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16. Abstract

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This report investigates three methods of detecting voids underneath continuously reinforced concrete pavements. The methods; deflection, pumping, and vibration, are evaluated to find which has the highest probability of successfully detecting voids. The deflection method is shown to be very reliable in predicting voids beneath CRCP and as such a detailed procedure for void detection using this technique has been outlined.

The successful detection of such voids, by the method outlined in this report, can lead to the repair and subsequent restoration of pavements in which voids have developed. In this way, expensive major rehabilitation of pavements can be prevented.



17. Key Words
Continuously reinforced concrete pavements, void detection, Dynaflect, deflection measurements, pumping, Delam Tek, vibration, undersealing




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# DETECTION OF VOIDS UNDERNEATH CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

by

John W. Birkhoff

B. Frank McCullough

Research Report Number 177-18

Development and Implementation of the Design, Construction and Rehabilitation of Rigid Pavements

Research Project 3-8-75-177

conducted for

Texas State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR HIGHWAY RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

August 1979

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# PREFACE

This is the eighteenth in a series of reports that describes the work done in Research Project 3-8-75-177, "Detection of Voids Underneath Continuously Reinforced Concrete Pavements." The report deals directly with the rehabilitation of concrete pavements by detecting where voids are located and thereby enabling the future repair of the voided areas.

John W. Birkhoff
B. Frank McCullough

August 1979

## LIST OF REPORTS

Report No. 177-1, "Drying Shrinkage and Temperature Drop Stresses in Jointed Reinforced Concrete Pavement," by Felipe R. Vallejo, B. Frank McCullough, and W. Ronald Hudson, describes the development of a computerized system capable of analysis and design of a concrete pavement slab for drying shrinkage and temperature drop. August 1975.

Report No. 177-2, "A Sensitivity Analysis of Continuously Reinforced Concrete Pavement Model CRCP-1 for Highways," by Chypin Chiang, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this model, the relative importance of the input variables of the model and recommendations for efficient use of the computer program. August 1975.

Report No. 177-3, "A Study of the Performance of the Mays Ride Meter," by Yi Chin Hu, Hugh J. Williamson, B. Frank McCullough, and W. Ronald Hudson, discusses the accuracy of measurements made by the Mays Ride Meter and their relationship to roughness measurements made with the Surface Dynamics Profilometer. January 1977.

Report No. 177-4, "Laboratory Study of the Effect of Non-Uniform Foundation Support on CRC Pavements," by Enrique Jiminez, B. Frank McCullough, and W. Ronald Hudson, describes the laboratory tests of CRC slab models with voids beneath them. Deflection, crack width, load transfer, spalling, and cracking are considered. Also used is the SLAB 49 computer program that models the CRC laboratory slab as a theoretical approach. The physical laboratory results and the theoretical solutions are compared and analyzed, and the accuracy is determined. August 1977.

Report No. 177-6, "Sixteenth Year Progress Report on Experimental Continuously Reinforced Concrete Pavement in Walker County," by Thomas P. Chesney, and B. Frank McCullough, presents a summary of data collection and analysis over a 16-year period. During that period, numerous findings resulted in changes in specifications and design standards. These data will be valuable for shaping guidelines and for future construction. April 1976.

Report No. 177-7, "Continuously Reinforced Concrete Pavement: Structural Performance and Design/Construction Variables," by Pieter J. Strauss, B. Frank McCullough, and W. Ronald Hudson, describes a detailed analysis of design, construction, and environmental variables that may have an effect on the structural performance of a CRCP. May 1977.

Report No. 177-9, "CRCP-2, An Improved Computer Program for the Analysis of Continuously Reinforced Concrete Pavements," by James Ma and B. Frank McCullough, describes the modification of a computerized system capable of analysis of a continuously reinforced concrete pavement based on drying shrinkage and temperature drop. August 1977.

Report No. 177-10, "Development of Photographic Techniques for Performance Condition Surveys," by Pieter J. Strauss, James Long, and B. Frank McCullough, discusses the development of a technique for surveying heavily trafficked highways without interrupting the flow of traffic. May 1977.

Report No. 177-11, "A Sensitivity Analysis of Rigid Pavement-Overlay Design Procedure," by B. C. Nayak, B. Frank McCullough, and W. Ronald Hudson, gives a sensitivity analysis of input variables of Federal Highway Administration computer-based overlay design procedure RPOD1. June 1977.

Report No. 177-12, "A Study of CRCP Performance: New Construction versus Overlay," by James I. Daniel, B. Frank McCullough, and W. Ronald Hudson, documents the performance of several continuously reinforced concrete pavements (CRCP) in Texas. April 1978.

Report No. 177-13, "A Rigid Pavement Overlay Design Procedure for Texas SDHPT," by Otto Schnitter, B. Frank McCullough, and W. Ronald Hudson, describes a procedure recommended for use by the Texas SDHPT for designing both rigid and flexible overlays on existing rigid pavements. The procedure incorporates the results of condition surveys to predict the existing pavement remaining life, field and lab testing to determine material properties, and elastic layer theory to predict the critical stresses in the pavement structure. May 1978.

Report No. 177-14, "A Methodology to Determine an Optimum Time to Overlay," by James I. Daniel, B. Frank McCullough, and W. Ronald Hudson, describes the development of a mathematical model for predicting the optimum time to overlay an existing rigid pavement.

Report No. 177-15, "Precast Repair of Continuously Reinforced Concrete Pavement," by Gary E. Elkins, B. Frank McCullough, and W. Ronald Hudson, describes an investigation into the applicability of using precast slabs to repair CRCP, presents alternate repair strategies, and makes new recommendations on installation and field testing procedures.

Report No. 177-16, "Nomographs for the Design of CRCP Steel Reinforcement," by C. S. Noble, B. F.McCullough, and J. C. M. Ma, presents the results of an analytical study undertaken to develop regression equations and nomographs for use as a supplementary tool in the design of steel reinforcement in continuously reinforced concrete pavement by the Texas State Department of Highways and Public Transportation. August 1979.

Report No. 177-17, "Limiting Criteria for the Design of CRCP," by J. C. M. Ma, B. F. McCullough and C. S. Noble, presents a set of criteria which limits values of a set of variables to be used in the design of CRCP. These criteria are to be used in conjunction with Report No. 177-16. August 1979.

Report No. 177-18, "Detection of voids underneath continuously Reinforced Concrete Pavements," by John Birkhoff and B. Frank McCullough, presents the results of an investigation in which three methods for detecting voids underneath CRC pavements (deflection, pumping and virbration) are evaluated with respect to reliability of successful void detection. August 1979.

## ABSTRACT

The basic assumption in pavement design is that there is full support throughout the length of the pavement. When a void develops, this is not true.

This report investigates three methods of detecting voids underneath concrete pavements. The methods, deflection, pumping, and vibration, are evaluated to find with which there is the highest probability of successfully detecting voids. The deflection method is shown to be very reliable in predicting voids underneath CRCP, and a detailed procedure for void detection using this technique has been outlined.

The successful detection of such voids, by the method outlined in this report, can lead to the repair and subsequent restoration of pavements in which voids have developed. In this way, expensive major rehabilitation of pavements can be prevented.



KEY WORDS: continuously reinfoced concrete pavements, void detection, dynaflect, deflection measurements, pumping, Delam Tek vibration, undersealing.

## SUMMARY

The existence of voids beneath CRCP may result in the occurrence of punchouts and failures and consequent increase in maintenance cost. Thus, it is desirable to locate these voids for preventive maintenance. Through extensive field investigation, it was found that a deflection-based method can be used to detect voids under CRCP with a very high probability of being correct. Two other methods, based on vibratory measurements and edge pumping surveys, were investigated, but neither produced satisfactory results.

With data obtained from Dynaflect equipment, deflection profiles were compared on a relative basis. Large deflections were judged as areas with voids, whereas small deflections were assumed to indicate no voids or very small voids only. Subsequent coring and excavation methods indicated voids at every area selected.

# IMPLEMENTATION

The results of this study indicate recommendation of the use of Dynaflect equipment for the detection of voids. Deflection profiles obtained from Dynaflect data lead to a simple and quick method for the determination of void locations.

It is proposed that the deflection-based method be used by the Texas SDHPT to locate void areas for preventive maintenance, such as pressure grouting. The Dynaflect can be requested from the Research Section of the Planning Survey Division (D-10R). Deflection measurements should be taken as outlined in the report, and a deflection profile should be plotted with the computer or by hand. These plots should be reviewed to locate the potential void areas as outlined in the report. These potential problem areas may be designated and programmed for maintenance.

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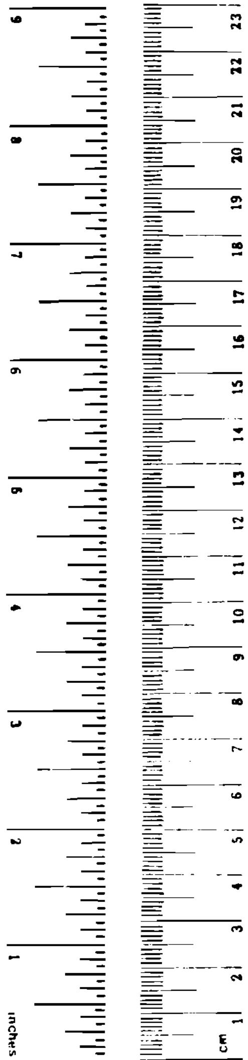
# METRIC CONVERSION FACTORS

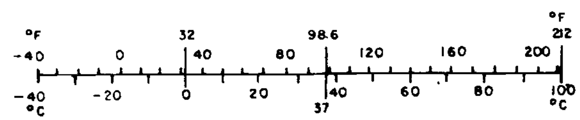
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



# INTRODUCTION

In recent years, it has been found that one of the most significant factors in reducing the life of concrete pavements is the presence of voids beneath the pavement. In designing pavements, a basic assumption is made that full support is obtained throughout the length of the pavement. When a small void develops beneath the pavement, this support condition is lost, and, thus, the loads are not distributed as intended in design. Therefore, the stress level in a pavement with a void increases significantly. For example, an 18-square-foot (1.67 $m^2$) void in an 8-inch (20.3 cm) pavement with an 18-kip ($8.17 \times 10^3$ kg) load will increase the stress level from 315 to 354 psi (2.17 MPa to 2.44 MPa). If the void size is increased to 70 square feet (6.50 $m^2$), the stress level will increase from 315 to 492 psi (2.17 to 3.39 MPa). The stresses have increased 12 percent and 56 percent, respectively. Thus, the overall fatigue life of the pavement is significantly reduced.

In visualizing the problem, the reader must keep in mind that a void is not necessarily a large hole beneath the pavement. For example, a gap of 0.050 in ($1.27 \times 10^{-1}$cm) between the slab and the subbase represents a void, because the slab will deflect down and touch the subbase. Hence, the support condition is lost with any gap of 0.050 inch ($1.27 \times 10^{-1}$cm) or greater between the slab and the subbase.

One of the merits of CRCP is its ability to provide a smooth ride due to the full continuity condition inherent in a continuously reinforced pavement. Hence, if a small void develops beneath the pavement, the pavement tends to bridge the gap, whereas jointed concrete spans tend to deform to the boundaries of the void, producing a rough riding condition that eventually requires an overlay. For the CRCP case, the pavement stress conditions are increased significantly.

Voids can develop in a number of ways, but the most significant factors creating void conditions beneath concrete pavements in Texas are

(1) pumping of the subbase material,
(2) deep soil movements, such as a swelling or settlement action,

(3) mudjacking which causes the pavement to raise excessively, thus producing a high point with a void on each side, and

(4) unconsolidated, honeycombed concrete.

In other states, similar types of problems have been experienced. There is also the possibility that additional densification of the subbase can produce voids. If the entire subbase densified at the same rate, the void would not increase; the problem is differential densification. This same problem is true of deep soil movements. If the entire pavement moved the same amount, then a differential condition would not exist; the problem exists where differential movements are experienced and, hence, voids are created.

The first problem with voids is to detect and fill them prior to the condition's being excessively detrimental to the pavement. Over the past few years, a number of different methods have been proposed for investigation, including the use of density measuring equipment, vibratory equipment, deflection measuring equipment and visual observation of distress manifestations, such as pumping. Various districts in Texas have experimented on a very limited basis with these various techniques, but no detailed studies have been made or reported to date.

In addition to detecting the voids, it is necessary to fill them in some way. In recent years, various districts have experimented with using mudjacking and undersealing. Recently, a firm in Mississippi developed a method for undersealing CRC pavements with a cement grout. This method was applied with some success in Mississippi, and, therefore, the Maintenance Division (D-18) of the Texas State Department of Highways and Public Transportation (SDHPT) decided to institute it on an experimental basis in Texas. A contract was prepared for a .47-mile (.76-km) project on Interstate 10 in District 13 and a .47-mile (.76-km) project on Interstate 45 in District 17.

Since these two projects represent one of the most extensive applications of undersealing in the state, representatives from the Highway Design Division, the Research Section of the Transportation Planning Division, and the Maintenance Division, along with the Center for Highway Research representatives, met together to explore methods to evaluate these sections. As a result of several conferences, it was decided that a study should be developed in two parts. The first objective would be to evaluate several alternative methods of detecting the voids beneath the CRCP. The second overall objective would be to evaluate the capabilities of undersealing the pavement and the long-term performance of pavements that were undersealed. This report is concerned with the first of the two overall objectives.

Objective of Study

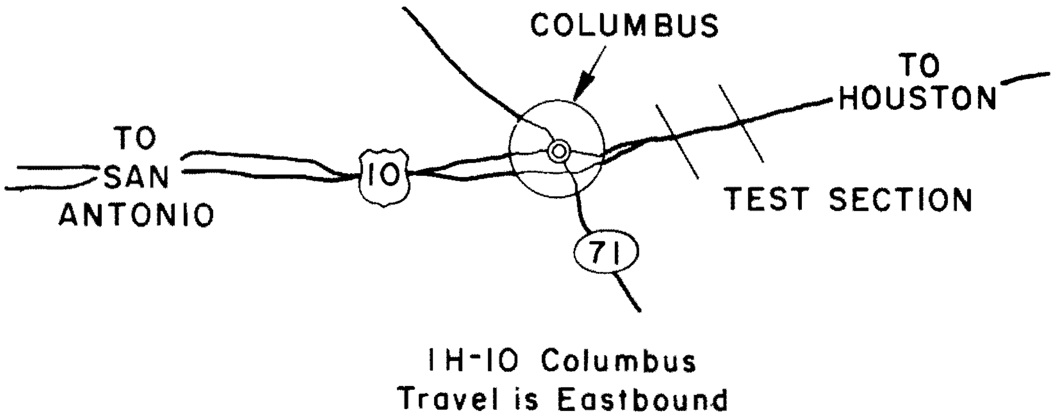
This report describes an evaluation of the feasibility of and the practicality of various methods of detecting voids beneath concrete pavements, especially those methods having a high probability of success. Specifically, the purpose of this study was to evaluate in a controlled experiment the feasibility of using deflection devices, vibratory devices, and visual means and to recommend a detailed procedure for void detection which would incorporate the most reliable technique.

Scope of Study

Since it was not practical to evaluate the entire length of the projects being undersealed, the basic decision was made to select two 2500-foot (762-m) test sections on each project. The basic criteria for choice of these sections were minimal grade changes along the 2500 feet (762 m), uniform soil conditions, and uniform cross section. Test sections to meet these criteria were selected through a joint inspection by representatives of the Austin Office Division of the SDHPT, the Center for Highway Research, and the respective District.

The locations for the test sections on IH-10 and IH-45 are shown in Fig 1. As may be seen, these sections are east of Columbus, Texas, and south of Fairfield, Texas, respectively. A cross section for the pavement structures on IH-10 consisted of 8 inches (20.32 cm) of CRCP and 6 inches (15.24 cm) of cement-stabilized base. The project on IH-45 has a cross section consisting of 8 inches (20.32 cm) of CRCP on a 4-inch (10.16 cm) asphalt-stabilized base.

The limits for the test sections on the respective highways are presented in Table 1. These limits are shown in terms of both mile posts and station numbers. The roadway directions are also shown.



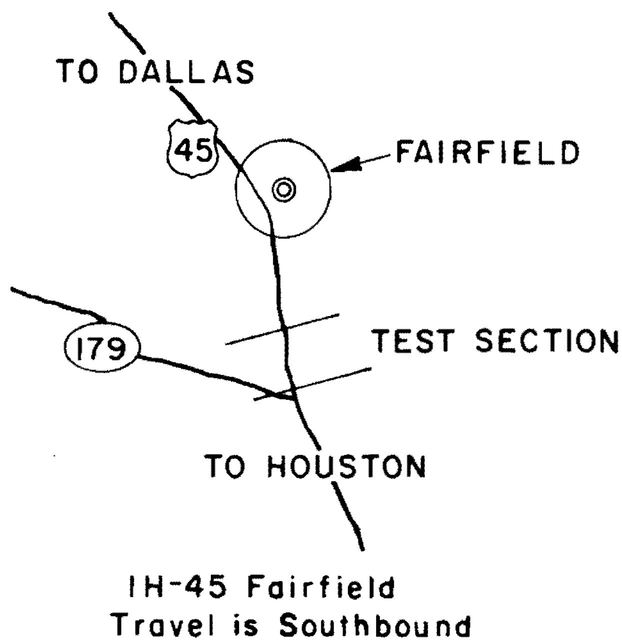




Fig 1. Locations of test sections.

TABLE 1. TEST SECTION LIMITS

| Location | Section | Mile Post | Section |
|---|---|---|---|
| IH-10 Columbus, | 1 | 700.75 to 701.22 | 221 + 54 to 246 + 50 |
| travel Eastbound | 2 | 704.6 to 705.1 | 427 + 50 to 452 + 49 |
| IH-45 Fairfield, | 1 | 191.9 to 191.3 | 577 + 70 to 552 + 70 |
| travel Southbound | 2 | 190.7 to 190.1 | 521 + 02 to 496 + 02 |

## Scope of Report

Proposed methods of using deflection, pumping, and vibration in the detection of voids are presented and identified briefly as to function. A basic experiment using each method was developed and implemented in the field. Field data were collected and put into a factorial format for analysis. After analyzing these data and using coring and excavation for verification, the methods having the highest probability of detecting voids were chosen. Of these, the deflection method was selected as the most reliable, and a definitive procedure was established for its implementation.

# FIELD EXPERIMENT FOR VOID AREA SELECTION

The first step in the study was to establish tentative procedures for utilizing each of the proposed methods of void testing. The next step was to apply these procedures on in-service pavements to select prospective locations where voids might be present. After application of the procedures, an experiment was designed for a field investigation to determine if voids existed in the areas predicted by the various procedures.

## Description of Proposed Methods

As mentioned in the objectives, deflection testing, vibratory equipment, and visual observations were selected as the methods for evaluation. Since the SDHPT has several Dynaflects available for measuring deflections, this equipment was selected for evaluating the deflection method. Figure 2 shows the Dynaflect in operation with geophones in an operational position. The Dynaflect was used in two ways:

(a) for an evaluation of the deflection basin using all the geophone measurements and

(b) to make a comparison using the deflection from the number one sensor (geophone one) only.

The desire, of course, was for the latter method to be satisfactory since less field time and analysis time would be required to locate the voids.

The vibratory equipment selected for evaluation is basically a vibrator on steel wheels that applies small vibratory loads to the pavement. It is manufactured by S.I.E., Inc., under the trade name Delam Tek and is shown in operation in Fig 3. Basically, the equipment provides a continuous reading along the roadway. This provides an advantage over the Dynaflect, since the Dynaflect has to be stopped at a specific point to make a reading and then moved forward again to the next measurement point. It was felt that if the Delam Tek equipment was functional, a more extensive investigation could be made.

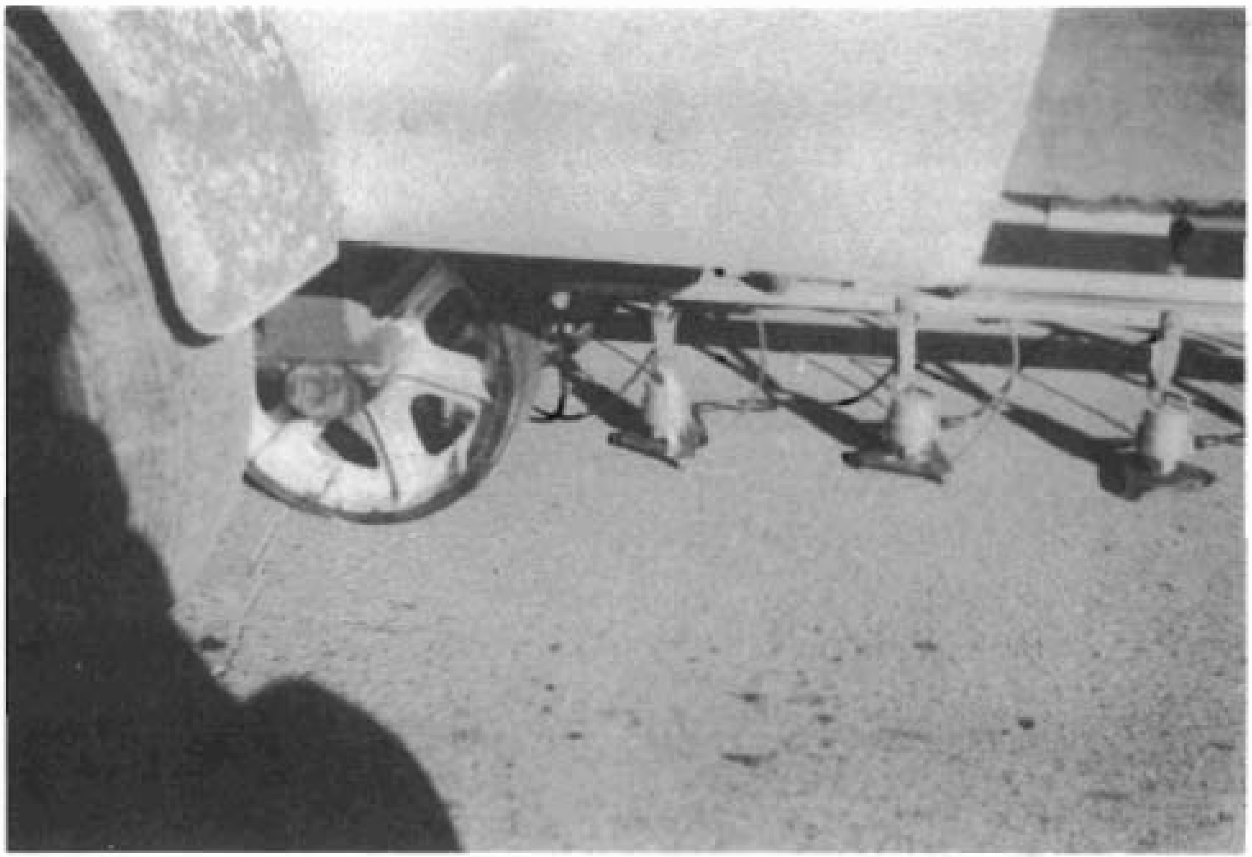


Fig 2. Dynaflect in operation.

Fig 3. The vibrator.

For the visual surveys, edge pumping was used as a criterion. In connection with Project 3-8-74-21, "Pragmatic Applications of Rigid Pavement Research," definitions of major and minor pumping were developed. Primarily, minor pumping was denoted by the presence of water stains on the edge of the pavement, whereas major pumping was shown by the deposits of material on the edge. Figure 4 is a photograph of a CRC pavement where major edge pumping has been experienced along the roadway. The photograph illustrates a severe case; at this point problem areas have started to develop.

## Procedures for Proposed Methods

Two lines of deflection measurements were taken on each test section, as shown in Fig 5. One line was 3 feet (.91 m) from the outside edge, to characeterize the outside lane (higher probability of voids), and the second line was 3 feet (.91 m) from the center line to characterize the inside lane (lower probability of voids). A reading was then taken at every other crack, except where excessive pumping occurred, where a reading was taken at every crack. At each crack, the equipment was stopped and all five geophones were read.

For the basin method, the data were supplied to a previously prepared computer program, and a plot of the basin shape was developed. Figure 6 illustrates two different basin shapes that were typical of those found on the project. Only five readings are obtained with the Dynaflect, but the computer program assumes symmetry, and, thus, the entire basin shape is shown. Based upon previous experience in comparing basin shapes with excavations along the edge of the pavement, it was postulated that the location could be determined by the shape of the basin. In the upper part of Fig 6, a smooth flat curve is shown. Excavations in this type of deflection basin indicated that full support of the pavement was being maintained. In the lower part of Fig 6, the basin is deeper, and the curvature is much sharper. In cases similar to this, excavations indicated that voids were present beneath the slab.

For the use of the deflection measurements from geophone one only, plots were made of the inside and outside deflection profiles. These were overlaid as illustrated in Fig 7. The basic hypothesis in this method was that

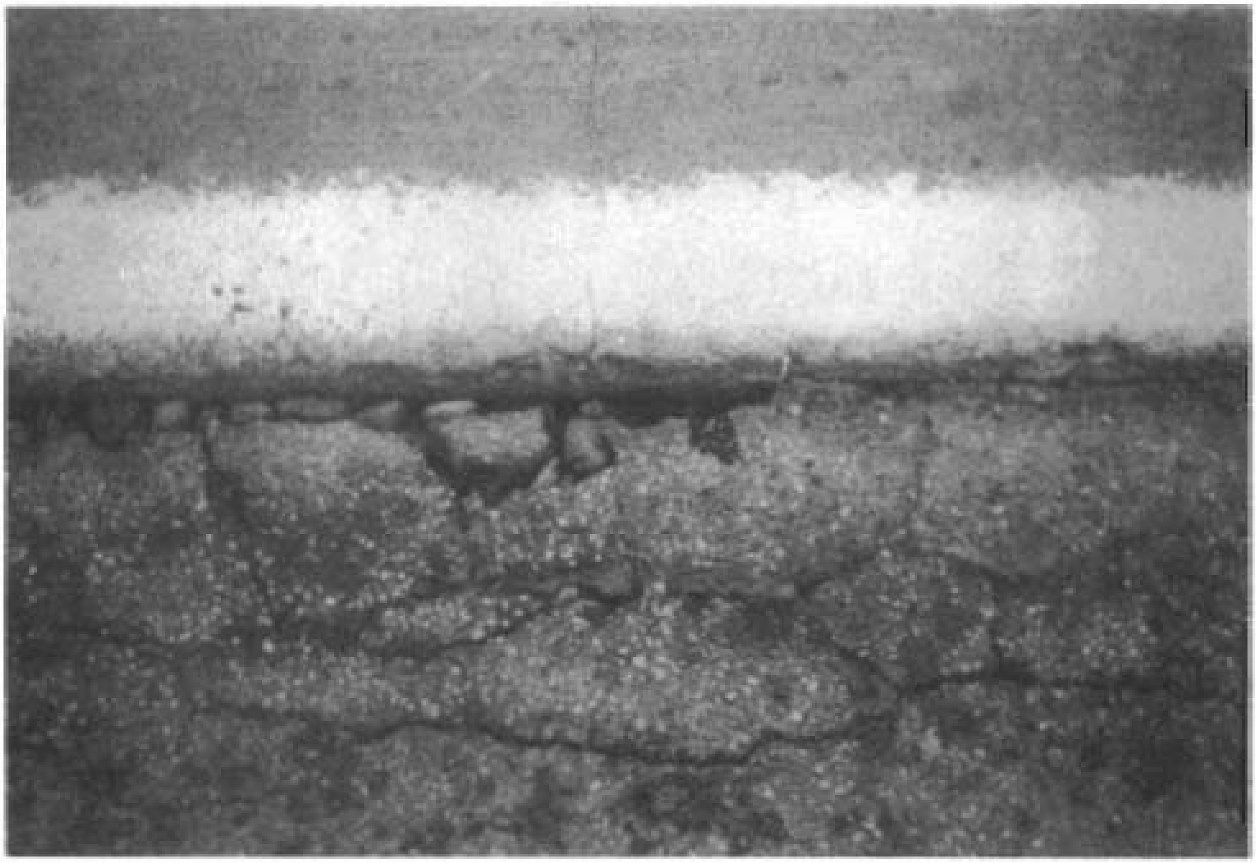


Fig 4. Severe edge pumping condition on CRCP.

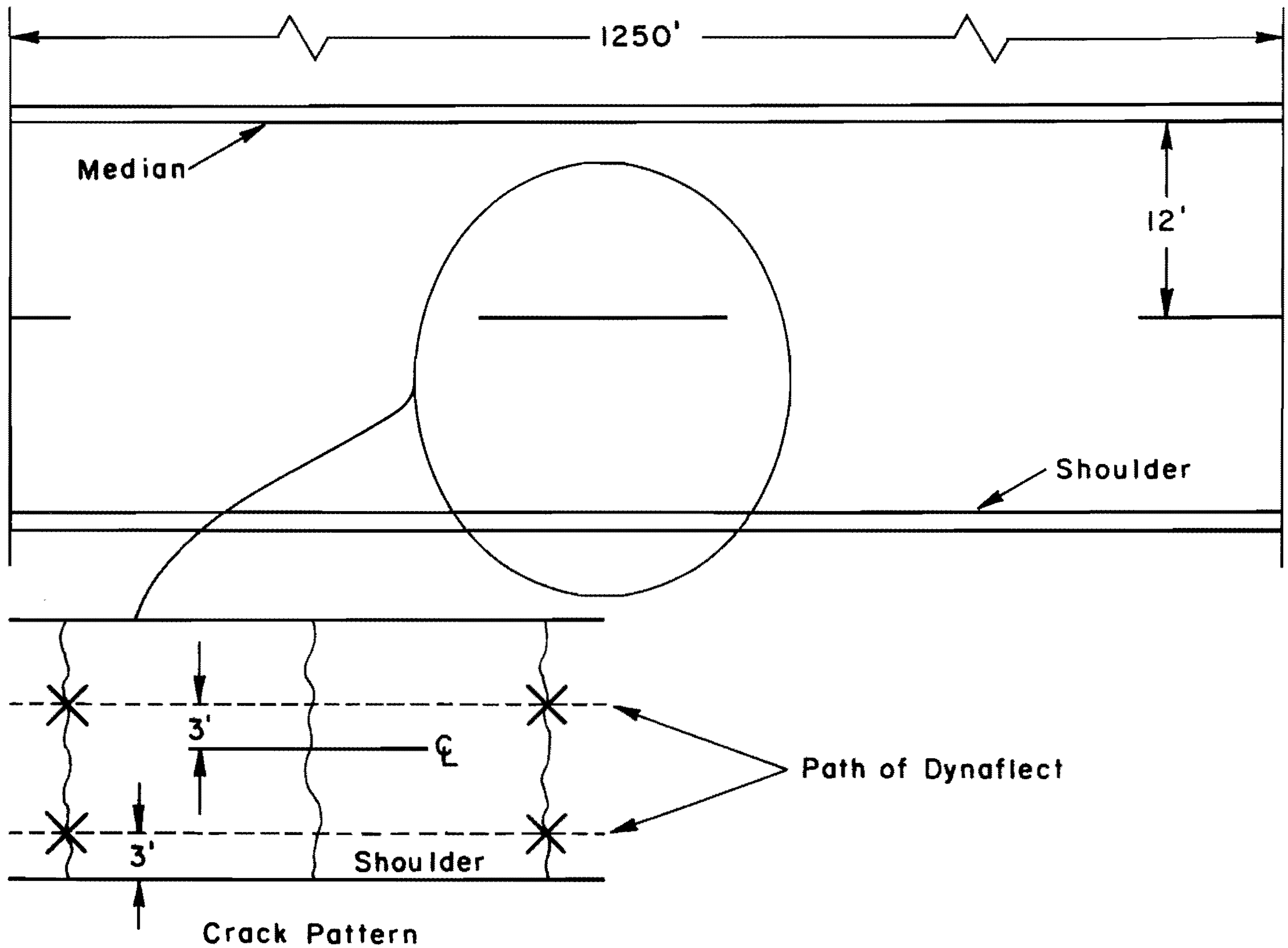
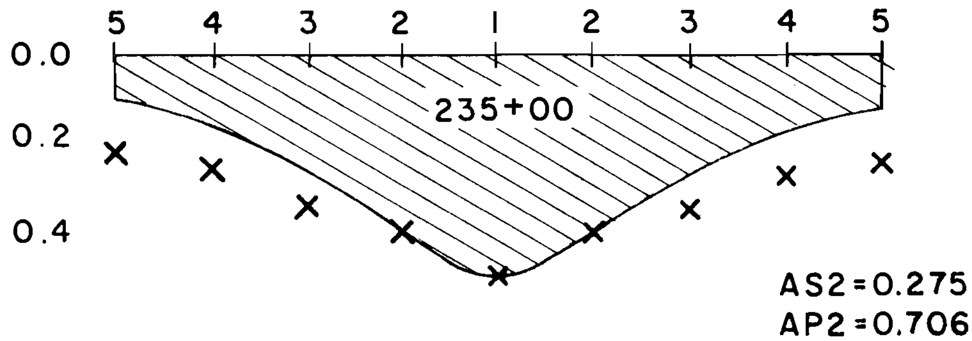



Fig 5. Layout of test sections for deflection testing.



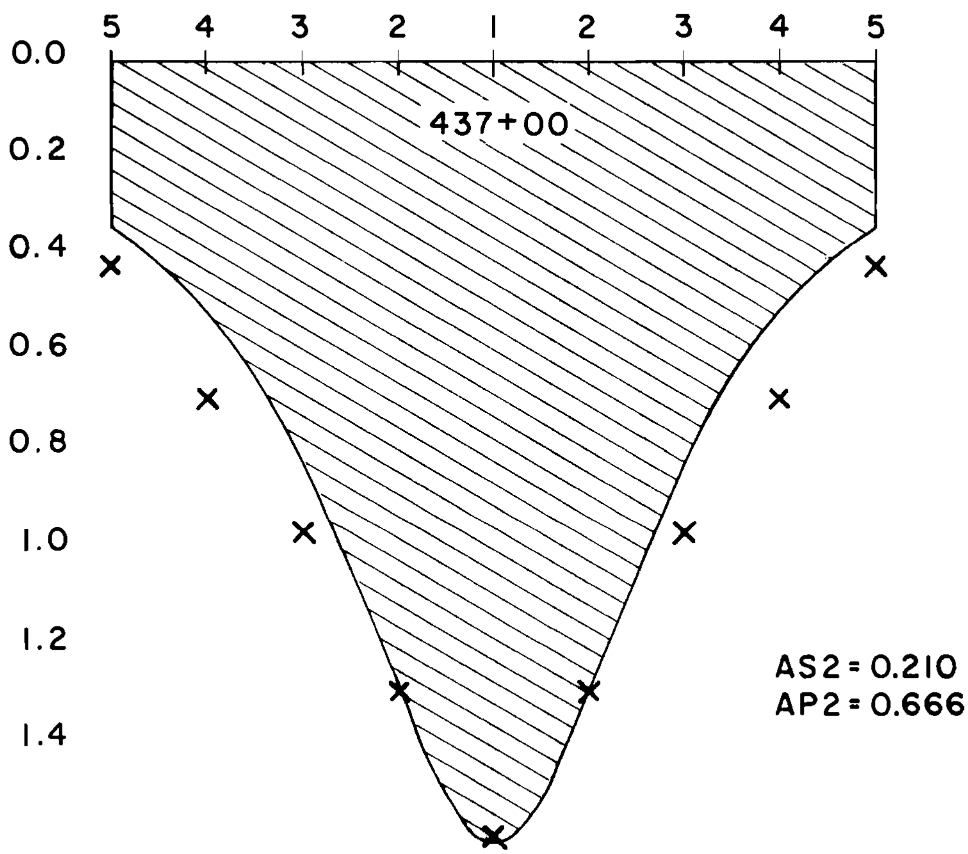




Fig 6. Comparison of high deflection and low deflection basins.

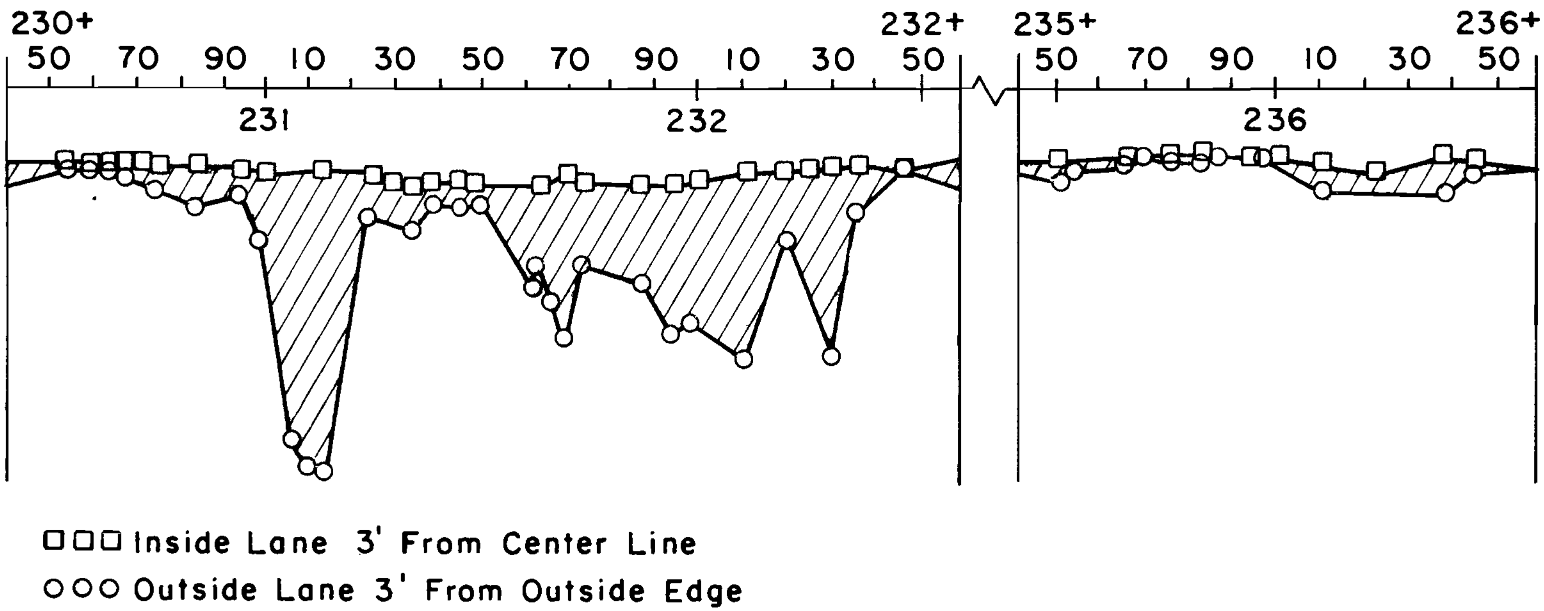



Fig 7. Deflection profile of inside and outside lanes.

radical changes in the deflection, either longitudinally or transversely, indicated a high probability of voids beneath the pavement. The inside lane was used for comparison since very little pumping was observed on inside lanes, and, thus, if voids are present, these voids are normally in the outside lane. A comparison of the inside lane values to the outside lane values shows that very little difference in deflection should be experienced if uniform support is present. In Fig 7, note that approximately five locations are marked as prospective void areas.

Figure 8 is a typical output of the vibratory equipment. The personnel involved had limited experience in using this equipment, but it was assumed that, if a void were present, a sharp change in the output would be observed. For the pumping condition, a plan view of the section was drawn, and the points where pumping was observed were marked on it. This then provided a reference as to sections that might have voids beneath the pavement.

## Void Selection Experiment Using Proposed Methods

Field measurements were taken in late 1977 with each of the proposed methods on both IH-10 and IH-45. After analyzing the data, it appeared that void areas could be selected using the Dynaflect deflections and the pumping observations. Unfortunately, the measurements obtained with vibratory equipment were inconsistent and no patterns appeared. Therefore, at this point, it was decided that using the vibratory equipment was not a feasible method for selecting voids beneath concrete pavements. For the deflection and pumping methods, there was generally reasonable overlap; however, a diagreement did appear, in that, in some areas where voids were selected based on high deflections, there was no pumping. In other cases, where pumping was used as an indicator, there were low deflection measurements. Therefore, a two-by-two factorial was set up to compare pumping and deflection predictions at two levels of each. For pumping, the levels were yes (present) and no (not present), and, for deflection, they were high and low.

Table 2 shows the two-by-two factorial experiment set up for comparing the two methods with respect to probability of successfully detecting voids. The factorial cells were chosen so as to indicate areas of high and low deflections versus pumping and no pumping. In each case, three replicate

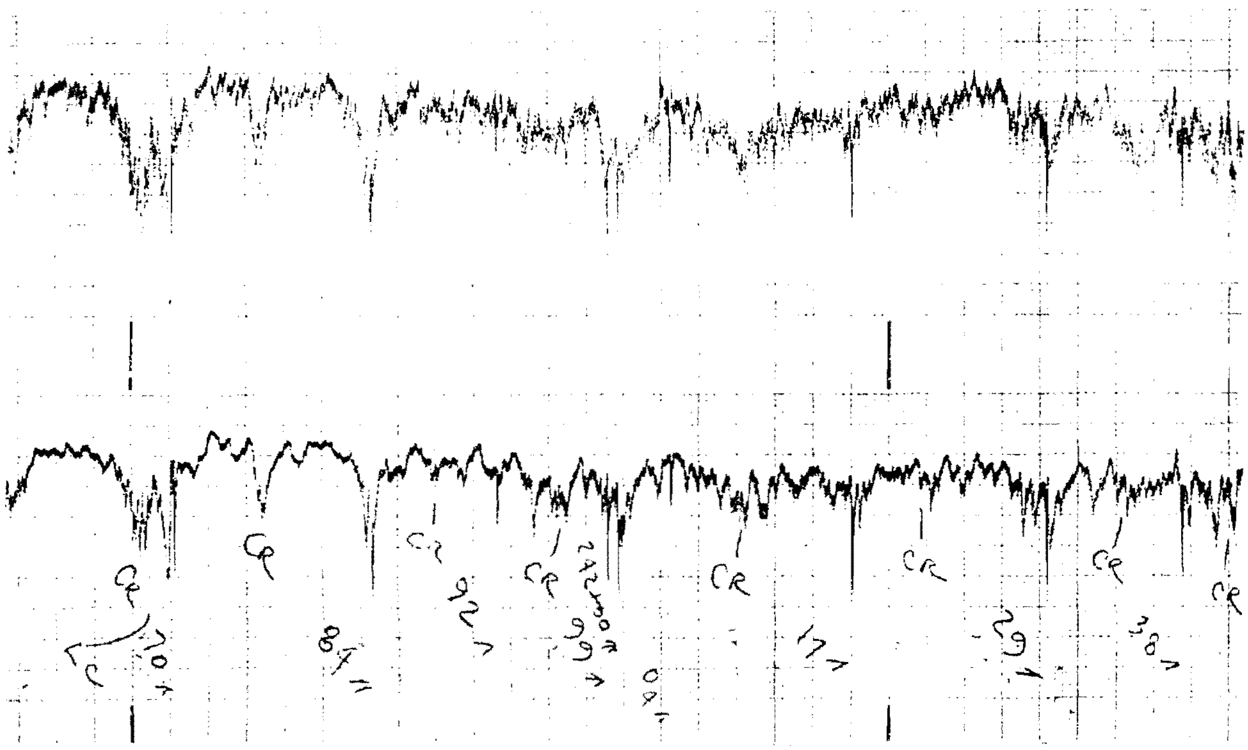



Fig 8. Sample output for the vibratory tester.

TABLE 2. DESCRIPTION OF THE FACTORIAL EXPERIMENT FOR EVALUATING THE USE OF DEFLECTION AND PUMPING FOR DETECTING VOIDS*

| Location | Pumping | Deflection: High | | | Low | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| IH-10 | Yes | 231 + 06 | 439 + 85 | 448 + 95 | 432 + 25 | 230 + 50 | 441 + 35 |
| | No | 229 + 20 | 232 + 00 | 437 + 05 | 443 + 35 | 446 + 20 | 235 + 00 |
| IH-45 | Yes | 564 + 50 | 556 + 80 | 514 + 36 | 553 + 18 | 572 + 50 | 513 + 75 |
| | No | X | 508 + 96 | 500 + 96 | 509 + 96 | 573 + 97 | 498 + 97 |

*Station numbers are for locations meeting the criteria for the factorial cell sections were selected for each of the levels. Thus, 24 points were selected on the two projects for extensive field investigation. The station numbers for each of the locations are shown in the factorial. Deflection basin plots for some of the cells in the factorial are included as Appendices 1 and 2, for IH-10 and IH-45, respectively.

The next step was to develop an extensive field investigation to evaluate the reliability of the two methods, and it is described in more detail in the next section.

## Analysis of Field Observations and Laboratory Test Results

The locations selected for further field studies, indicated in Table 2, were tested during the first part of 1978. On the IH-10 sections, both coring and excavation along the edge of the pavement were utilized to ascertain if a void was present. Side excavation was permissible on IH-10 since the shoulder consisted of granular material with a thin surfacing material. Figure 9 shows the coring operation where a 6-inch (15.24-cm) diameter core was taken from the pavement. After the core was removed from the pavement, a mirror was inserted into the hole to ascertain by visual observation whether or not a void existed between the concrete pavement and the subbase. In addition to coring through the concrete pavement, a core was taken through the stabilized subbase also. This permitted an evaluation of the surface of the subbase to see if erosion had occurred on the surface. All cores were taken 3 feet (.91 m) in from the outside edge of the pavement along the line where the deflection measurements were taken.

Figure 10 shows a typical excavation along the edge of the pavement on IH-10. A trench was dug approximately 14 inches (35.56 cm) deep and 18 inches (45.72 cm) wide with a backhoe. This permitted observers a side view of the void, as may be seen in Fig 11, which shows a typical edge condition where a void was present.

On IH-45, the same type of operation was performed except that the edge excavation was not utilized. The primary reason the edge excavation was omitted was that the shoulder base was a stabilized asphalt concrete, and replacement was difficult. Furthermore, the IH-10 investigations had indicated that satisfactory results could be obtained with the coring operation.

Fig 9. Coring operation.

Fig 10. View of site excavation.

Fig 11. Edge view of site excavation.

Appendix 3 summarizes the observations made during the field investigations for both projects. The station numbers and the basic observations in the field were recorded. Upon removal of the core, observations as to the condition of the core and the cored area were recorded for later analytical comparisons. Void indicators used include discoloration of subbase materials, separation of subbase material, cracking in the core, water running into the cored area, condition of the surface where the core was taken, and visable signs of a void.

Table 3 presents a comparison of the two methods of void selection in terms of the factorial previously presented in Table 2. The table is a compilation of the data for both IH-10 and IH-45 and permits a comparison of the reliability of each method in detecting voids. In studying the data, note that, if high deflections are present, there is a 100 percent probability of a void existing, whereas, if low deflections are present, there is zero probability of a void being present. In looking at the factorial for the pumping method, it appeared that voids were present only in conditions where there were high deflections. For cases where there were pumping and low deflections, a void did not exist. Thus, based on these data, it may be concluded that the deflection method of void selection has promise and the visual method has a lower probability of correctly predicting the location of a void.

One of the reasons for this lack of prediction accuracy where pumping indicates a void may be that the water moves down the grade slightly from the point where the erosion starts. By the time it surfaces, it may be several feet beyond the point where the base material went into suspension in the water. Thus, by looking at the deposits on the shoulder, the observer may be off by several feet in selecting the exact location of the void.

## Testing of Cores

In order to eliminate the possibility that the higher deflections may be related in some way to the strength and stiffness of the concrete, the cores were tested in a lab, using a splitting tensile test. Basically, the core was sawed into a top section and a bottom section. The specimens were then 6 inches (15.24 cm) in diameter and 2.5 inches (6.35 cm) high. A

TABLE 3. SUMMARY FACTORIAL OF THE PROBABILITY THAT VOIDS EXIST

| Pumping \ Deflection | High | Low |
|---|---|---|
| Yes | 5/5 | 0/6 |
| No | 5/5 | 0/6 |

5/5 - Five of the five locations selected for investigation had a void beneath the pavement.

0/6 - None of the six locations selected for investigation had a void beneath the pavement.

statistical analysis of the tensile strength data using a student's t distribtuion and other analysis-of-variance tests indicated there was no significant difference in strength and stiffness when areas where voids existed were compared to areas where voids were absent. Thus, it was concluded that the strength in the void areas and that in the non-void areas were equal and strength was not a factor affecting the deflection.

## RECOMMENDED PROCEDURE

The basic procedure for employing deflection as a method for the detection of voids includes the use of Dynaflect measuring equipment. The procedure includes

(1) Measurements. Deflection measurements are taken along lines 3 feet (.91 m) from the outside edge of the outside lane and 3 feet (.91 m) from the centerline of the inside lane. An example layout is shown in Fig 5. These measurements are taken at every other crack, except where severe pumping exists; then, in that case, they are taken at every crack. The Dynaflect load wheels are placed just downstream beyond each crack, the geophones are set solidly on the pavement, and the load is applied by the operator. Readings are recorded by the second crew member.

(2) Compilation of Data. Raw data are input into the SDHPT computer program STCOEI (stiffness coefficient) to obtain deflection basin plots. In addition, deflection profile plots are made based on geophone one (largest deflection). The inside and outside lanes are plotted on the same diagram, as illustrated in Fig 7.

(3) Analysis of Data. The deflection basin plots are compared on a relative basis to determine where high and steep basins exist. At these locations, a void exists.

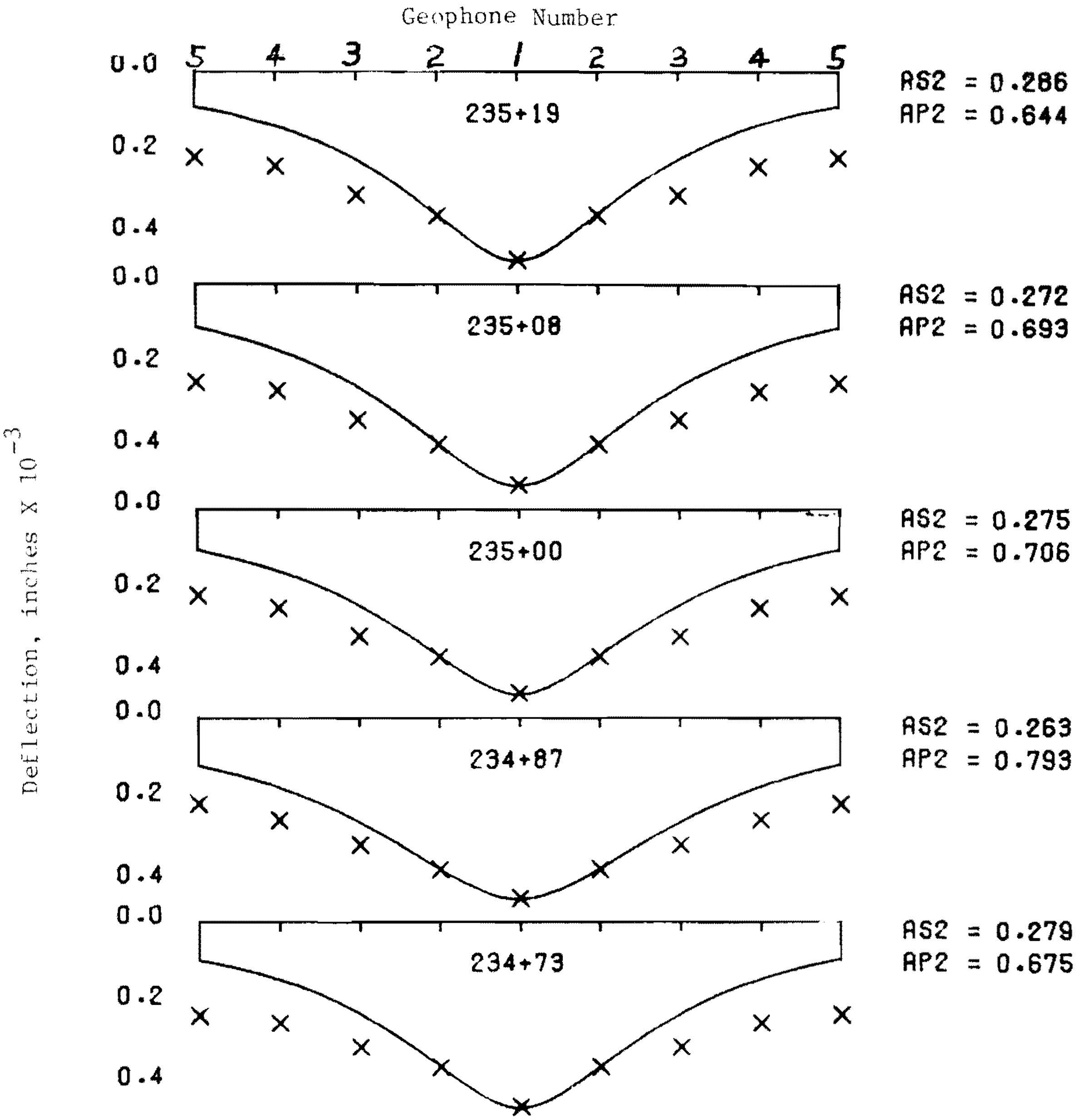
# CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, it can be concluded that deflection techniques can be used successfully to predict the presence of voids beneath CRC pavements. The Dynaflect was used successfully in measuring deflection. The use of condition surveys, e.g., pumping, as an indicator indicated that the probability of successfully locating a void was only 50 percent. The Delam Tek vibratory equipment was found to be unsuccessful in predicting voids beneath the pavement.

Based on the successful application of the deflection procedure, it is recommended that the procedure outlined herein for the Dynaflect be utilized on highways where the development of punchout type failures is a continual problem. By successfully locating these voids in advance of failure and correcting them, the punchout problem can be severely reduced and the life of the pavement extended. Since it is not feasible to run a detailed deflection survey of the pavement, the procedure should be judiciously applied in areas where it is suspected that voids exist beneath the pavement.

# APPENDIX 1

## DEFLECTION BASINS FOR IH-10

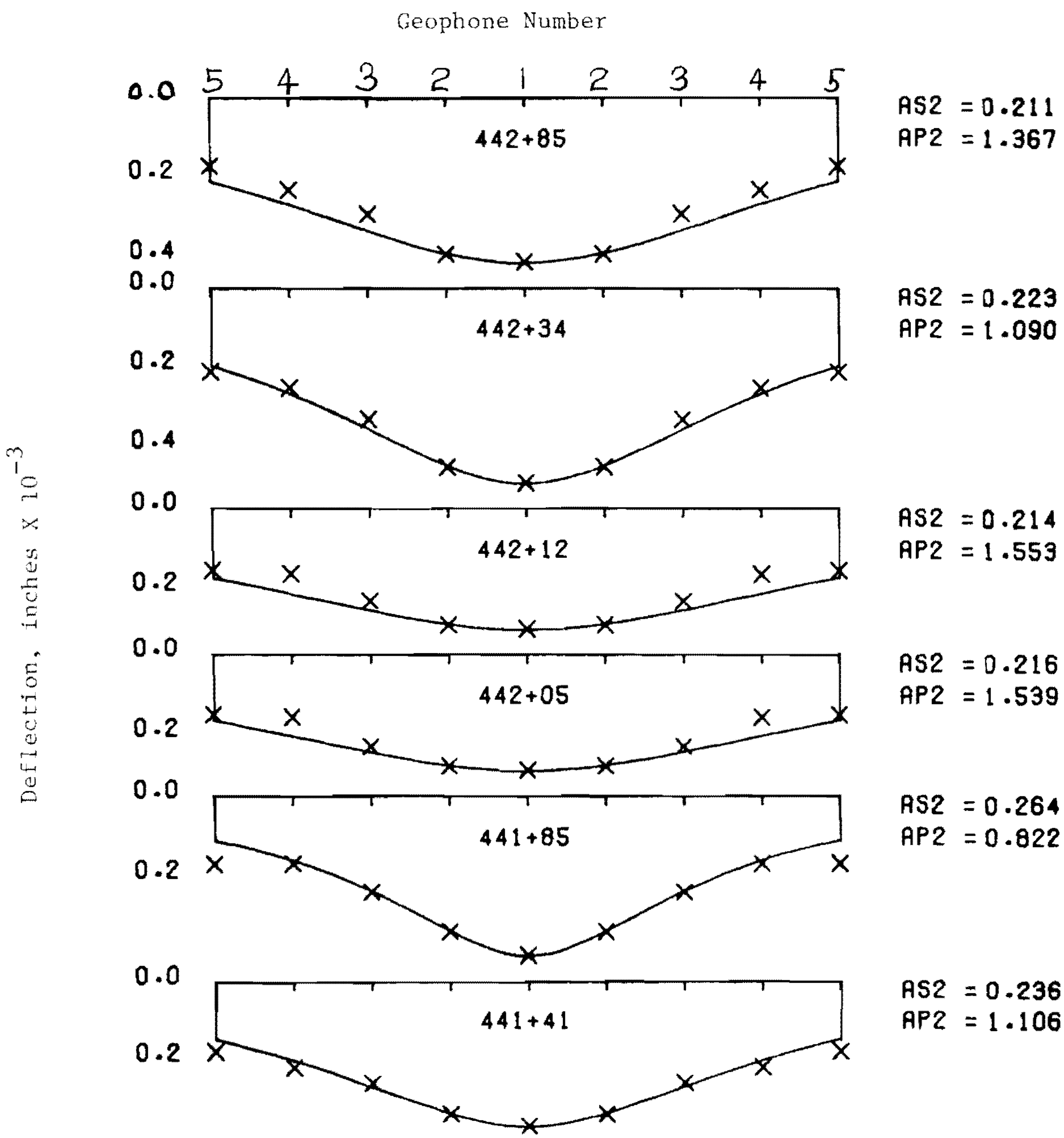



AS2 = Stiffness Coefficient of the subgrade

AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-10, Section 1A, Outside Lane

Low Deflection: No Pumping

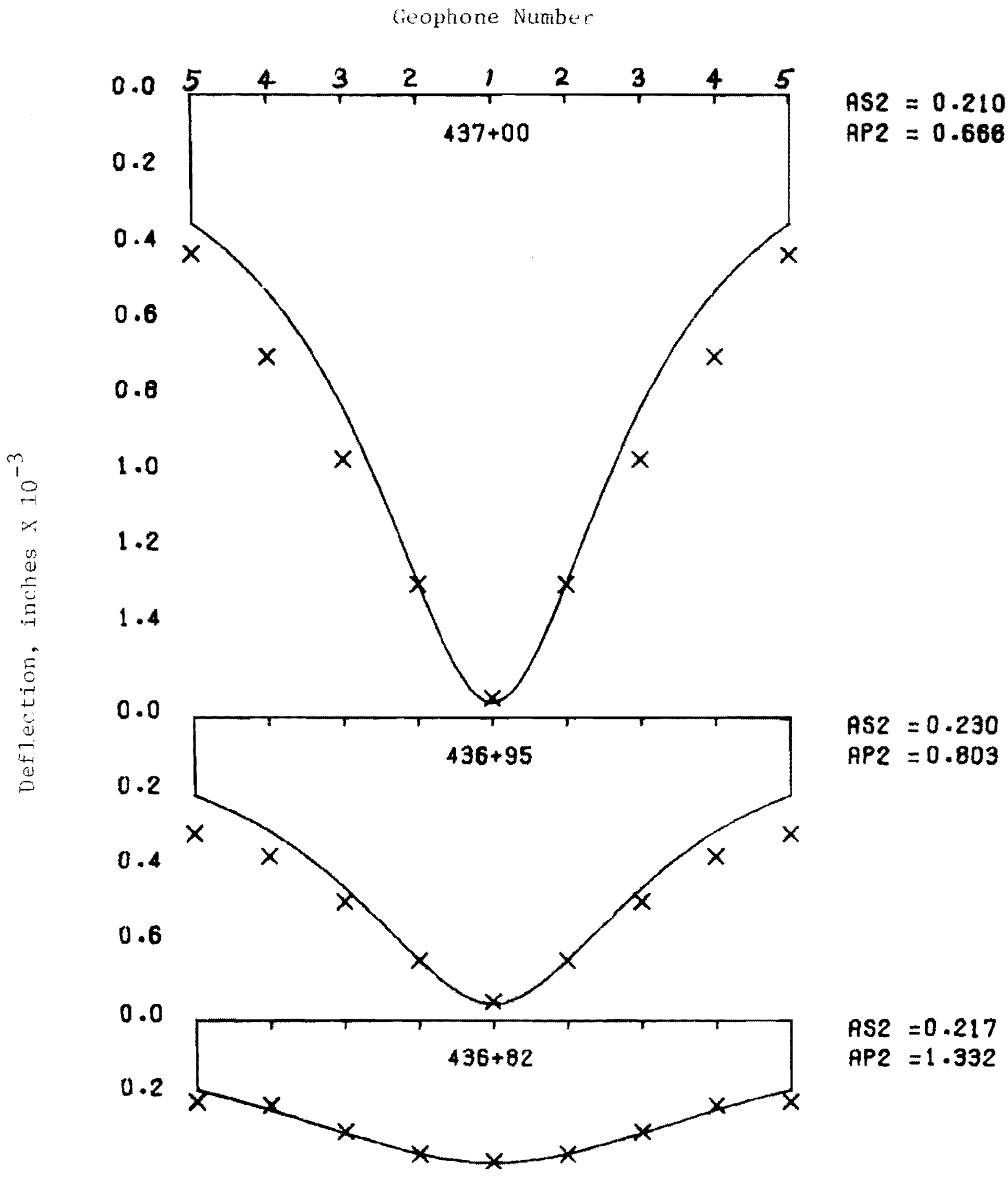



AS2 = Stiffness Coefficient of the subgrade

AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-10, Section 2B, Outside Lane

Low Deflection: Pumping

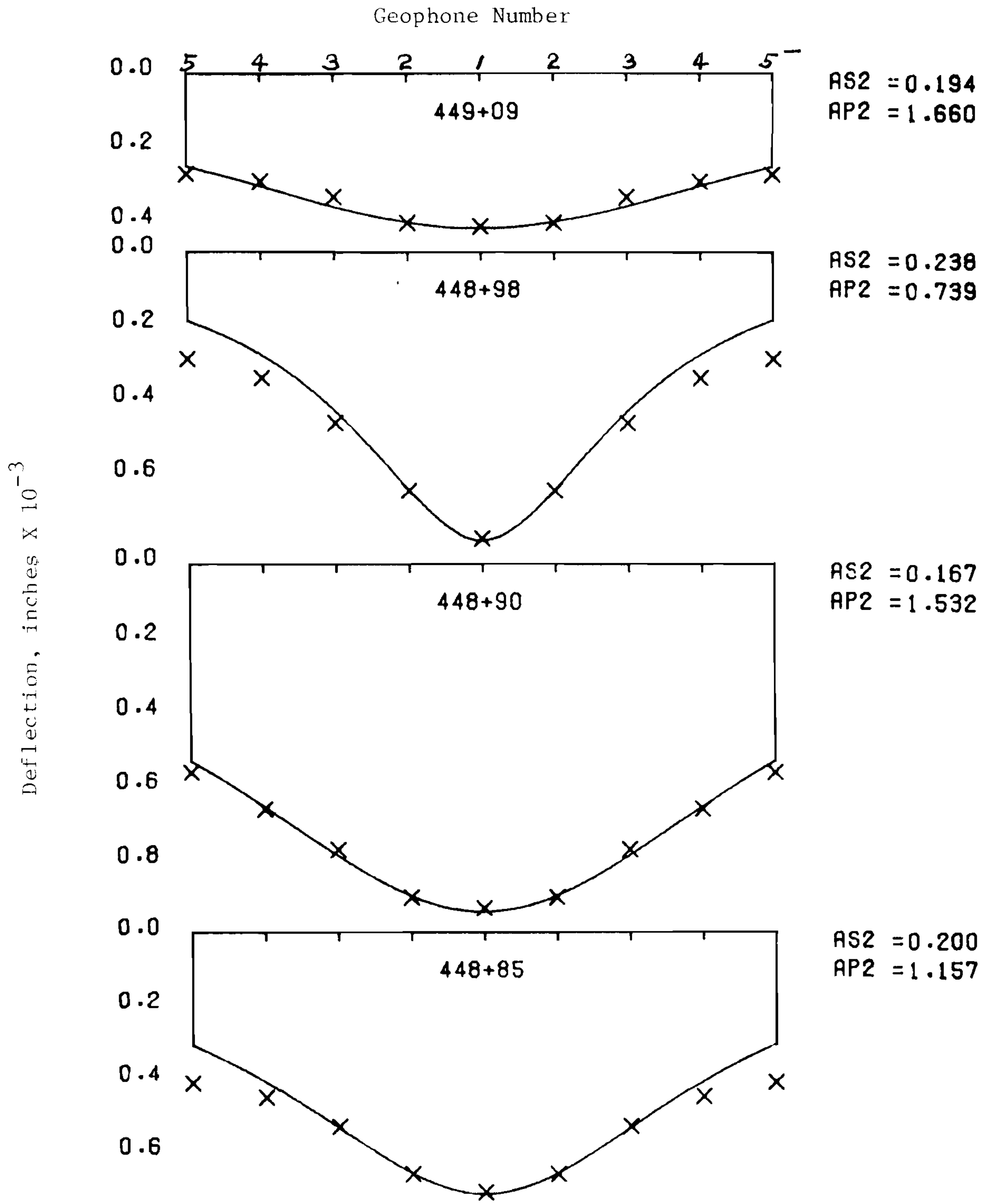



AS2 = Stiffness Coefficient of the subgrade

AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-10, Section 2A, Outside Lane

High Deflection: No Pumping




AS2 = Stiffness Coefficient of the subgrade

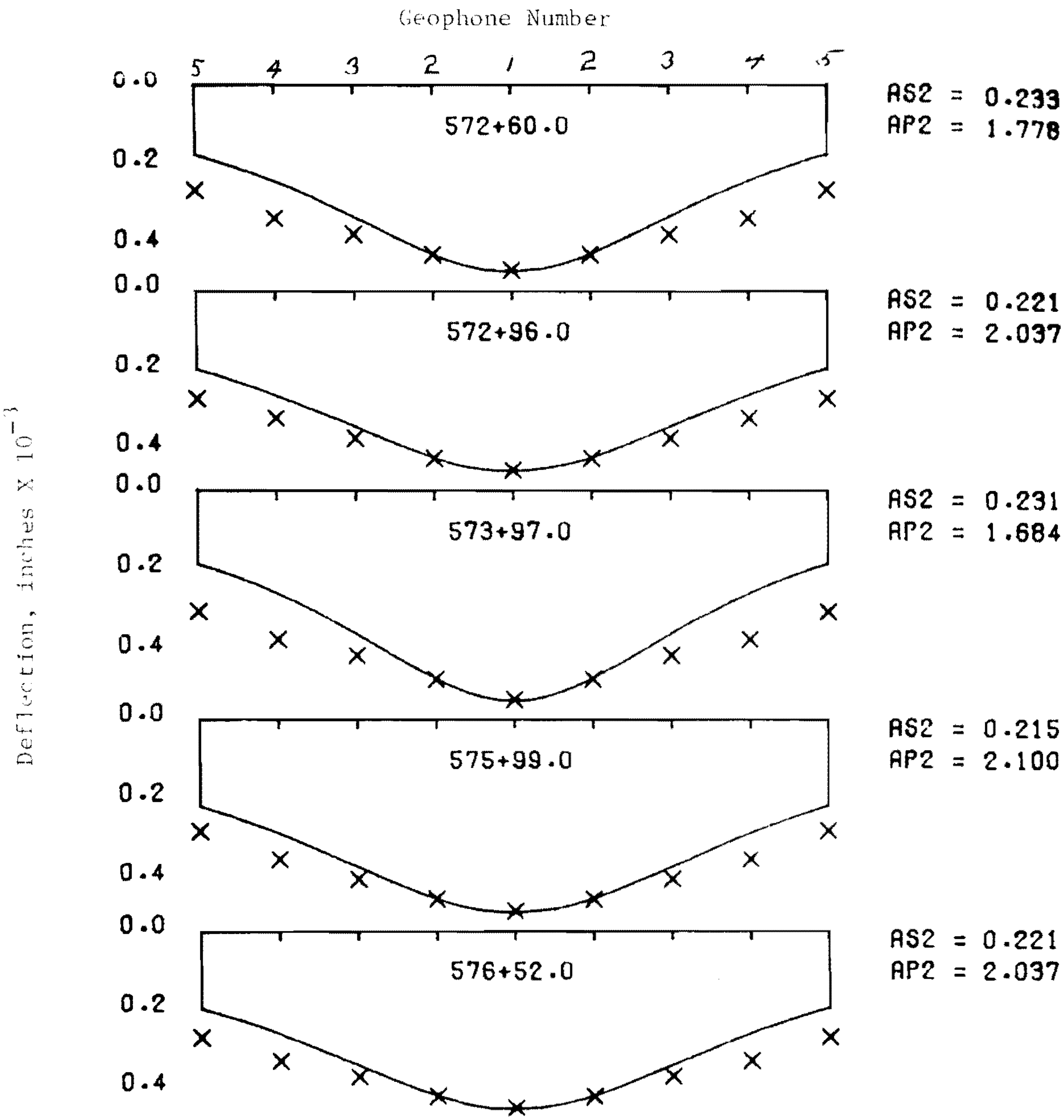
AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-10, Section 2B, Outside Lane

High Deflection: Pumping

# APPENDIX 2

# DEFLECTION BASINS FOR IH-45

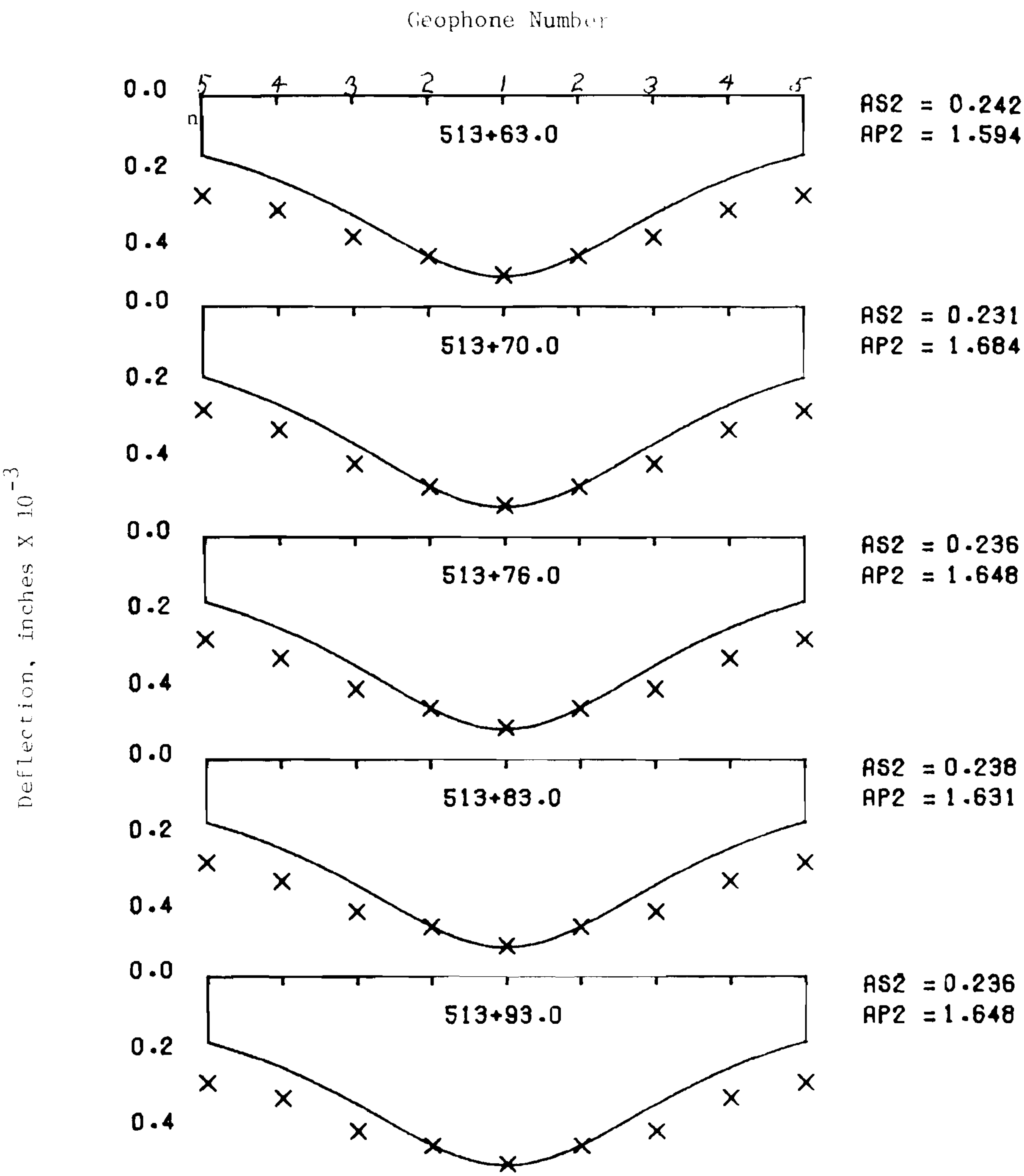



AS2 = Stiffness Coefficient of the subgrade

AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-45, Section 1A, Outside Lane

Low Deflection: No Pumping

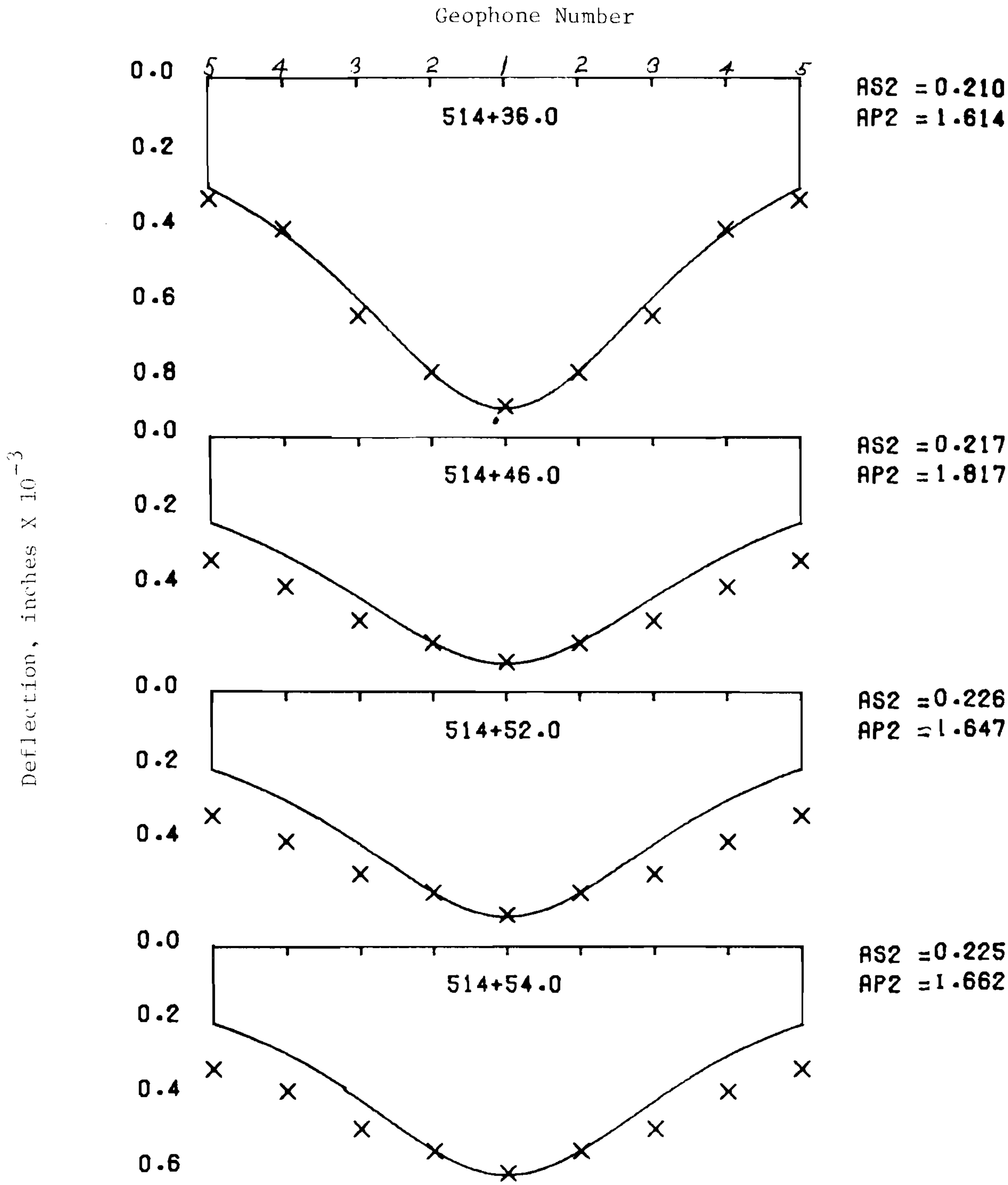



AS2 = Stiffness Coefficient of the subgrade

AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-45, Section 2A, Outside Lane

Low Deflection: Pumping




AS2 = Stiffness Coefficient of the subgrade

AP2 = Stiffness Coefficient of the pavement

Deflection Basins for IH-45, Section 2A, Outside Lane
High Deflection: Pumping

# APPENDIX 3

# CORE CONDITION

# APPENDIX 3. CORE CONDITION

Columbus, Colorado County, IH-10

| | | | |
|---|---|---|---|
| (1) | high deflection, no pumping | Sta. 229 + 22 | Water running from edge, core parted from base; possible void, sand fluffy on top of subbase; cored area, water seeping in, concrete and base look ok. |
| (2) | low deflection, pumping | 230 + 55 | Core parted from base, but no void showing; on edge, not much void; concrete and base look ok. |
| (3) | high deflection, pumping | 231 + 06 | Core parted from base, void showing in core and edge; bailing wire shoved in edge at crack about 6 inches; core split, and broke horizontally, probably due to coring operation; crack is very wide (relatively), void size very small, possible channels. |
| (4) | high deflection, no pumping | 232 + 00 | Core parted, void in core and edge, water running in both; sand is fluffy on top of subbase but not as bad as (1); vertical crack in subbase as viewed from core about 1/4 inch wide at core. |
| (5) | low deflection, no pumping | 235 + 00 | Core parted but subbase material stuck to core; no void showing. |
| (6) | low deflection, pumping | 432 + 25 | Core parted; no void along edge, possible void at core; concrete core looks good, would guess only a small or no void this location. |

| | | | |
|---|---|---|---|
| (7) | high deflection, no pumping | 437 + 05 | Core parted; possible voids in core and edge; water flowing in edge and core. |
| (8) | high deflection, pumping | 439 + 85 | Core parted; voids are apparent in core and edge; subbase core contained a vertical crack, water pouring in under pressure between concrete and subbase. |
| (9) | low deflection, pumping | 441 + 35 | No voids, no water coming in; looks good. |
| (10) | low deflection, no pumping | 443 + 55 | No voids, no water coming in; looks good. |

Fairfield, Freestone County, IH-45

| | | | |
|---|---|---|---|
| (1) | low deflection, no pumping | Sta. 498 + 97 | The core came out separated; there was not quite as much discoloration in this one as there has been in the others. The water did not fall back into the hole and it looks like there is probably not a void under it. |
| (2) | high deflection, no pumping | 500 + 96 | Also separated and the asphalt stabilized base was discolored on the top leading us to believe again that it was separated; it came out in two pieces; there was no water running back into it. We are on superelevated curve at this point. |
| (3) | high deflection, no pumping | 508 + 96 | Appeared to come out in two pieces indicating that it was separated; the asphalt stabilized base is discolored at the top, leading us to believe that it was separated from the slab; also, water was running back in as quickly as we could dip it out. |

| | | | |
|---|---|---|---|
| (4) | low deflection, no pumping | 509 + 96 | Came out in two pieces; in one spot it looked like there might be a very small void, but there was not any noticeable water draining back into the hole so we concluded that there was no void. |
| (5) | low deflection, pumping | 513 + 75 | Came out in two pieces with those coming out in two pieces showing a slight discoloration on the top of the asphalt which could be signs of pumping; did not have water coming back into it. |
| (6) | high deflection, pumping | 514 + 36 | Came out in two pieces; water was running in as fast as we could empty it out; there appeared to be a void. |
| (7) | low deflection, pumping | 553 + 18 | Core and base came out together as one piece; no visible signs of void; no water running back in. |
| (8) | high deflection, pumping | 562 + 80 | Asphalt stabilized base separated from the pavement, the core; but there seemed to be very little void if any at all from looking at it; water was running back into the hole. |
| (9) | high deflection, pumping | 564 + 50 | About the same condition as (10); water was coming in from the edge of the pavement faster than we could take it out. The concise opinion was that there was a void under the pavement again. The core stradled a crack. Preliminary investigation shows that the crack did not go into the asphalt stabilized base. After looking at the base in the lab, I found that the crack did go into the base. |

| | | | |
|---|---|---|---|
| (10) | high deflection, pumping | 566 + 80 | Small amount of black base was stuck to the core when it came out, but it was very likely separated prior to the coring; looked like there was mud between what was left on the core and the asphalt stabilized base. The water was running into the hole as fast as we could dip it out; we were adjacent to a void or punchout area; very likely there was a void under there; the void might have been down in the asphalt stabilized base from 1/4 to 1/2 inches down. |
| (11) | high deflection, no pumping | 572 + 50 | As small amounts of asphalt stabilized base were stuck to the core itself when it came out, there were no visible means of water running into the hole after the core was taken out; there appeared to be no void. |
| (12) | low deflection, no pumping | 573 + 97 | The core and subbase separated which is the asphalt stabilized base; it was separated from the core but some was stuck to the core; no void showing with no water running back into the hole. |

THE AUTHORS

John Wayne Birkhoff has recently completed a Bachelor of Science Degree in Civil Engineering with a strong interest in Transportation Engineering. He is employed by the Center for Highway Research and is currently involved in a research project which deals with the rehabilitation of pavements.

B. Frank McCullough is a Professor of Civil Engineering at The University of Texas at Austin. He has developed design methods for continuously reinforced concrete pavements currently used by the Texas State Department of Highways and Public Trnasportation, U.S. Steel Corporation, and others. He has also developed overlay design methods now being used by the Federal Aviation Administration, U.S. Air Force, and the Federal Highway Administration. During nine years with the Texas State Department of Highways and Public Transportation, he was active in a variety of research and design activities. He has authored more than 250 publications which have appeared in national journals, and research reports.