80"	2.160	70	1400	550
5F	0.4"	0.70"	1.863	64	2000	425



▼ Average for joints faulted ≤ ¼"

■ Average for joints faulted > ¼"

FIGURE 10

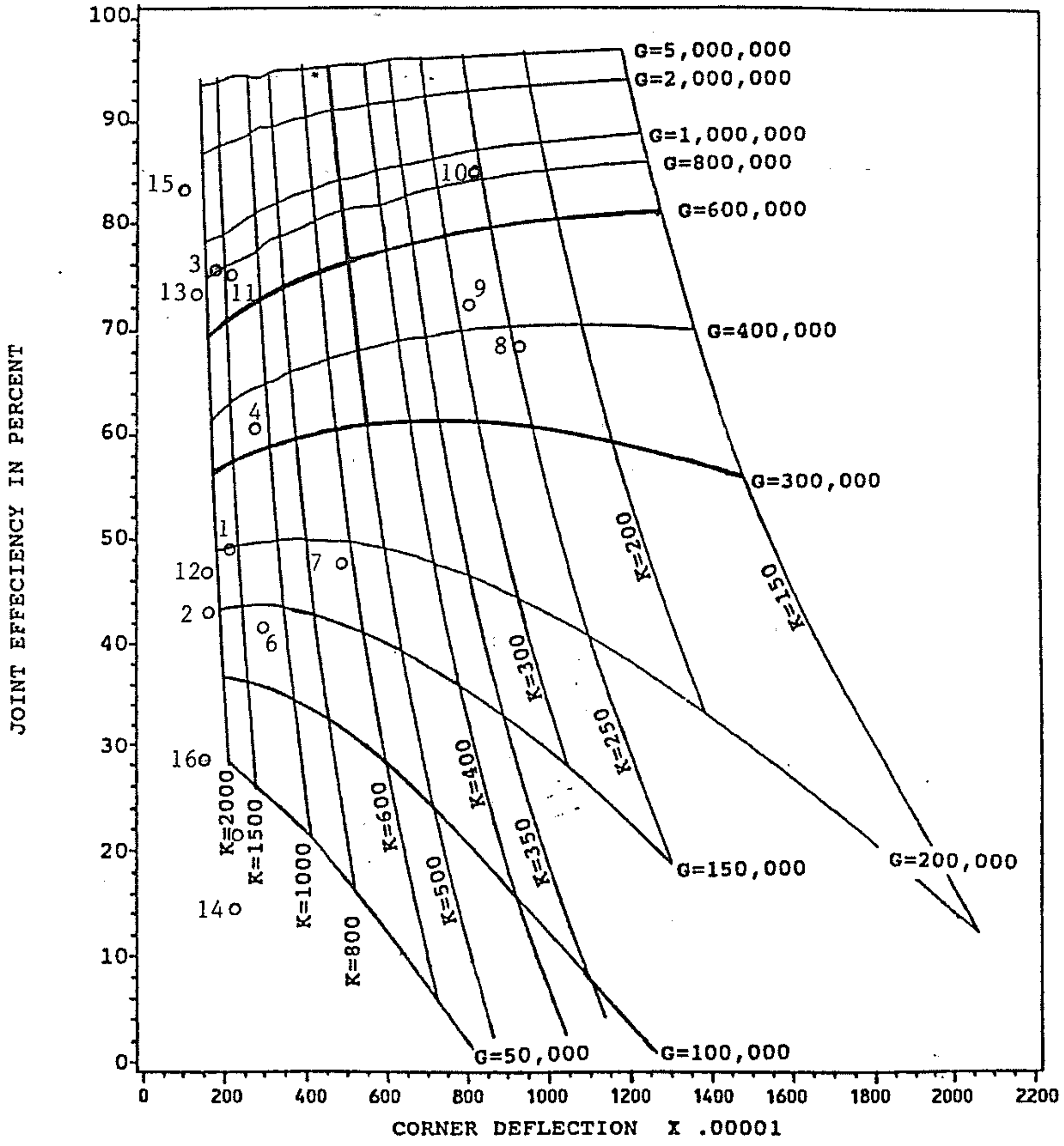
I-10 (EDEN ISLES, NEAR SLIDELL) WEST BOUND
ST. TAMMANY PARISH
REAR AXLE WEIGHT = 17,450 LBS.
10" CONCRETE

The joint faulting survey shown in Table 7 indicated that approximately one half of the joints were faulted greater than 1/4". Also approximately one half of the joints exceeded a width opening of 1-inch. The deflection analysis indicated that most of the joints are exhibiting a major loss in load transfer. Wide joints due to pavement growth and the use of starlugs as the load transverse device are cited as reasons for this loss. Figure 10 indicates a wide variety of conditions exist.

RECOMMENDATIONS: It is recommended that at least the following alternatives be considered for rehabilitation of this project: 1) Full reconstruction; 2) Large sized patches (20 ft. minimum) for each joint.

TABLE 7

JOINT NUMBER	JOINT FAULTING	JOINT WIDTH	CORNER DEFLECTION (MILS)	JOINT EFFICIENCY	K	G x 1000
1	0.00 in.	1.65 in.	2.232	49	1500	200
2	0.40 in.	1.50 in.	1.746	42	2200	140
3	0.30 in.	1.60 in.	1.782	75	1800	800
4	0.40 in.	1.40 in.	2.727	60	1200	325
5	0.50 in.	1.00 in.	2.745	21	1600	< 50
6	0.30 in.	1.00 in.	3.087	41	1200	130
7	0.10 in.	0.85 in.	5.103	47	630	180
8	0.00 in.	0.90 in.	9.342	68	250	380
9	0.10 in.	0.95 in.	7.920	72	280	450
10	0.15 in.	1.00 in.	8.244	85	250	850
11	0.15 in.	0.35 in.	2.034	75	1500	800
12	0.40 in.	0.50 in.	1.683	46	2200	180
13	0.35 in.	0.50 in.	1.422	73	2100	750
14	0.70 in.	0.60 in.	2.493	14	2000	< 50
15	0.75 in.	0.80 in.	1.080	83	2500	1600
16	0.40 in.	0.50 in.	1.710	28	2400	< 50



JOINT EFFECIENCY IN PERCENT
CORNER DEFLECTION X .00001
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G=600,000
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G=300,000
G=200,000
G=150,000
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FIGURE 11

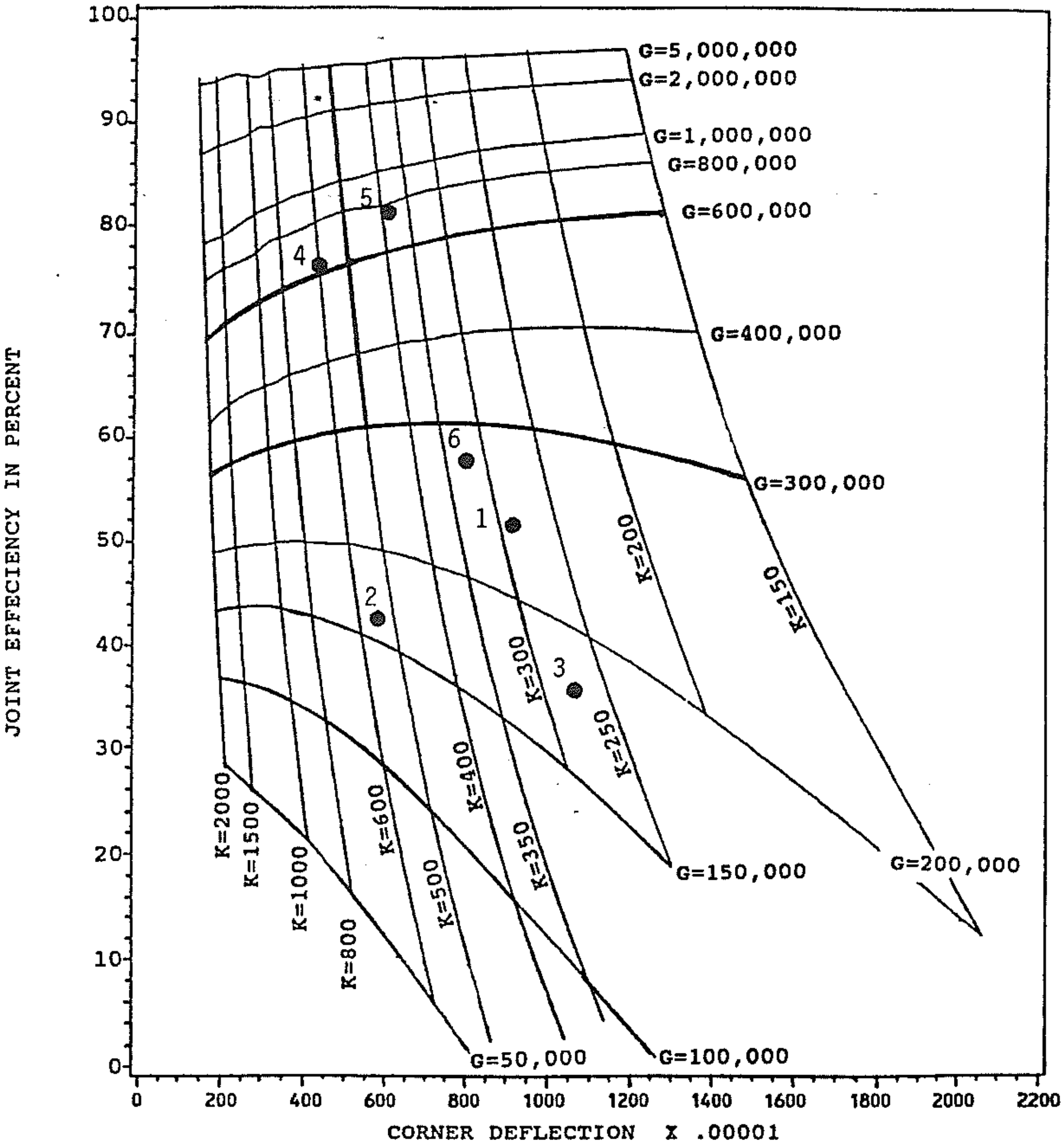
US 90 (DIST 03, AIRPORT TO BROUSSARD POST OFFICE) EAST BOUND
LAFAYETTE PARISH
REAR AXLE WEIGHT = 16,800 LBS.
10" CONCRETE

This analysis was under taken to determine the suitability of the pavement to receive a thin bonded concrete overlay. The pavement had been in service for 25 years under heavy truck loads and had become rough due to differential settlement and blowups. Generally low joint efficiencies indicated a symmetrical loss in load transfer at the transverse joints. There was also an indication of reduced support. The pavement was not recommended for a thin bonded concrete overlay.

TABLE 8

JOINT NUMBER	JOINT FAULTING	JOINT WIDTH	CORNER DEFLECTION (MILS)	JOINT EFFICIENCY %	K	G x 1000
1	N/A	N/A	8.883	55	290	240
2	N/A	N/A	5.715	42	550	160
3	N/A	N/A	10.593	35	275	175
4	N/A	N/A	4.257	76	600	650
5	N/A	N/A	5.661	81	400	780
6	N/A	N/A	8.082	57	325	270

N/A = VALUES NOT AVAILABLE


JOINT EFFECIENCY IN PERCENT
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CORNER DEFLECTION X .00001
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200
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600
800
1000
1200
1400
1600
1800
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2200
G=5,000,000
G=2,000,000
G=1,000,000
G=800,000
G=600,000
G=400,000
G=300,000
G=200,000
G=150,000
G=100,000
G=50,000
K=2000
K=1500
K=1000
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K=600
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K=250
K=200
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FIGURE 12