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16. Abstract

This report summarizes the design, construction, and use of an instrumented portland cement concrete pavement research facility. Instrumentation includes devices to monitor static deflections, temperature gradient of the slab, and moisture contents of the supporting layers. These data can be automatically collected and stored. The slab contains a movable doweled joint with tapered dowels such that load transfer across the joint can be varied by opening and closing the joint. Two voids were constructed under the slab, one at a joint corner and the other at the edge of the pavement for the purpose of evaluating the void detection capabilities of various devices.

The facility is equipped with environmental devices to monitor ambient temperature, wind velocity, relative humidity, and solar radiation.

Research has been conducted at the facility to evaluate deflection measuring equipment for its ability to estimate insitu properties of the pavement layers, to detect voids underneath the pavement, and to measure load transfer efficiency at joints.

Data have been collected to evaluate environmental effects on the slab and how those effects influence deflection measurements.

The facility is located at the Balcones Research Center, The University of Texas at Austin.

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Instrumented Rigid Pavement for Multipurpose Research

by

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Research Report 355-2F

Construct Research Pavement Slabs for Testing Deflection Measuring Devices
Research Project 3-8-83-355

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 Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

November 1986

PREFACE

This is the final report describing construction of a rigid pavement test facility at Balcones Research Center (BRC) conducted under Research Project 3-8-83-355, "Design and Construction of a Rigid Pavement Research Facility." This research project was conducted by the Center for Transportation Research, The University of Texas at Austin, as part of the Cooperative Highway Research Program sponsored by the Texas State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration (FHWA). This report summarizes the construction of the facility, the instrumentation, and the research activities performed.

The authors are especially grateful to the staff of the Center for Transportation Research and the technical staff of the SDHPT involved in the research project. Special thanks are due to Eduardo Ricci and Carl Bertrand, who supervised various aspects of the work.

A. H. Meyer
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LIST OF REPORTS

Report No. 355-1, "Design and Construction of a Rigid Pavement Research Facility," by Ronald White, W. R. Hudson, and Alvin H. Meyer, details the design construction and instrumentation of a rigid pavement research facility for evaluating nondestructive testing equipment. August 1984.

Report No. 355-2F, "Instrumented Rigid Pavement for Multipurpose Research," by A. H. Meyer, W. R. Hudson, C. L. Saraf, and K. H. Stokoe, II, details the design, construction, and instrumentation of a rigid pavement research facility. November 1986.

ABSTRACT

This report summarizes the design, construction, and use of an instrumented portland cement concrete pavement research facility. Instrumentation includes devices to monitor static deflections, temperature gradient of the slab, and moisture contents of the supporting layers. These data can be automatically collected and stored. The slab contains a movable doweled joint with tapered dowels such that load transfer across the joint can be varied by opening and closing the joint. Two voids were constructed under the slab, one at a joint corner and the other at the edge of the pavement for the purpose of evaluating the void detection capabilities of various devices.

The facility is equipped with environmental devices to monitor ambient temperature, wind velocity, relative humidity, and solar radiation.

Research has been conducted at the facility to evaluate deflection measuring equipment for its ability to estimate insitu properties of the pavement layers, to detect voids underneath the pavement, and to measure load transfer efficiency at joints.

Data have been collected to evaluate environmental effects on the slab and how those effects influence deflection measurements.

The facility is located at the Balcones Research Center, The University of Texas at Austin.

KEYWORDS: Rigid pavement, test facility, instrumented, research, load tranfer, voids, environmental affects.

SUMMARY

Structural evaluation of existing pavements is a basic part of good pavement management and is the initial step for developing meaningful rehabilitation strategies. Current structural evaluation methods primarily involve non-destructive deflection testing. However, the variability in field pavements and the multitude of pavement evaluation devices available make it difficult to select an evaluation device and an appropriate methodology for use therewith.

After considerable discussion with the Pavement Group of the Design Division of the Texas State Department of Highways and Public Transportation, the decision was made to design, construct, and utilize a pavement research facility to evaluate current and future non-destructive pavement evaluation devices in an attempt to upgrade pavement rehabilitation strategies for the State of Texas.

These are objectives for this study.

(1) Construct a research slab facility for evaluating special problems in rigid pavements (such as with joints, shoulders, voids, base support, aggregate types, moisture effects, curling effects, prestressed repairs, etc.).

(2) Evaluate potential or innovative rehabilitation methods (such as precast-prestressed PCC overlays and precast joint assemblies).

(3) Investigate new design concepts in PCC pavements.

(4) Design the facility to accommodate the evaluation of test methods and pavement evaluation equipment (such as Dynaflect, Falling Weight Deflectometer, Spectral Analysis of Surface Waves, and Road Rater).

(5) Incorporate instrumentation to measure, moisture, deflection, and related basic properties and responses.

This final report summarizes the work done since the beginning of the project in 1982. The scope of work outlined for this project includes the initial design and construction of the facility and preliminary testing of the facility using the Dynaflect and the Falling Weight Deflectometer. Significant variables were evaluated and identified by the advisory panel to be monitored as part of the study. Variables selected included (1) sublayer moisture, (2) slab temperature gradient, (3) load transfer, and (4) voids in the base course.

Provisions were made for subsequent studies of shoulder effects and substantial room was provided to allow for additional studies as required.

This research report describes a test facility which has been designed and constructed as a part of Research Project 3-8-83-355 entitled, "Pavement Slab for Deflection Device Testing." This test facility provides the capability of measuring the actual deflection of the slab using buried deflection reference rods and LVDTs while at the same time providing the capability of monitoring pavement temperature and moisture conditions within the subgrade. This capability makes it possible to examine the true deflected shape of the slab and compare this to various outputs of available equipment for surface deflection measurements. This report describes the instrumentation available and describes the use of the slab through its first year ending August 31, 1986. The results today are quite promising and the results are already being implemented by the State Department of Highways and Public transportation.

The facility has also served for field studies in several other projects since they have been making tests of their own before launching full scale field work. This gives them the chance to improve their ideas, check instrumentation and analyze important variables that may affect their future work. They can estimate the magnitude of field variables from measurements on pilot tests. The following projects have used the facility.

Project 401 -- "Prestressed Concrete Pavement Design and Construction of Overlay Applications." On the south part of the facility this project constructed a small prestressed concrete test slab, it was used to test the functioning of instrumentation equipment to be implemented at Waco, the overlay project, and to verify predicted strengths of concrete against zone failure.

Project 387 -- "Purchasing and Adapting a Falling Weight Deflectometer for Non-Destructive Evaluation and Research on Rigid Pavements in Texas" has been using intensely the research facility collecting data with the FWD and Dynaflect for load transfer efficiency and for structural characterization of the soil properties.

Project 459 -- "Development of Subbase Friction Information for Use in Design of Concrete Pavement." This project has been using the slab facility building a small slab and using the data acquisition system and the project personnel. The objectives of the project are: instead of the traditional push-off to measure subbase friction, this experiment will measure subbase friction indirectly under actual behavior due to temperature variations. By measuring movements, change in temperature, modulus of elasticity, and the coefficient of thermal expansion, these variables will be input into computer program while adjusting the friction-force profile until the generated movements match the actual movements. The change in temperature will be performed artificially using a kerosine heater inside of a small temperature chamber. One end of the slab is pinned to an anchor below so as to in effect double the size of the slab. Vertical movements will also be measured to keep an eye on curling effects.

Project 460, "Assessment of Load Transfer Across Joints and Cracks in Rigid Pavements Using the FWD." The testing facility at Balcones Research Center is extensively being used by this project. This project is studying the following aspects at the present time:

(1) the effect that the temperature differential on the pavement slab has on the deflections measured by means of the Falling Weight Deflectometer (curling effects).

(2) evaluation of longitudinal joints by means of the Falling Weight Deflectometer.

IMPLEMENTATION STATEMENT

The facility has been in continuous use since its construction in 1984. Numerous projects have used the facility for many purposes. The data collected have generated and will continue to generate recommendations for the use of deflection measuring equipment for pavement evaluation, the use of spectral analysis of surface wave equipment for pavement evaluation, the evaluation of joints both transverse and longitudinal, the design of prestressed pavements, and the design of overlays.

It is recommended that the facility is continued to be used for evaluation of non-destructive testing devices and be expanded to include other pavement sections for testing.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Structural evaluation of existing pavements is a basic part of good pavement management and is the initial step for developing meaningful rehabilitation strategies. Current structural evaluation methods primarily involve non-destructive deflection testing. However, the variability in field pavements and the multitude of pavement evaluation devices available make it difficult to select an evaluation device and an appropriate methodology for use therewith.

After considerable discussion with the Pavement Group of the Design Division of the Texas State Department of Highways and Public Transportation, the decision was made to design, construct, and utilize a pavement research facility to evaluate current and future non-destructive pavement evaluation devices in an attempt to upgrade pavement rehabilitation strategies for the State of Texas.

The project began as a Type B study in 1982. A project advisory committee was formed which included both SDHPT and FHWA personnel. After considerable discussion with this advisory panel it was decided to design and construct a pavement facility under carefully controlled construction conditions which could be used as a bench mark for testing and comparing non-destructive testing devices. This pavement slab was to be constructed with and without voids underneath and with a variable load transfer joint. There was to be a capability for measuring moisture content of the subgrade and temperature within the concrete slab to determine possible effects on pavement evaluation.

OBJECTIVES

As a result of the Type B study and on recommendations of the advisory panel, a more detailed project was initiated in the normal research program of the SDHPT with the following objectives.

(1) Construct a research slab facility for evaluating special problems in rigid pavements (such as with joints, shoulders, voids, base support, aggregate types, moisture effects, curling effects, prestressed repairs, etc.).

(2) Evaluate potential or innovative rehabilitation methods (such as precast-prestressed PCC overlays and precast joint assemblies).

(3) Investigate new design concepts in PCC pavements.

(4) Design the facility to accommodate the evaluation of test methods and pavement evaluation equipment (such as Dynaflect, Falling Weight Deflectometer, Spectral Analysis of Surface Waves, and Road Rater).

(5) Incorporate instrumentation to measure, moisture, deflection, and related basic properties and responses.

VARIABLES

Several significant variables were chosen for monitoring after being identified by the Advisory Panel. These variables include sub-layer moisture, slab temperature gradient, load transfer, and curling. Two under slab voids were added as a condition variable that will be monitored. The effect of shoulders on pavement deflection was to be studied in future projects. Deflections of concrete pavements with continuous concrete shoulders are substantially lower than of rigid pavements constructed with asphaltic concrete shoulders. This difference will be evaluated at some future time. A temporary crushed stone shoulder was placed to provide protection of the pavement edge and access to the pavement surface.

SCOPE OF WORK

This final report summarizes the work done since the beginning of the Type B project in 1982. The scope of work outlined for this project included the initial design and construction of the facility and preliminary testing of the facility using the dynaflect and the falling weight deflectometer. Significant variables were evaluated and identified by the advisory panel to be monitored as part of the study. Variables selected include (1) sublayer moisture, (2) slab temperature gradient, (3) load transfer, and (4) voids in the base course.

Provisions were made for subsequent studies of shoulder effects and substantial room was provided to allow for additional studies as required.

The initial report, No. 355-1 (Ref 1), was written in September 1984; it describes the initial plans for the project and the initial design and construction of the slab, including the selection of instrumentation. That initial report provides a good reference and the information is not repeated here.

This report describes the construction and use of the slab and the findings from early test results.

CHAPTER 2. CONSTRUCTION OF TEST SLAB

INTRODUCTION

Research Report 355-1, entitled "Design and Construction of a Rigid Pavement Research Facility" (Ref 1), summarizes activities prior to construction, including the design and construction specifications for the facility and the guidelines for the instrumentation to be installed.

During the first year of the project a site was carefully selected in order to satisfy the needs of the project. The factors used in site selection were (1) protection from unauthorized access, (2) availability of utilities, (3) interference with other activities, and (4) soil conditions on the site.

Several sites were considered as potential locations for the research facility. These included a State Department of Highways and Public Transportation (SDHPT) maintenance yard, the University of Texas Balcones Research Center (BRC), and various state road rights of way. The BRC site was chosen because it fulfilled most of the site selection criteria. It is completely fenced, giving the area security. Utilities are available and there are no plans by the University to build other structures on the site in the foreseeable future. The only problem associated with using this location was the local soil conditions.

Several sites at Balcones Research Center were considered by project personnel (Fig 2.1). After making exploratory borings, it was discovered that the subgrade became more shallow toward the north end of Balcones Research Center (BRC). This eliminated several sites to the north, which had only 18 inches of subgrade. Site number 3, to the west of nearby railroad tracks, was also rejected because no utilities were available at this site and, though still on Univeristy property, it did not lie within the protective fencing at BRC.

The site that was chosen and approved (site number 1 on Fig 2.1) has a subgrade depth of 3 feet. The final six inches of subgrade, adjacent to the bedrock, is composed primarily of broken rock mixed with the natural soil. A fill section was constructed to increase the soil depth to 6 to 10 feet. The site is situated in a large open field where other slabs could be constructed if desired at some later date.

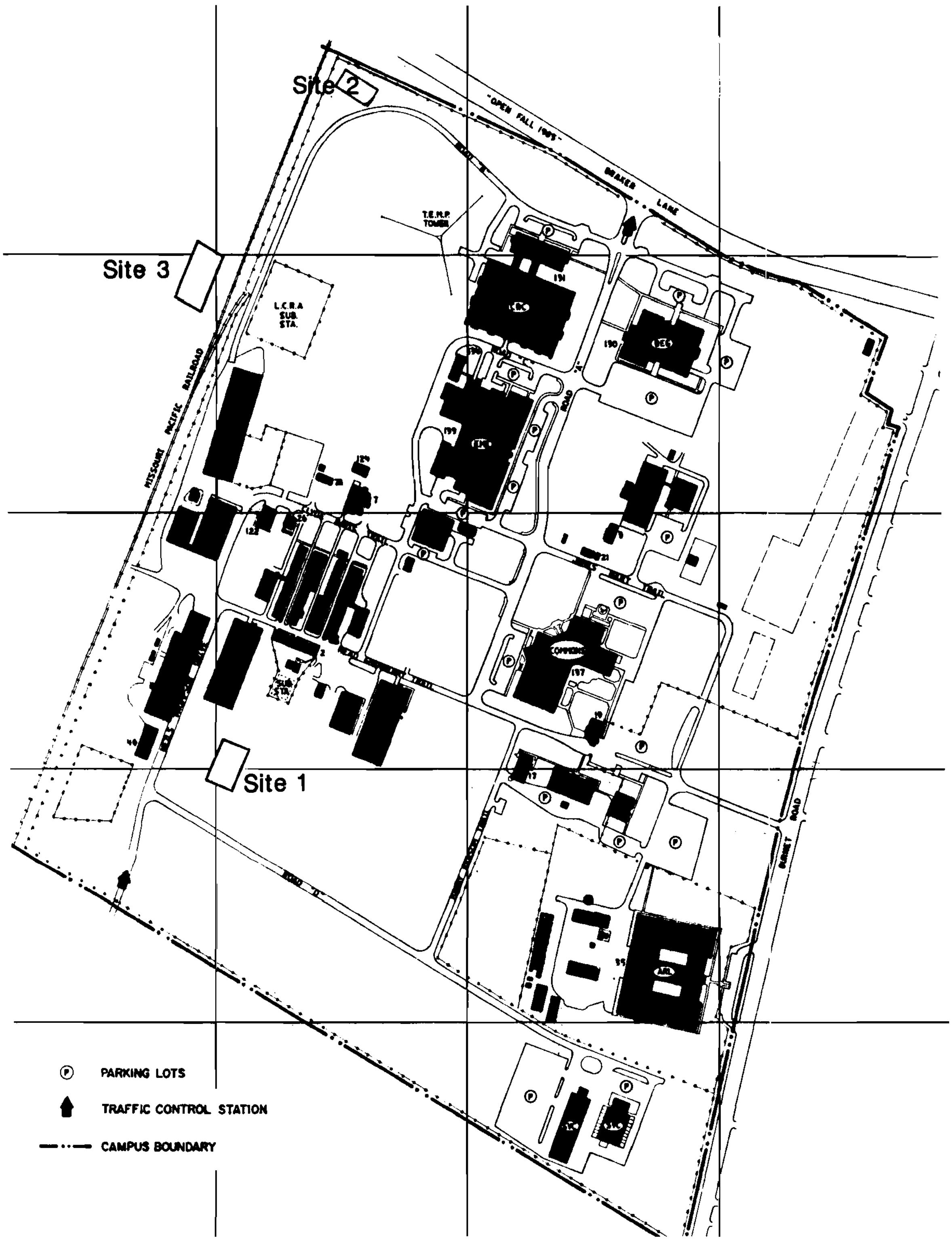


Fig 2.1. Sites considered at Balcones Research Center.

CONSTRUCTION

When the plans and specifications were in final form, site work began with the removal of top soil and the placement of about 1,000 cy of fill material to raise the height of the subgrade above bedrock (Figs 2.2 and 2.3). The work was done by a contractor working on another construction project at BRC. The material was furnished and compacted at the site at a rate of $1.00 per cy.

After all of the earthwork had been completed and slopes of the embankment stabilized with top soil, the contractor placed and compacted the select fill and the crushed stone subbase. The District 14 personnel of SDHPT performed in-place density tests on the select fill and base. All tests passed the specified compaction requirements.

After the placement of the crushed stone subbase was completed and accepted, a prime coat was placed, it was followed by asphaltic base material (Fig 2.4, which completed the preparation of all supporting layers prior to placing the slab. At this point, a drilling contractor was engaged to drill a number of borings into the bed rock for placement of reference rods and other test equipment (Fig 2.5). Thirty-six borings were made: thirty for deflection reference rods, four for moisture sensors, and two for nuclear moisture reading and for use in cross-hole tests for elastic modulus using surface wave characteristics. (Figs 2.6 and 2.7). As each boring was made, the appropriate instrument, usually a steel reference rod, was placed into the hole and anchored into the bed rock by a small dollop of mortar in the bottom of the hole (Fig 2.8). The next step was to insert a PVC pipe to insulate and protect the reference rod from surrounding soil and to imbed the end of PVC pipe in the concrete at the bottom of the hole, thus sealing it effectively. Once the concrete hardened, the holes were back filled around the PVC pipe and compacted with a special tamper fabricated to fit closely around the pipe. (Fig 2.9). After each of the reference rods was placed and compaction completed, each was checked for proper alignment (Fig 2.10), and the PVC pipes were cut to the appropriate length and capped with a plexiglass plug to provide a bearing area for the core of the DCDT deflection measuring device to be placed within the slab (Fig 2.11). Once this job was completed a specially fabricated mounting bracket for the DCDT was placed over each of the reference rods and anchored to the ACP base to prevent movement during the placement of concrete (Fig 2.12).

Subsequently, the form work for the concrete slabs was prepared and wiring and electrical work for the instrumentation done prior to placement of the concrete. All the wires placed were carried out west of the slab near the instrumentation building.

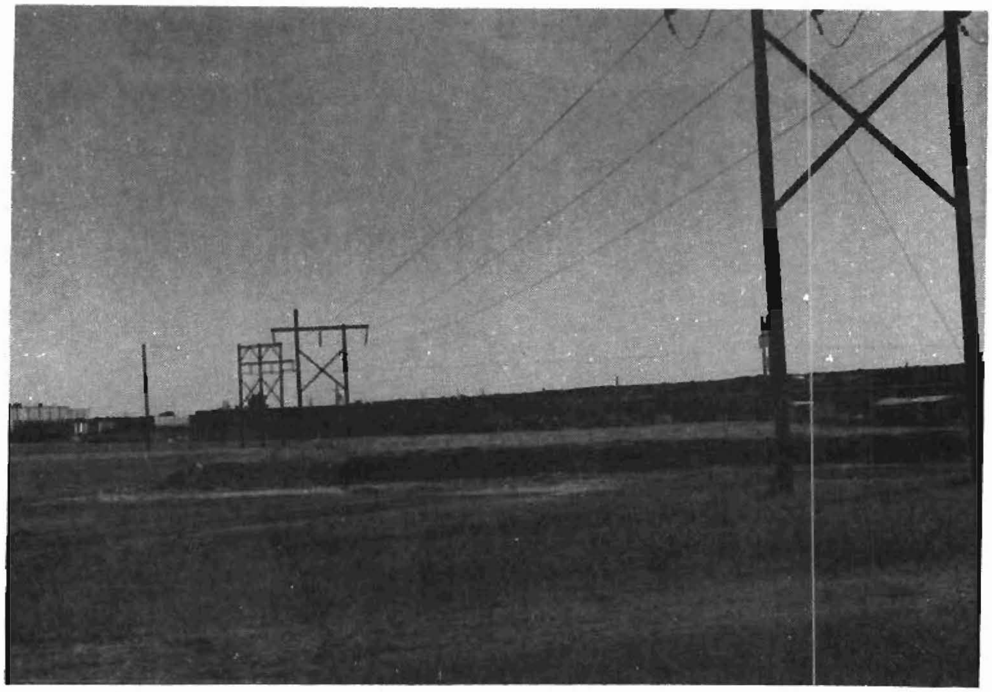


Fig 2.2 Removal of top soil and placement of free material.

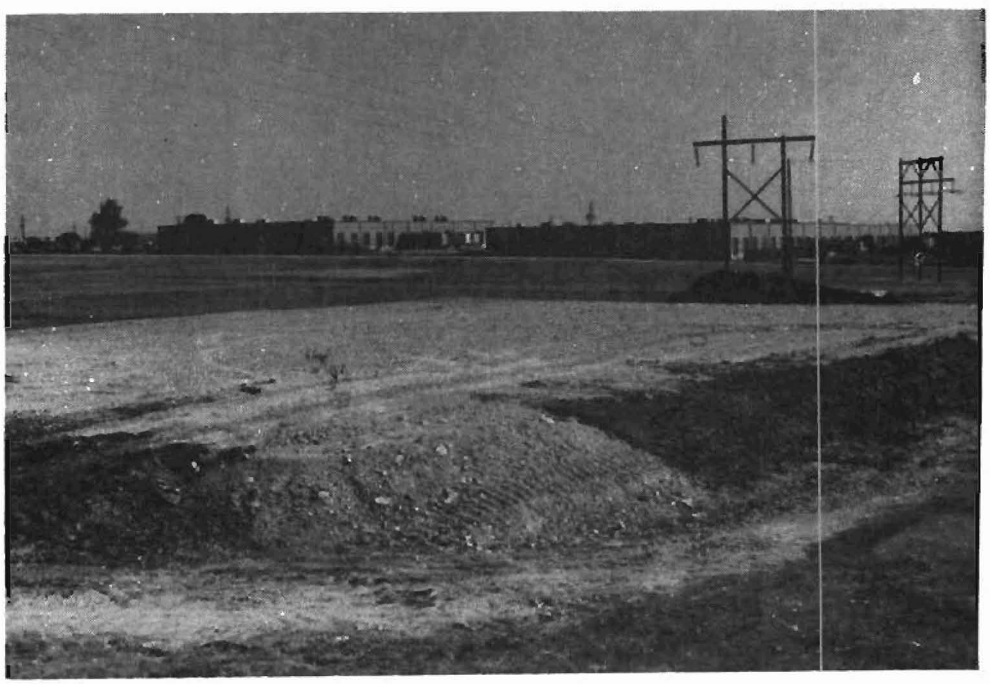


Fig 2.3. Fill at subgrade level waiting for the subbase course.

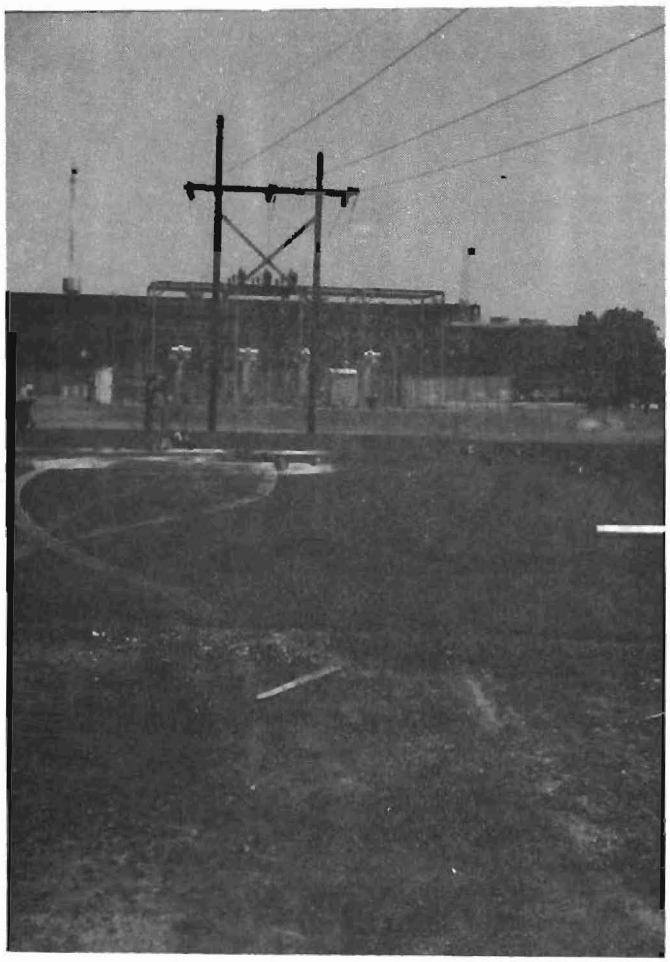


Fig 2.4. Asphalt concrete base before placing of PCC.

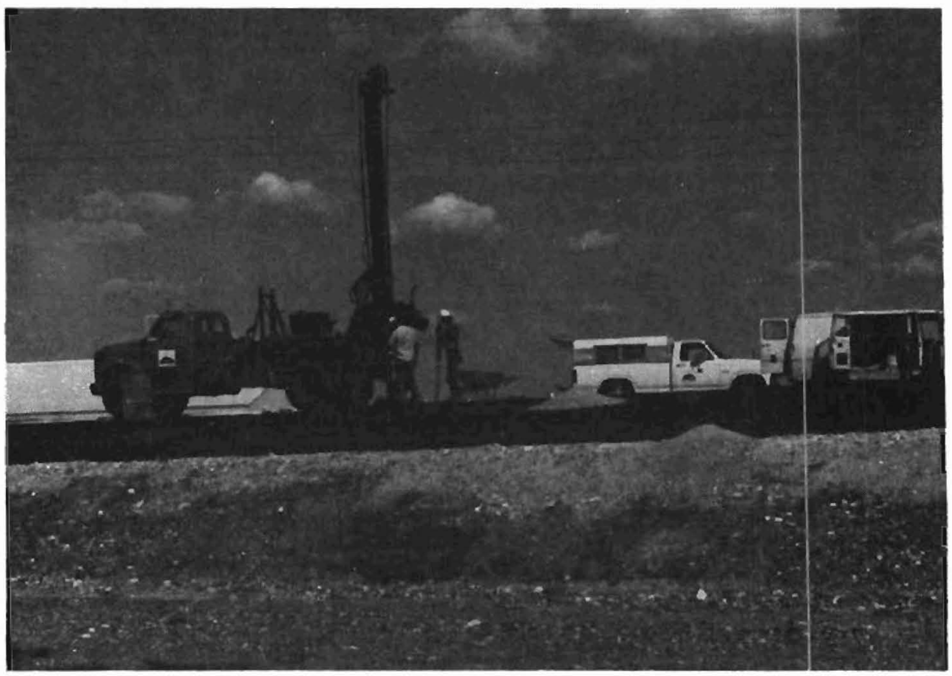


Fig 2.5. Drilling equipment working on top of the ACP drilling holes for the reference rods.

Fig 2.6. Boring for instrumentation.

Fig 2.7. Close view of the drilling equipment.

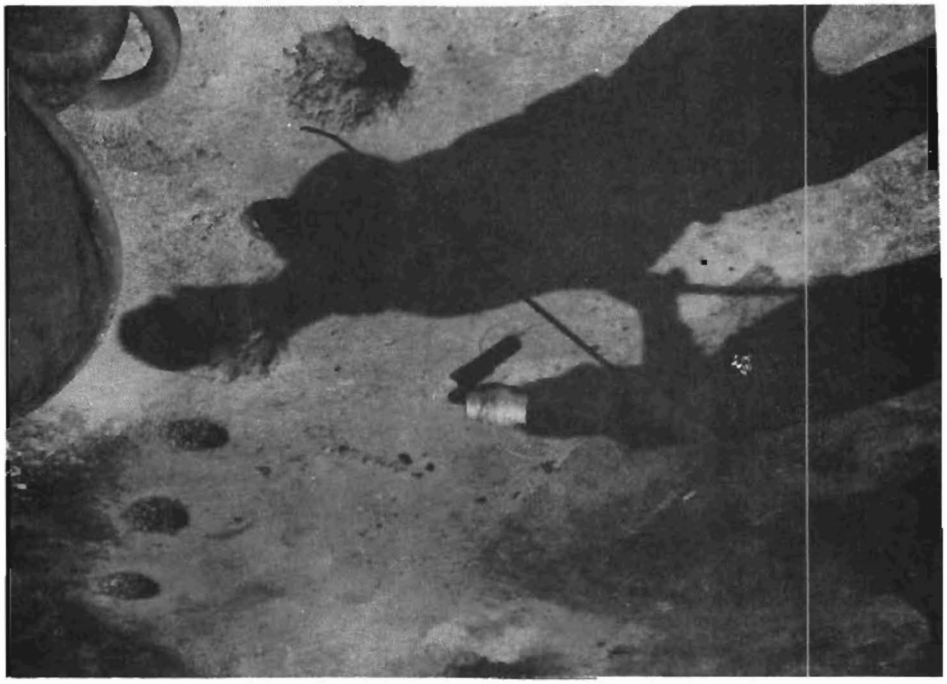


Fig 2.8. Placing steel rods into the holes and anchoring them to the bottom.

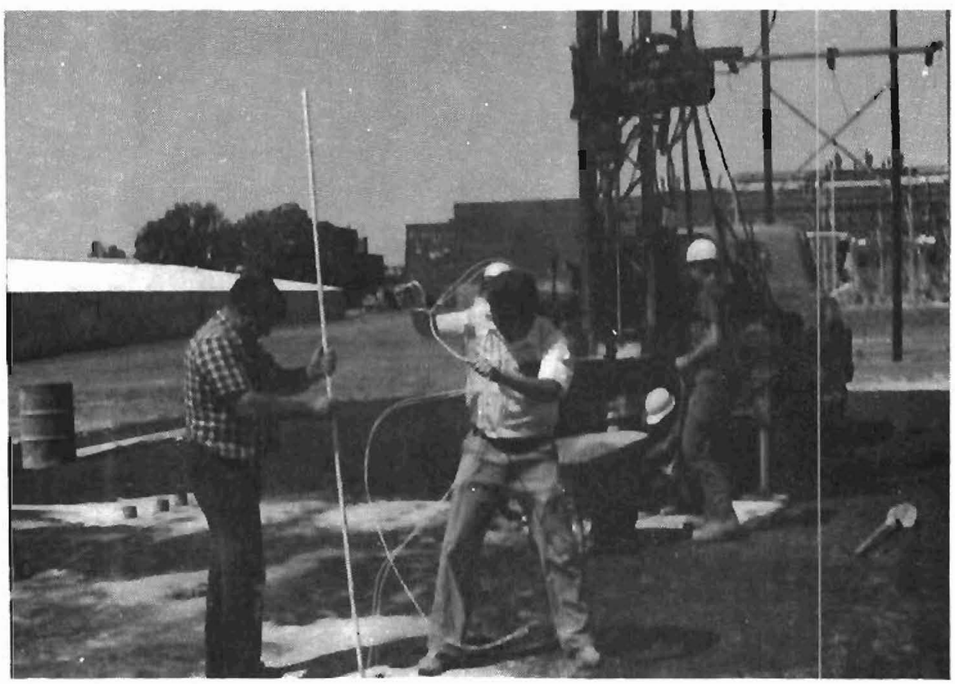


Fig 2.9. Compacting the soil around the PVC pipe that protected the steel rod.

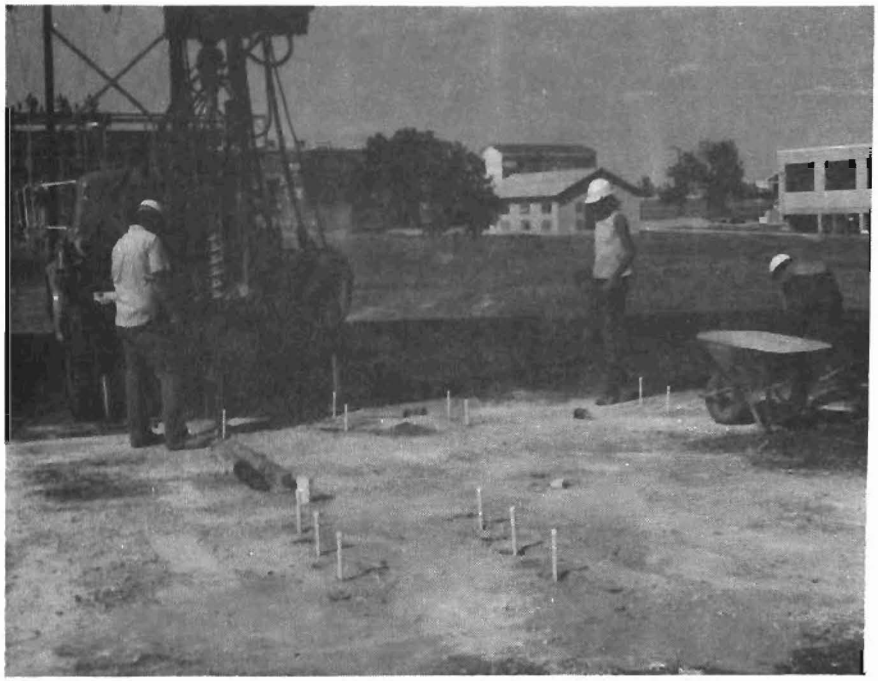


Fig 2.10. General view of the reference rods after being placed and anchored into the bed rock.

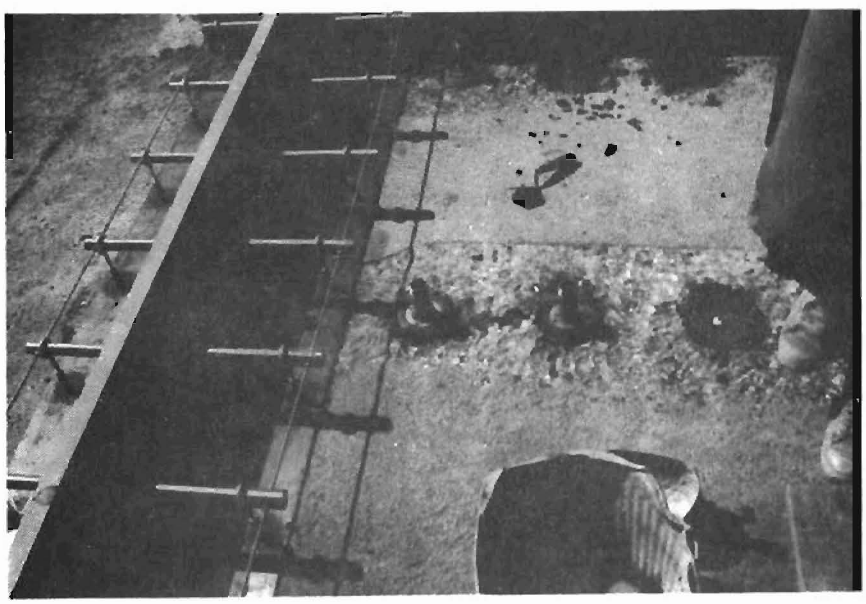


Fig 2.11. Reference rods capped before placing of the DCDT holding units and the joint support system.

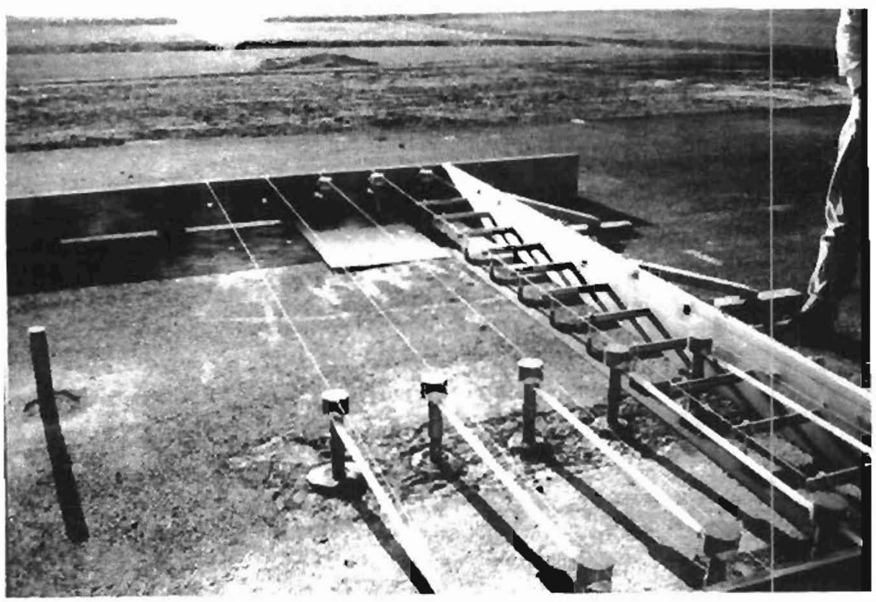


Fig 2.12. DCDT holding units in place before pouring of the concrete.

As shown in Fig 2.13 , the joint was held in place by 12-inch wooden forms which were provided to develop a smooth even joint; thus, the load transfer characteristics were provided only by the cone shaped dowels, as previously discussed in Ref 1. The form work was also used to provide support to the dowels and to hold them in place during the placement of the concrete.

Special mounts were also fabricated to hold the thermocouple blocks in place during the placing of the reinforcement and prior to placing of the concrete. Three thermocouples were carefully located at the planned dimension and at the right depth: one inch from the top at middepth, and one inch from the bottom of the slab (Fig 2.14).

Finally, the reinforcement was placed, anchors and attachments for the load frame were secured, and the contractor placed and finished the concrete as necessary. The concrete was cured using normal curing methods (Fig 2.15). During this time two sheets of 4-mil polyethylene were placed beneath the location specified for the small or movable slab. The form work for the small slab was then placed for subsequent pouring of concrete for this movable slab. Additional DCDT holding units were placed and after four days the form work at the joint was removed and the face of the concrete at the joint was covered with a polyethylene sheet to insure loss of adhesion of the small slab over the joint (Figs 2.16 and 2.17). The male components of the dowels were reinserted into the female dowels and realignment established to insure proper functioning during subsequent tests of the slab over the next several years (Fig 2.18). Subsequently, the loading frame and the hydraulic ram mounts which are used to open and close the joint were completed.

After the completion of the concrete work and the mounting of the brackets and load frames, and instrumentation, the final stages of the construction, including the wiring and construction of the control panel in the instrumentation building, were accomplished. The small instrumentation building at the slab is supplied with electric power to operate a heat pump, an air conditioner for year round climate control of the instrumentation, and the data acquisition systems.

The complete characteristics of the concrete, asphalt, and other materials used in the test are reproduced in Appendix A. Detailed data are on file in the project records at CTR.

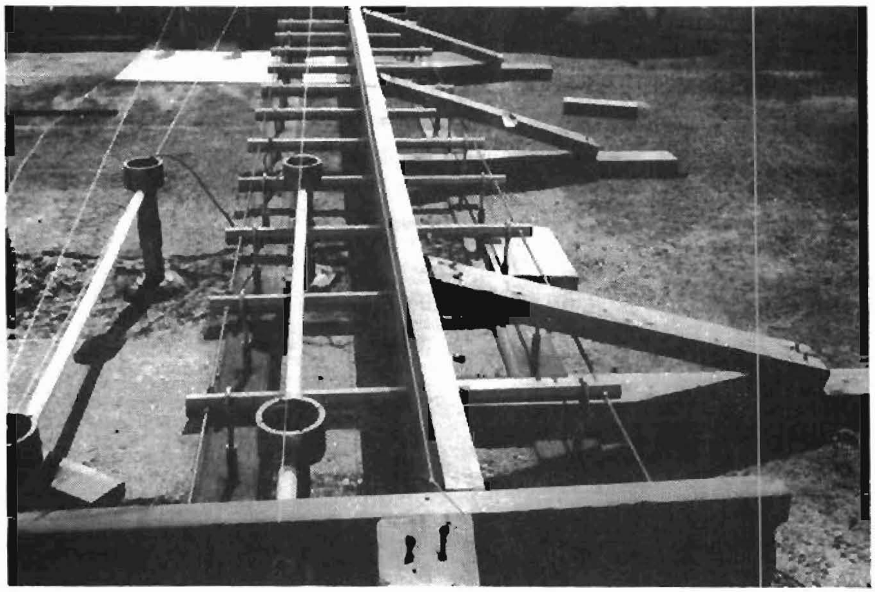


Fig 2.13. Joint assembly and dowel bars.

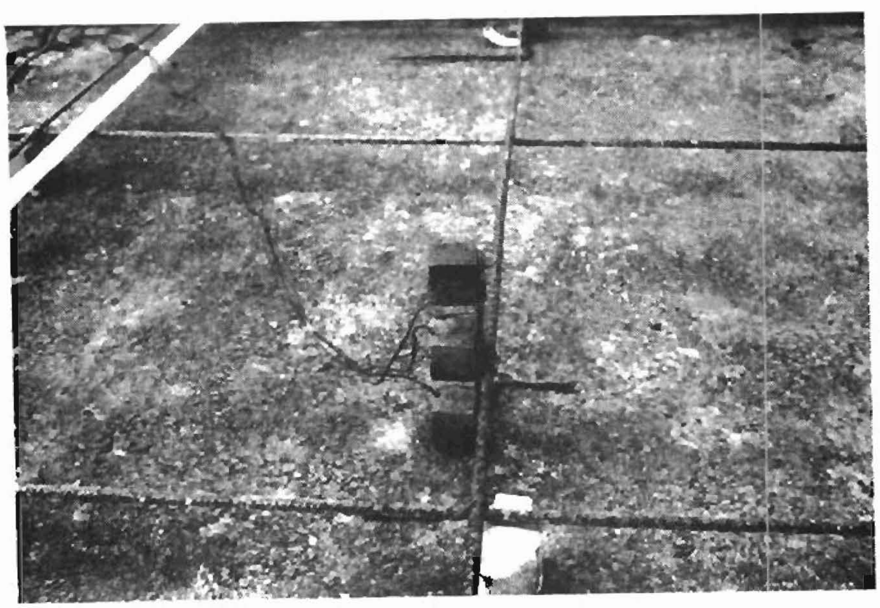


Fig 2.14. Thermocouple blocks.

Fig 2.15. Large slab during curing.

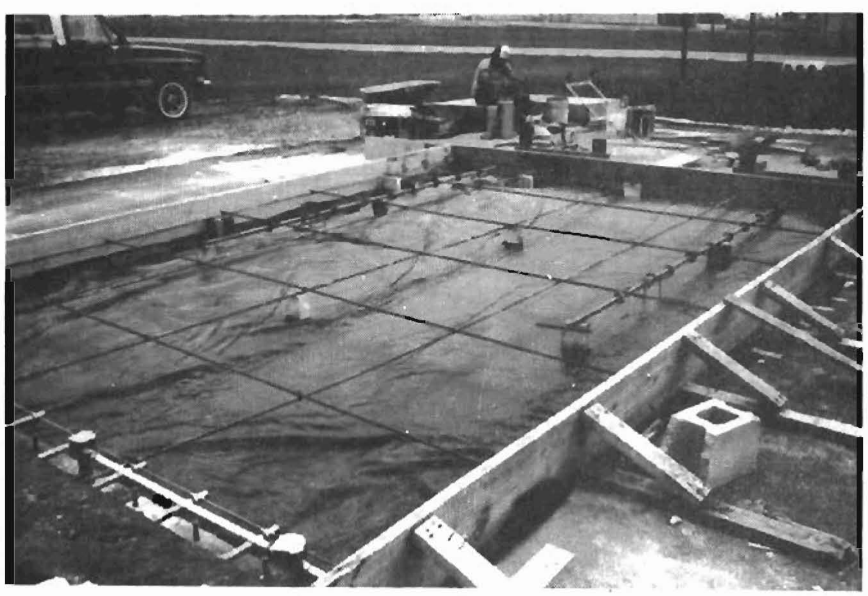


Fig 2.16. Small slab.

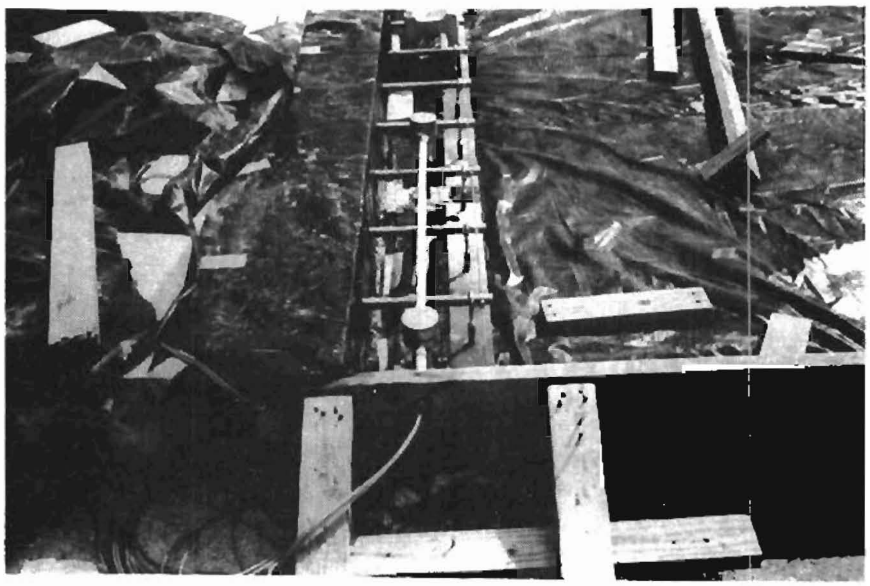
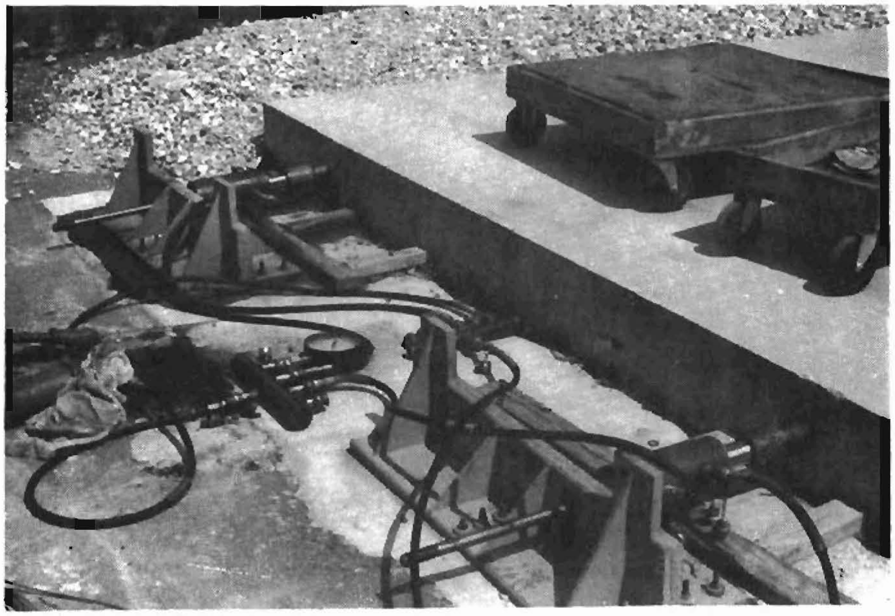


Fig 2.17. Small slab instrumentation and joint.



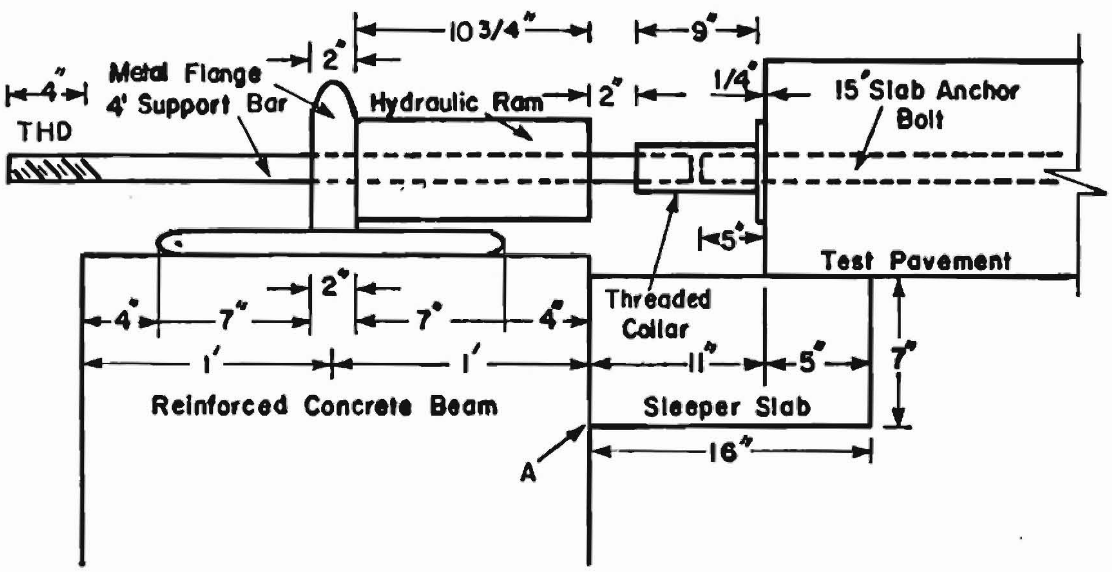


Fig 2.18. Joint gap adjustment hardware.

CHAPTER 3. INSTRUMENTATION OF TEST FACILITY

PRINCIPAL VARIABLES

The objective of this project was to construct a test pavement for monitoring the variables that influence pavement behavior and how these variables influence nondestructive testing devices and other research instruments.

The variables chosen for study were voids, slab temperature, gradient, moisture, load transfer, warping, curling, and atmospheric conditions, such as wind velocity, ambient temperature, relative humidity, and solar radiation. Deflection is measured by using Linear Variable Differential Transformers (LVDTs) for slab deflections. Any other measurement devices, such as strain gages and load cells, can be added at a later date to make precise measurements.

VOIDS

In order to study the effect of voids, two special voids were created under the pavement during the construction of the slab by placing a one-inch-thick layer of foamed styrene into depressions formed in the asphalt concrete base. After the slab was poured, and before the shoulder was constructed, the styrene foam was dissolved using an appropriate solvent, thus leaving two voids. The voids, on one side of the slab, measured 3 feet by 3 feet and were placed at the midspan and at the corner, as shown in Fig 3.1.

TEMPERATURE MEASUREMENTS

Thermocouples have been used successfully in the past to measure rigid pavement temperatures (Ref 2). Therefore, after a thorough study of available thermocouples, type "T", were selected for measuring the vertical temperature gradient within the slab at four separate locations. At each location the temperatures at the top, mid-depth, and bottom of the slab are to be monitored; thus, a total of twelve thermocouples were cast into the slab. They were fabricated and calibrated in the Department of Civil Engineering Laboratories prior to

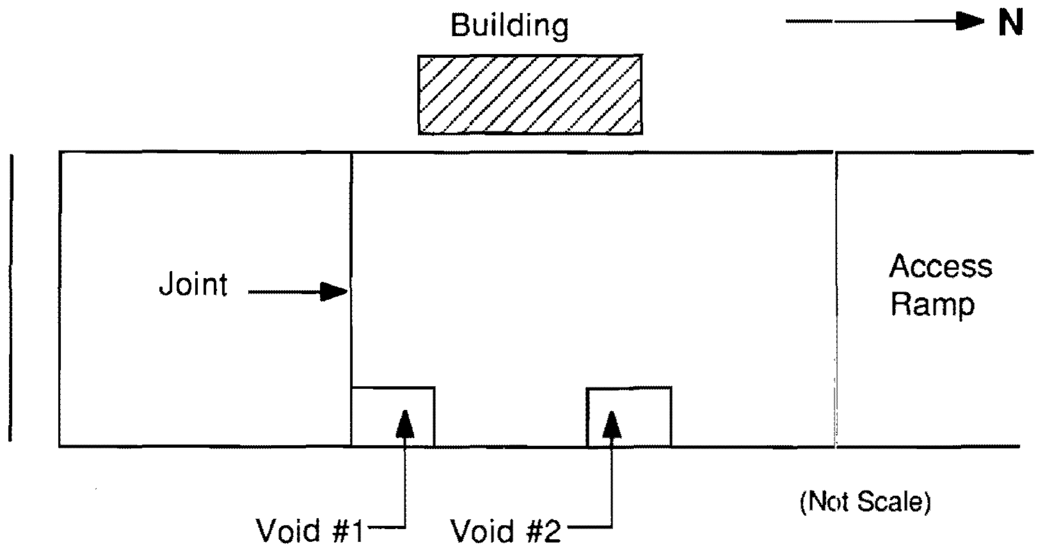


Fig 3.1. Void locations at the slab (schematic).

placement. Copper constantan thermocouple wire (outside insultation of polyvinyle) was used to minimize corrosion over a long period of time. Each thermocouple was fabricated by taking a 50-foot length of thermocouple wire and connecting the two dissimilar wires at one end with Leads and Northrup Quiktip thermocouple pressure connectors. Each temperature sensor was then cast into a small block of concrete mortar, as shown in Fig 3.2. These blocks were secured to the reinforcement in the proper location within the slab prior to placement of the concrete. Extreme care was taken by technicians working with the contractor to see that the blocks remained in the proper location as the concrete was poured. The lead wires from the thermocouples, where they run along the reinforcement, are protected and run out the west side of the test slab to the instrumentation building by being placed inside PVC pipes which are buried along the west side of the slab. The temperature gradient can be monitored automatically by connecting the lead wires to a thermocouple interface board located in the Hewlett-Packard data acquisition system.

MOISTURE MEASUREMENTS

After thorough study no really reliable method of measuring soil moisture over a long period of time was found. Also, the results of several of the systems are not reliable since the calibration of some of the devices seems to change with time. For these two reasons, three separate systems for measuring moisture were selected and set up in the subgrade layers. Having redundant systems could possibly cover the failure of one or more of the methodologies and a comparison can be made between the systems to check for accuracy. The systems used to test soil moisture condition were (1) soil test fiberglass blocks (manufactured by Soil-Test), (2) WESCOR psychrometers, and (3) nuclear moisture gages. The fiberglass blocks use changes in electrical resistance to determine soil moisture. The blocks have a pair of electrodes embedded in a fiberglass material. The resistance between the electrodes varies with the moisture content of the soil which is in contact with the electrodes (Fig 3.3). The moisture content is monitored by taking an OHM reading and finding the corresponding moisture on the calibration curve of each block. As is well known, nuclear gages emit radioactive waves into the soil. The number of gamma rays reflected by the soil is recorded by the instrument and can be correlated with wet density and the number of hydrogen atoms in

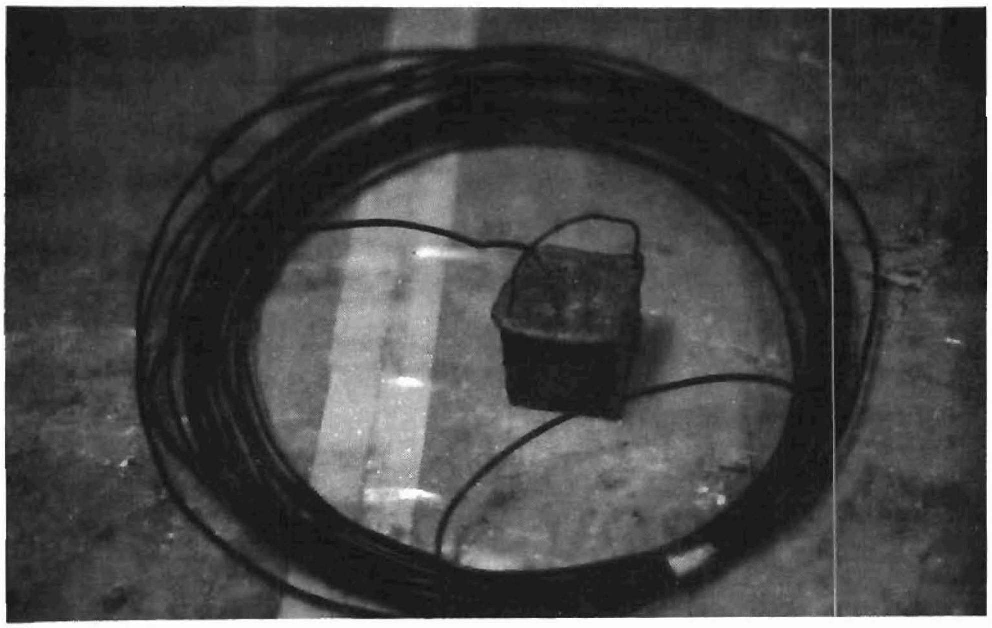


Fig 3.2. Concrete thermocouple block.

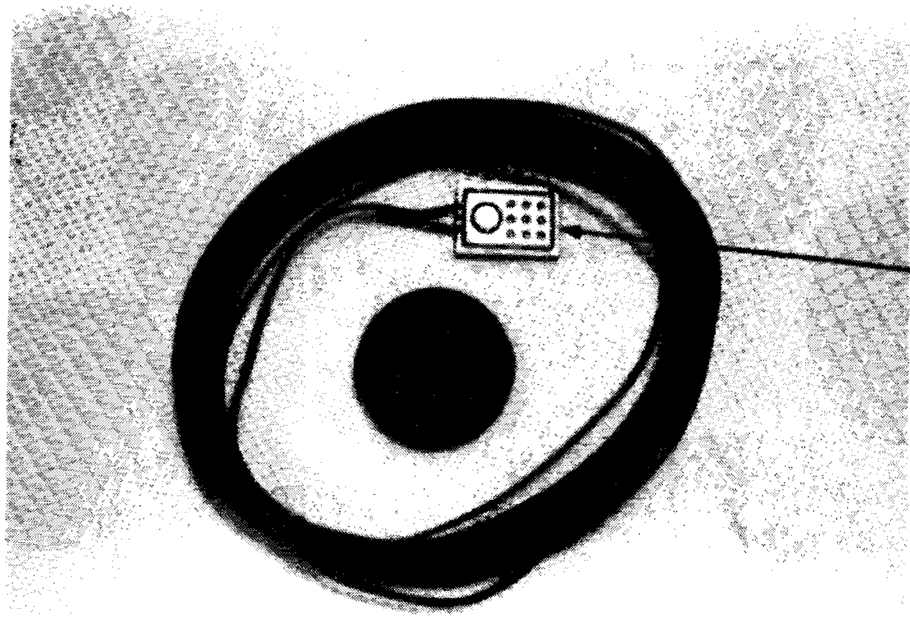


Fig 3.3. Fiberglass moisture block (Ref 2).

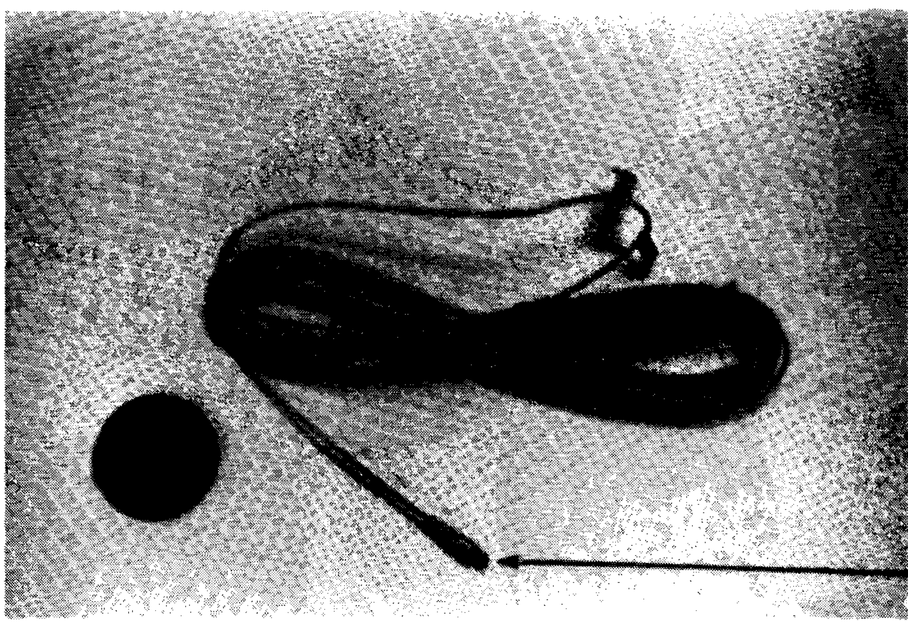


Fig 3.4. Psychrometer type moisture sensing block (Ref 2).

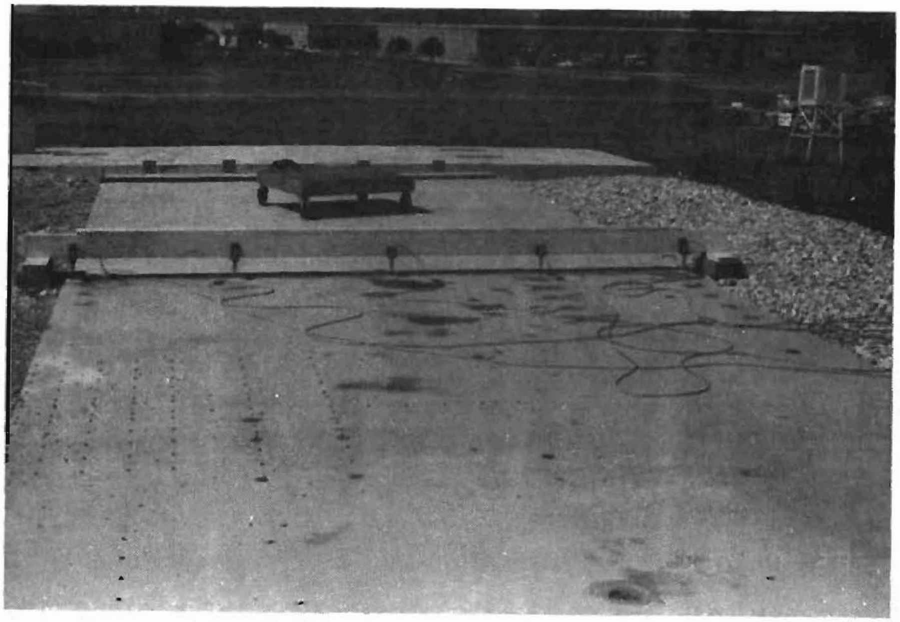
the soil-water mixture. The level of soil moisture is determined by the number of neutrons deflected to the calibrated instrument.

The psychrometer is an instrument used to measure the energy per unit volume required to remove pure water from solution, soil, or any other moist material (Fig 3.4). This energy is called the water potential and the unit of pressure is the "bar," which is equivalent to 10^6 dynes per square centimeter. The instrument uses a small chromel-constantan thermocouple mounted in a hollow porous bulb and a copper-constantan thermocouple for the reference temperature. Water is conducted to the inter surface of the hollow bulb where it evaporates, by electrically heating the bulb, until the humidity approaches 100 percent. The thermocouple is then cooled below the dew point and the evaporated water condenses on the thermocouple. After the cooling is discontinued, the thermocouple voltage inside the bulb is compared with the reference thermocouple voltage to obtain the relative humidity or the wet bulb depression, which is a function of the water potential. An electronic interface is needed to control the current for the heating cycle and the wait times for the heating and cooling cycles.

CURLING MEASUREMENTS

Curling is defined as the differential vertical movement of a slab surface due to environmental conditions, primarily temperature differential. Curling can also be caused by moisture gradients within the slab, although moisture gradients do not tend to change very rapidly.

Surface curling can be measured at this test site by a series of LVDT gages mounted on a wooden beam. Trans-Tek Series 240 transducers (manufactured by Trans-Tek) were used to measure the verical movements of the slab. These transucers can monitor movements of from 0 to 1 inch automatically with input voltages of 3 to 30 volts. The linearity of these transducers is ± 0.57 percent over full working range. The beam is treated and painted to avoid movement during testing due to variations in the beam's moisture content (Fig 3.5). Wood was used for the beam because it is much less susceptible to changes in temperature and thus to warping. Previous tests with aluminum and other materials at the AASHO Road Test (Ref 2) point out that wood is a superior material with regard to warping when properly sealed against moisture. LVDTs are temperature compensated and therefore, for the range of



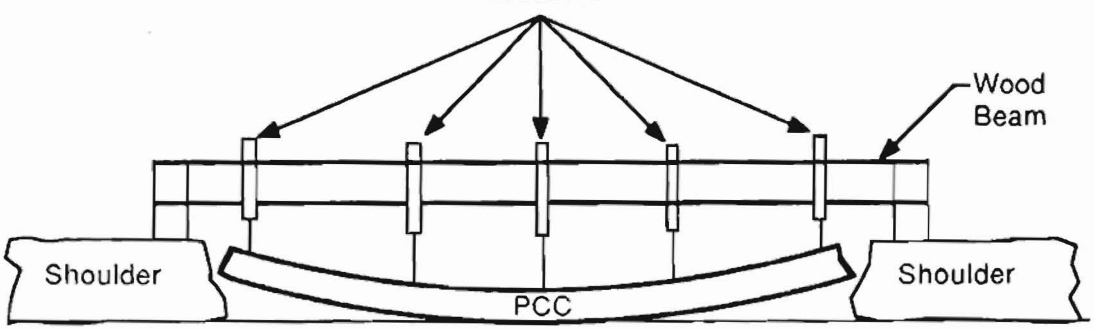


Fig 3.5. Wood beam designed for measurement curling using LVDTs interfaced to an HP data acquisition system for automatic readings.

temperatures encountered at the test site, provide the best method for collecting vertical measurements. Five LVDTs are connected to the Hewlett-Packard data acquisition system, which provides for recording deflection movements in a continuous mode. The time interval between readings can be as low as one minute and as high as one reading every 24 hours. The longest period of time a continuous test can be left running depends on the available disk space and the time interval between readings. Typical reading times for studies at the test site provide reading intervals of 30 minutes for each of the LVDT measurements and for continuous monitoring for up to one week.

WEATHER CONDITIONS

Environmental or weather conditions are very important variables affecting slab and instrumentation behavior. It is important to correlate ambient conditions to temperature and moisture conditions within the test facility and thus to provide potential correlation for long term observations. To cover this need a meteorological station was placed at the southwest corner of the embankment to hold a Belfort hygrothermograph instrument which records the air temperature and the relative humidity in a continuous mode for up to seven days (Fig 3.6). The continuous reading is obtained in the form of a strip chart with ambient temperature and relative hymidity recorded on special graph paper which is divided into hours and days. Resolution is approximately in 30 minute intervals. A Dwyer wind speed indicator was installed on the left front corner of the instrumentation building (Fig 3.7) and the readout is taken from the wind speed panel which was installed on the outside of the building (Fig 3.8). The two instruments listed above are purely mechanical and therefore can not be readily interfaced into the data acquisition system. The ambient temperature is being monitored with the data acquisition system by placing Type "T" thermocouple wire outside the instrumentation building and reading temperature with the Hewlett-Packard thermocouple interface.

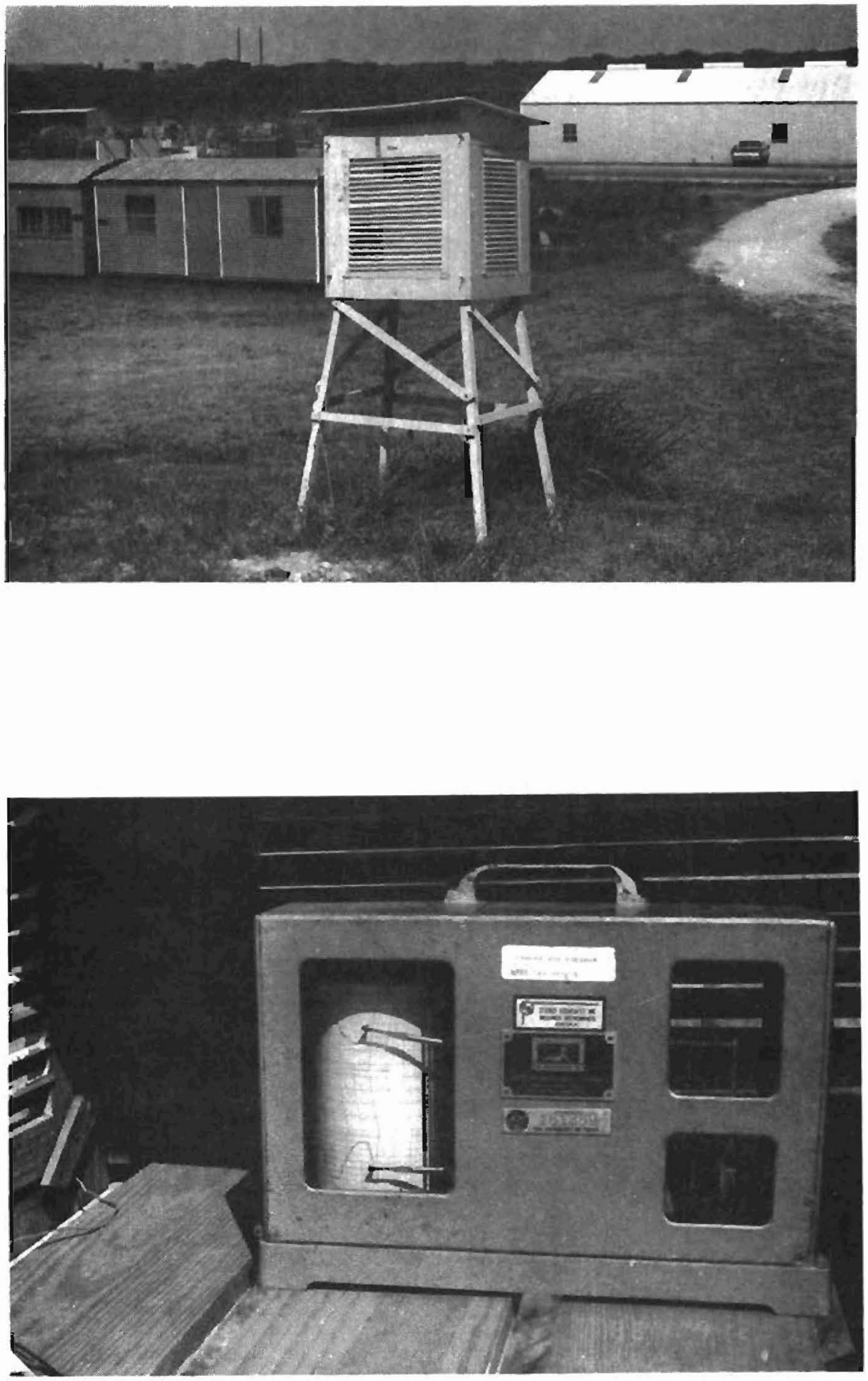


Fig 3.6. Meteorological station general view and hygro-thermograph.

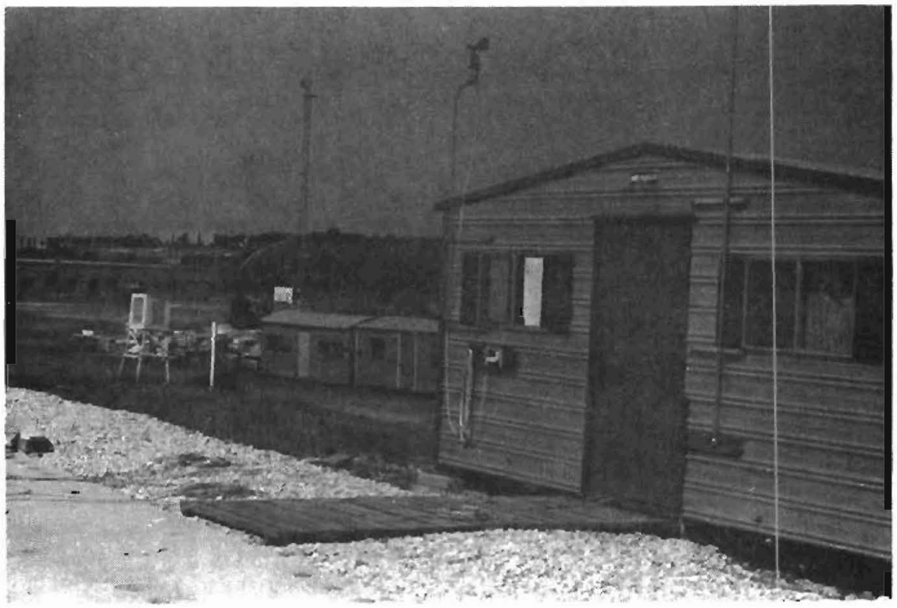


Fig 3.7. General view of the meteorological instruments and the building facility.

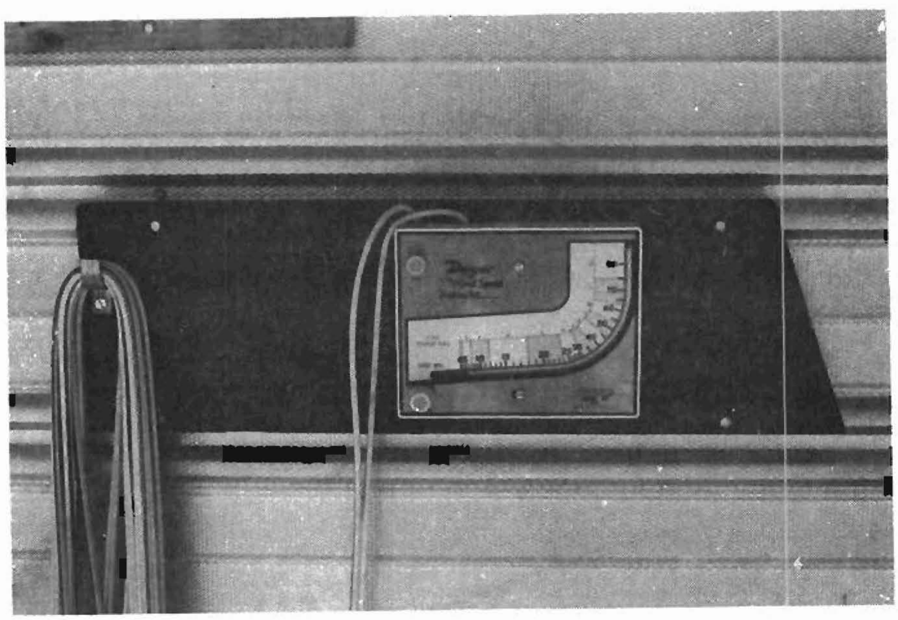


Fig 3.8. Close-up of the wind speed indicator readout panel.

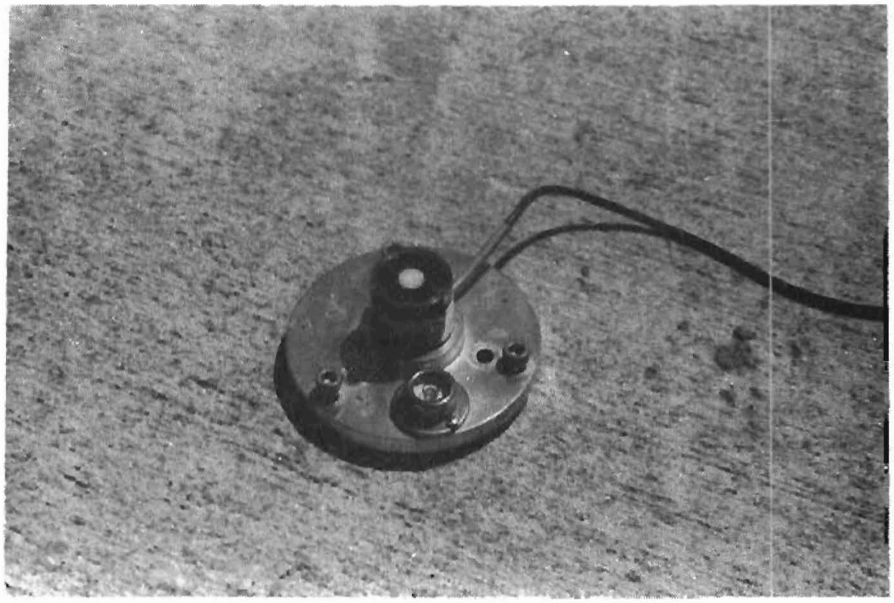
SOLAR RADIATION MONITOR

It was felt that it would be desirable, if at all possible, to examine the effects of solar radiation as they might relate to the environmental conditions in and around the test slab. Since solar radiation has, in previous studies, been shown to affect the absorption of heat within a slab, a LICOR Model LI-1776 solar monitor (Fig 3.9) was installed. This solar monitor is a microprocessor controlled light meter/integrator. Because of its sampling rate both instantaneous and integrated (totalized) measurements can be taken. The integrator totalizes the input signal over a period of time. That is, it determines the accumulated area under the curve of the input signal. For example, if the signal is proportional to solar irradiance in watts per square meter then the output of an integrator over a period of time would be in watt-hours per square meter, or the total accumulated energy per square meter in that time period. Dividing this total by the integration period gives the average watts per square meter over that period. The standard integration period of the LI-1776 is factory set at 24 hours. A different integration period can be chosen at the time the device is ordered. If an interface option is installed, the user can select one of nine integration periods for the LI-1776. We chose the 24-hour period because of its convenience in our time cycle.

The memory storage capacity of the standard LI-1776 is for 117 integration periods. Direct readout of both instantaneous and integrated radiation measurements is also possible with this instrument. Data are automatically stored and retained in the memory as long as power is supplied to the instrument and the data can be easily recalled from memory and displayed. The display control switches can be used in any combination of settings without losing data or interrupting the integration process.

DEFLECTION MEASUREMENTS

In order to compare the responses of various deflection measuring devices on the test slab, it is essential to have independent means of measuring deflection within the slab. Given such independent deflection measurements, it is possible to compare the results of the FWD, Road Rater, Dynaflect, and other such devices (Fig 3.10). Based on a wide variety of previous experience, the instrument chosen to measure these deflections is the DC-LVDT (direct



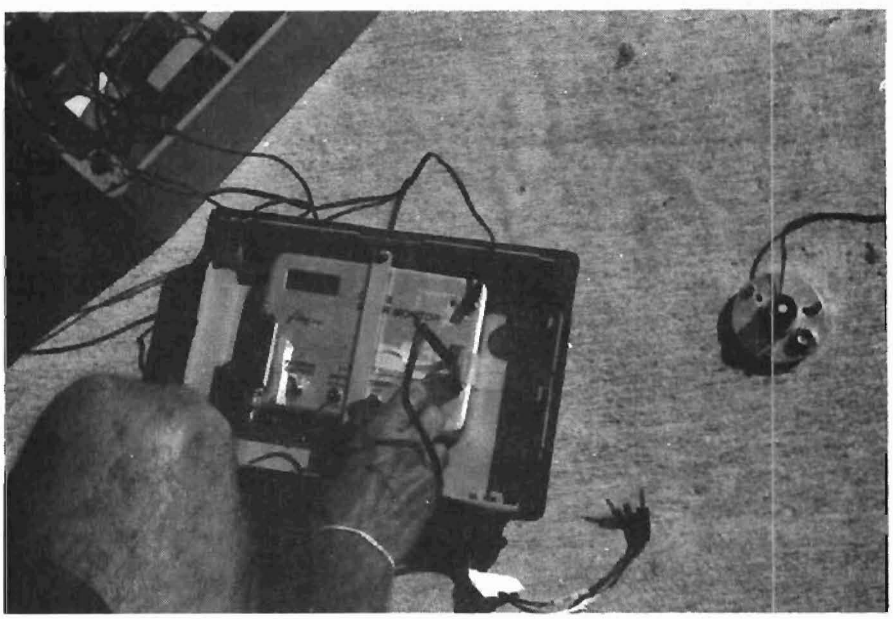


Fig 3.9. Solar radiation sensor and digital-programmable readout.

Fig 3.10. Static loading by means of a single axle dual tire truck.

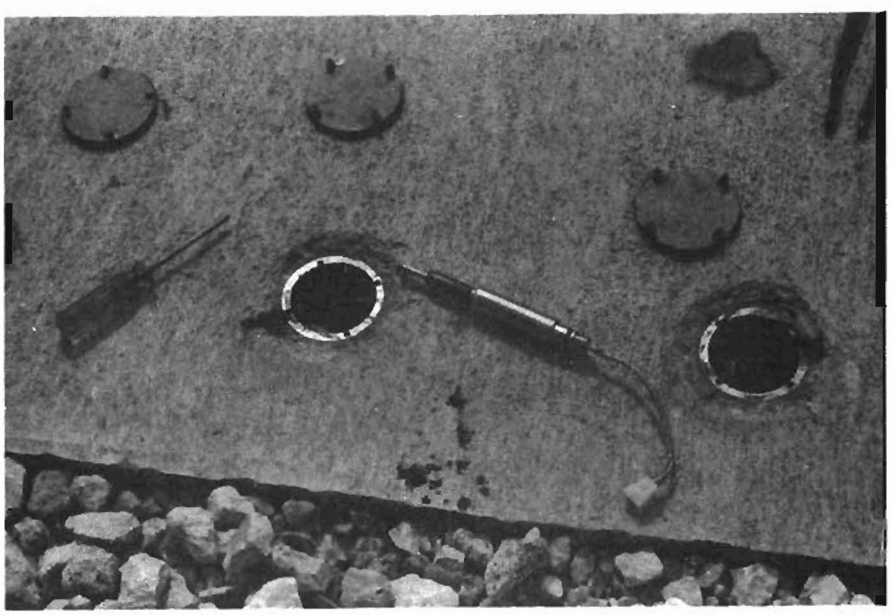


Fig 3.11. DC-LVDT and the holding unit cast in the slab.

current-linear variable differential transformer) (Fig 3.11). The Schaevitz Model GCD-121-050 LVDT (manufactured by Schaevitz) was chosen to monitor these deflections. These LVDT's operate on input voltages of ± 15V DC and have a working range of ±0.050 inches. The linearity over full range is ±0.25 percent and the operating temperatures are from 0°F to 160°F.

A special holding unit was designed by project personnel (Fig 3.11) to hold the LVDT rigid and vertically aligned within the concrete pavement during testing. It is necessary to install the LVDTs during the test and to remove them when tests are not in progress since they can be damaged by moisture and exposure to the elements. The holding units are constructed of steel welded together and cast in place in the pavement. When the pavement deflects, the entire holding unit deflects with it. The core of the LVDT rests on a reference rod buried to a 10-foot depth in the bedrock. The motion of the pavement relative to the reference rod is detected by the LVDT. The LVDTs are mounted inside the pavement to allow room for other equipment on the pavement surface.

Deflection measurements are monitored at up to thirty locations on the pavement, as shown in Fig 3.12. At the joint on the no-void side of the pavement there are two sets of six LVDT holding units each (one set at the edge and one set in the wheel path). There is also one set of five LVDT holding units at the pavement edge away from the joint and two sets of three LVDT holding units in the pavement wheel path away from the joint (these are clearly shown in Fig 3.12).

On the void side of the pavement there is one set of four LVDT holding units at the joint and one set of three LVDT holding units at the edge away from the joint. These are for the LVDTs for measuring the effect of the two voids. The LVDT gage heads are waterproof encased in stainless steel, and removable to permit extended outdoor use and for safe storage.

ELECTRONIC INSTRUMENTATION AND DATA ACQUISITION SYSTEMS

The instruments in place in the slab at the Balcones Research Center site consist of linear variable differential transformers, type "T" thermocouples, psychrometers, and moisture cells. These instruments have been previously described in this report. In addition, future projects may use embedded or surface strain gages to monitor movement due to external and internal forces. The following information concerns the wiring considerations, the attributes, and the limitation of the two acquisition systems available.

All of the wiring within the slab is channeled through PVC ducts and out of the slab into the instrumentation building. The wiring terminates at an instrumentation panel (Fig 3.14) to which power is supplied, by individual power supplies. The power is then routed to the individual instruments (Fig 3.14).

Signals from the instruments reach the acquisition systems by one of two paths. The MassComp system is connected to the instrumentation panel via a ribbon cable. Signals can be read and processed by patching an instrument location into the appropriate ribbon cable terminal on the instrumentation panel's front panel. The Hewlett–Packard system contains modules which can be connected from the instrumentation panel to the appropriate module and channel location for reading and processing the instrument signal.

The MassComp Model MC-500 acquisition system (Figs 3.16 and 3.17) is the faster system as far as data acquisition rates are concerned. Typical read speeds are from 100k Hz to 1M Hz for signal channel monitoring. It also has more storage space than the Hewlett–Packard system (Fig 3.15) as well as graphics capabilities. It can also be connected to a mainframe at The University of Texas via a telephone line and modem to provide quick access for data to be analyzed and to cut down on manhours necessary to transfer data via a keyboard. The MassComp system also has both A to D and D to A converters on board. It can monitor up to 15 channels of A to D signals and up to 4 channels of D to A signals.

The main limitations of the MassComp acquisition system are the level of programming expertise necessary to make the system function efficiently, and the software and hardware bugs found in the system in its present configuration. The first channel selected to be read is not always accessed and therefore data can be skewed. This is a major reliability problem when trying to obtain continuous read data. The system is also unable to read the microvolt signals from instruments such as the thermocouples, psychrometers, and strain gages without additional modules to condition the signals. This system is not portable because of its physical weight and the hard disk drive which is mounted inside the acquisition system.

In comparison, the Hewlett–Packard data acquisition system (Fig 3.13) is relatively easy to program and use. The HP system consists of a Model 3497A acquisition unit and a Model 150 computer. It is a portable unit which makes collection and storage of data at other field locations possible. The modules for reading microvolt signals from thermocouples, LVDTs, and strain gages at the time of this report were present and functional. Twenty

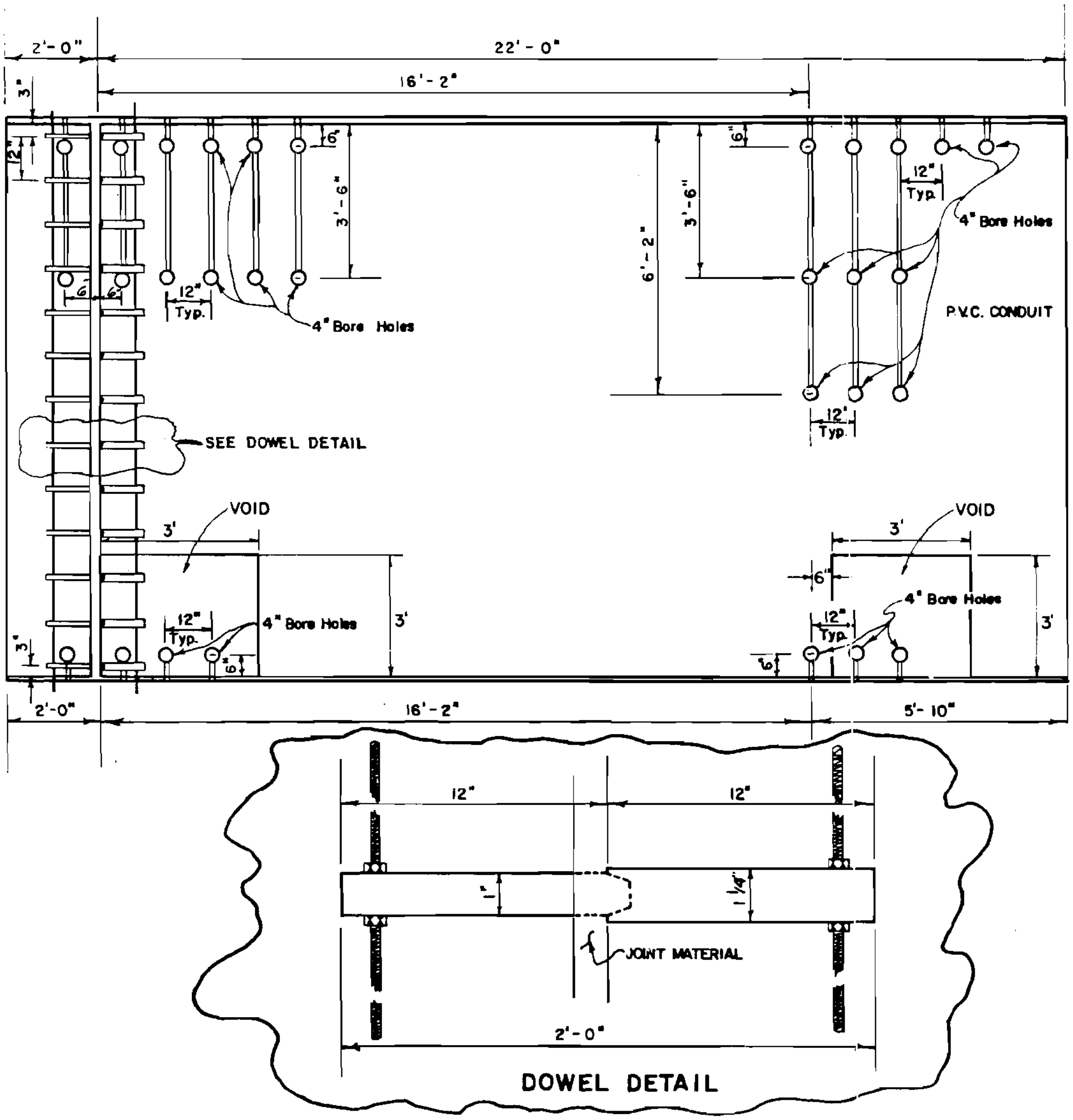


Fig 3.12. Slab details.

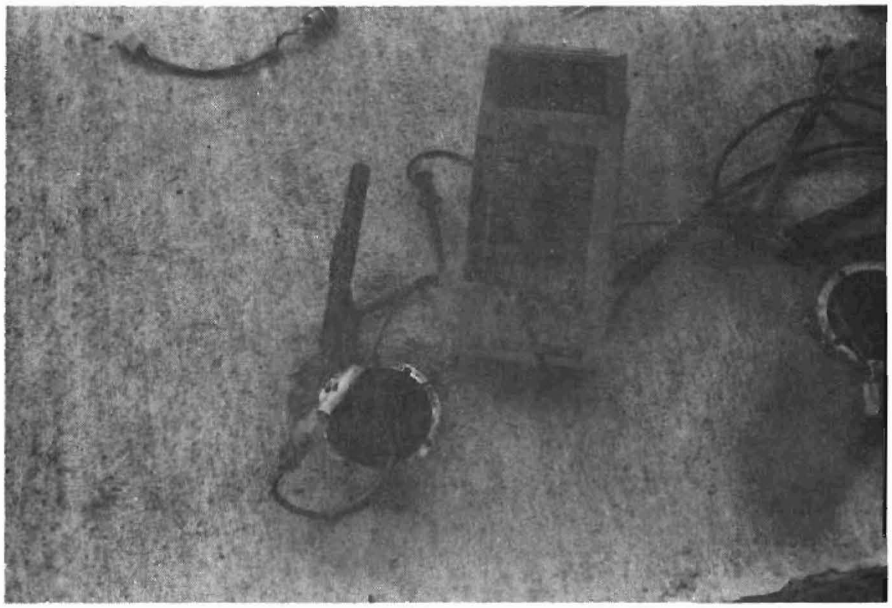


Fig 3.13. DC-LVDT being zeroed before testing begins.

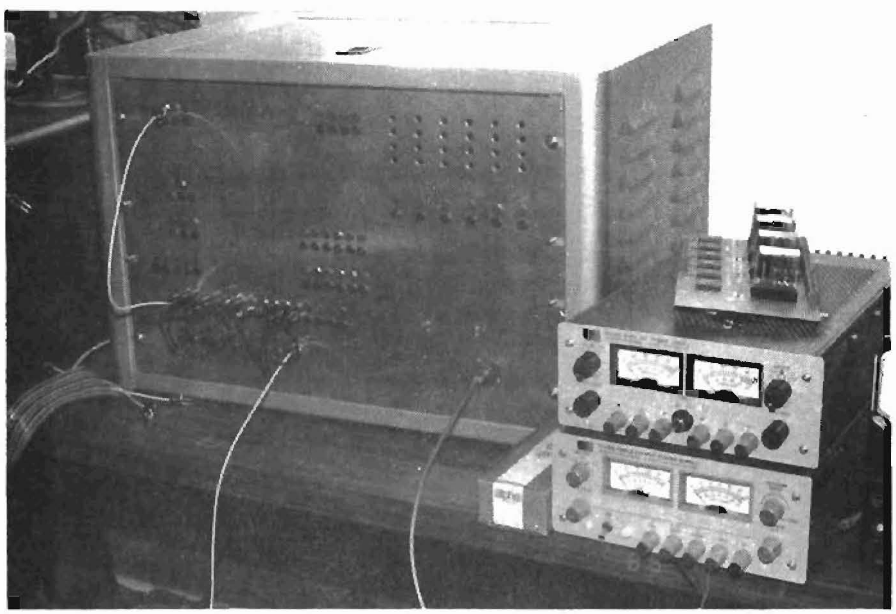


Fig 3.14. Instrumentation panel and power supply.

Fig 3.15. HP data acquisition system.

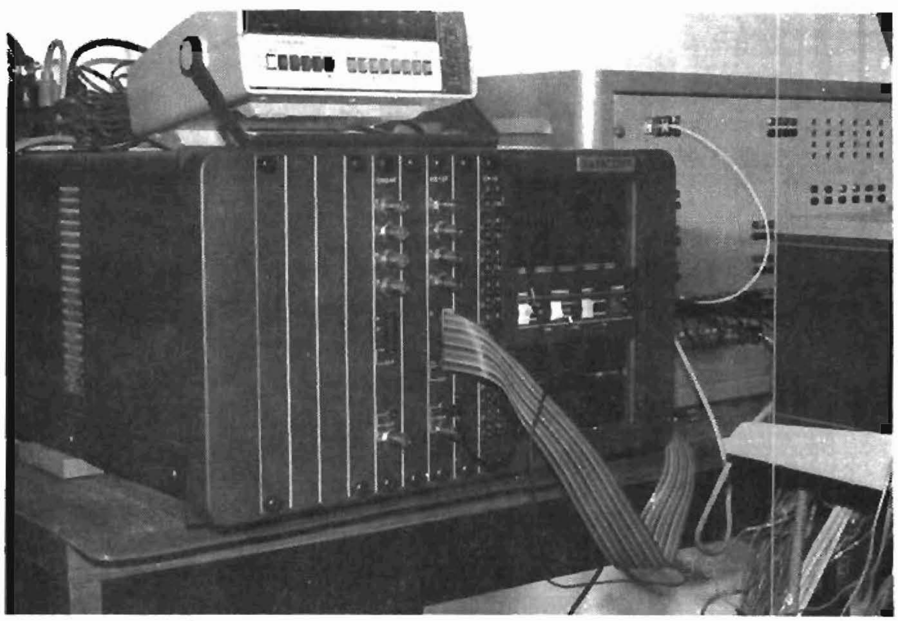


Fig 3.16. MassComp data acquisition system (A/D converter, had disk, disk drive, and input/output terminals.

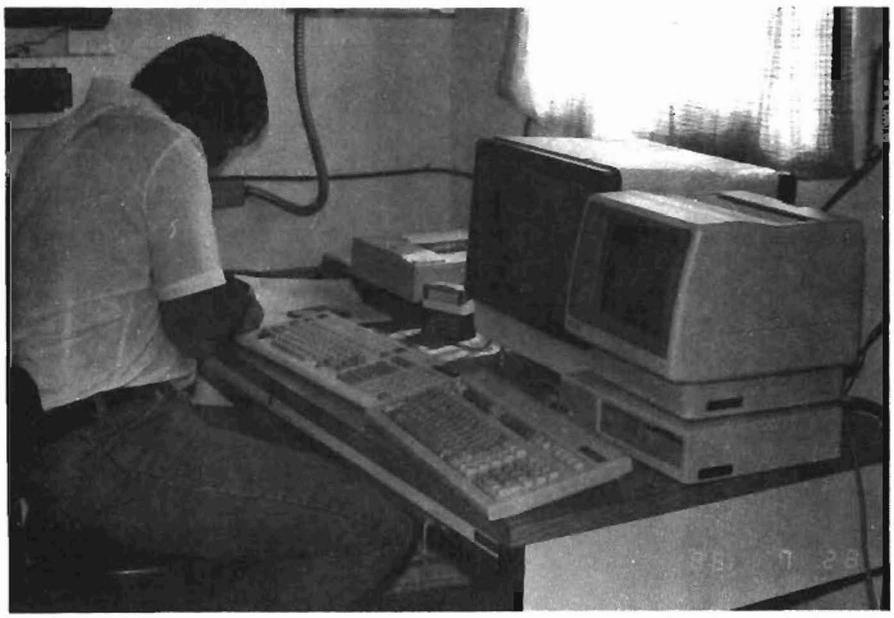


Fig 3.17. MassComp monitor, keyboard, and printer (left) and HP computer CPU and dual disk drive (right).

channels of LVDT's and strain gages can be connected and read, along with 19 channels of temperature in the present configuration.

This system can also be linked to the mainframes at The University of Texas at Austin via a telephone line, modem, and communication software. However, the access speed per channel of the Hewlett–Packard system is very slow when compared to the MassComp system. The HP system can read 10 to 12 channels per second with double precision. This means that the Hewlett–Packard System can not provide a function such as taking LVDT deflection readings from the FWD for comparison. The storage space for the Hewlett–Packard programs, vis-a-vis the amount of data the system can hold, is limited by the size of the single-sided 3.5-inch floppy disks.

CHAPTER 4. DATA COLLECTION

TEST SITE

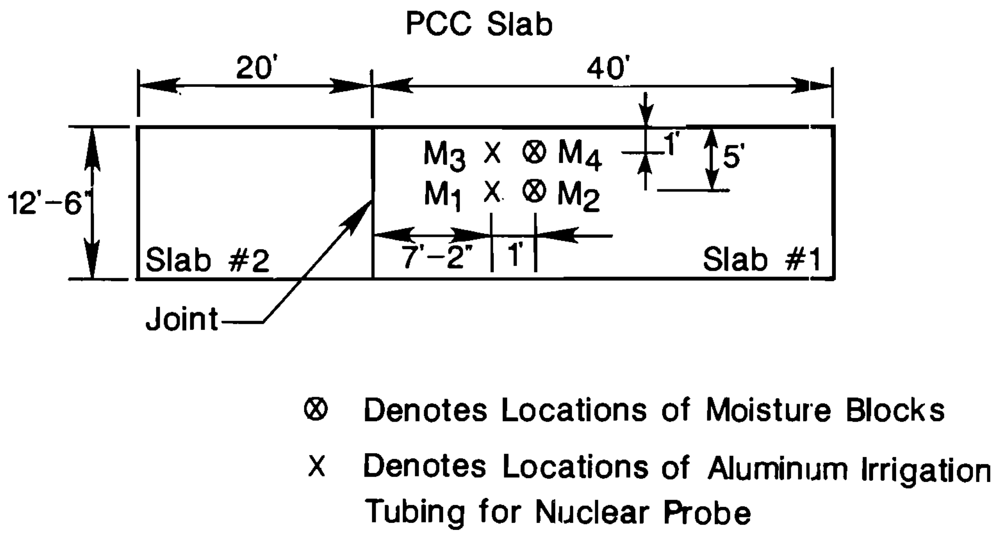
A general layout of the test slab is shown in Fig 4.1. The current testing facility includes a jointed concrete slab as previously described. The 10-inch-thick slab is in two sections. Both of these sections rest on a 3–inch–thick asphalt mix base. One section is 12 feet, 6 inches wide by 39 feet, 6 inches long and is anchored at one end. The other, movable, slab is 12 feet, 6 inches wide by 18 feet, 10 inches long with a thin plastic sheet in between the slab and the base. The details of the slab are described in Research Report 355-1 (Ref 1). The slab is instrumented with the following instruments, as described in Chapter 3.

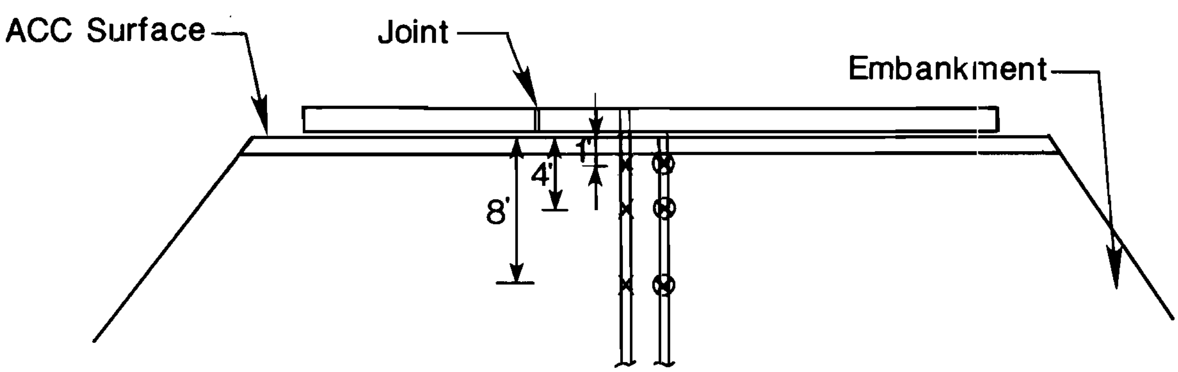
(1) DCDT rods anchored to the foundation rock for recording vertical movement of slabs.
(2) Moisture blocks and psychrometers to record the moisture content of fill and foundation material.
(3) Thermocouples to record the pavement temperature at the top, bottom, and mid-depth of the slab.
(4) LVDTs for measuring curling.

A detailed description of these elements is presented in Research Report 355-1 (Ref 1) and in Chapter 3 of this report.

TEST DATA

Through the end of the initial project, August 31, 1986, the test slab was used to collect data for several projects. Among these, the most frequent users were Project 3-8-84-387, entitled "Purchase and Adapting a Falling Weight Deflectometer for Non-destructive Evaluation and Research on Rigid Pavements in Texas," and Project 3-8-84-401, entitled "Prestressed Concrete Pavement Design - Design and Construction of Overlay Applications." Two new projects (Project 3-8-86-459, "Development of Subbase Friction Information for Use in Design of Concrete Pavement," and Project 3-8-86-460, "Assessment of Load





(Figures are not to scale).

Fig 4.1. Location of moisture detection devices under the pavement.

Transfer Across Joints and Cracks in Rigid Pavements Using the Falling Weight Deflectometer") are currently using the facility very extensively. To date, the following data items have been collected from the test site:

(1) moisture data for soil moisture profile,
(2) slab temperature and curling data,
(3) FWD and Dynaflect data,
(4) surface wave data, and
(5) meteorological data (air temperature, relative humidity, and rainfall.

The following paragraphs summarize the data collected at the site.

(1) Moisture Data for Soil Moisture Profile. Figure 4.1 shows the location of moisture detection devices under the test slab. Moisture blocks were placed at depths of 1, 4, and 8 feet from the surface, as indicated by M_2 and M_4 in the figure. Also, thin walled aluminum tubes were placed in the slab so that nuclear probes can be used to measure the moisture at various depths under the pavement. Moisture blocks located at M_2 and M_4 were used to measure the moisture contents of the soil layers underneath the pavement. Nuclear probes have not been used to date to measure the moisture content under the test slab. A summary of data recorded in the period between November 1984 and July 1986 is shown in Table 4.1. The raw data are available in Project 355 data files at the Center for Transporation Research.

A study of these records indicates that the moisture content readings of two moisture blocks differ considerably at depths of one and 4 feet. However, at a depth of 8 feet, the readings were consistent until July 5, 1985. The data recorded after October 25, 1985, however, show large differences between the two readings. Further study of these devices is required to determine the cause of such differencein the two observations.

(2) Slab Temperature and Curling Data. Twelve theromocouples were embedded in the test slab to measure the temperature distribution across the slab depth. The locations of these devices are shown in Fig 4.2. A total of five LVDTs were mounted on a wooden beam which spanned the width of the slab and rested on the gravel shoulder adjacent to the slab. These LVDTs are used to measure the curling of test slab. The locations of these LVDTs on the

TABLE 4.1. MOISTURE DATA, SLAB 1 (SEE FIG 4.1 FOR LOCATIONS OF MOISTURE DETECTION DEVICES)

	Sensors Identification											
	1M2 (No. 5)		4M2 (No. 3)		8M2 (No. 7)		1M4 (No. 6)		4M4 (No. 4)		8M4 (No. 8)	
	a 93.11	b 5.81	a 64.62	b 3.69	a 59.52	b 3.39	a 65.53	b 3.92	a 68.85	b 4.04	a 123.58	b 7.95
Date	Read (MΩ)	Percent	Read (MΩ)	Percent	Read (MΩ)	Percent	Read (MΩ)	Percent	Read (MΩ)	Percent	Read (MΩ)	Percent
11/13/84	0.82	13.9	10.40	5.0	1.67	10.9	7.90	3.3	11.50	3.2	1.33	11.7
12/13/84	1.88	9.2	5.28	7.5	1.76	10.8	1.46	3.5	5.35	6.3	1.50	10.5
01/18/85	1.91	9.1	4.36	8.2	2.26	9.9	10.65	2.1	3.35	8.2	1.40	11.1
03/13/85	2.09	8.6	5.37	7.4	2.53	9.5	10.45	2.2	2.38	9.5	1.61	9.9
06/03/85	0.50	16.8	3.95	8.5	1.23	11.9	1.95	8.7	0.64	14.8	1.27	11.8
07/05/85	0.38	18.5	3.18	9.4	3.10	8.8	1.74	9.2	.170	20.2	1.82	8.9
10/25/85	0.08	27.0	0.59	15.5	0.02	26.5	0.59	13.4	.014	30.3	.016	46.6
11/08/85	0.09	26.0	0.77	14.6	0.08	21.3	0.19	17.8	.003	36.7	.015	47.1
11/25/85	0.09	26.0	0.33	17.7	0.02	26.5	0.17	18.4	.012	31.2	.013	48.3
01/16/86	0.003	46.6	0.85	14.2	0.05	22.6	0.55	13.7	.285	18.1	.001	68.6
07/18/86	0.005	43.6	0.18	19.9	0.004	31.4	0.01	27.8	.028	27.5	.007	53.2

beam and the position of the beam in the slab are shown in Fig 4.2, along with the thermocouples.

At the present time only nine thermocouples located at T_1, T_2, and T_3 were read. At each location there are three thermocouples which are installed at different depths as shown in Fig 4.2. The depths, measured from the surface of the slab, are 1, 5, and 9 inches. These thermocouples are referred to as T_{top}, T_{mid}, and T_{bot}.

All these devices were connected to the HP data acquisition system and HP microcomputer so that the data could be read and stored automatically.

Whenever this test was conducted, the air temperature as well as the relative humidity was recorded on a separate chart of a mechanical metereological station. A typical record of this data is shown in Fig 4.3. A typical plot of thermocouple data recorded during the month of April 1986 is shown in Fig 4.4.

Figure 4.5(a) and (b) show the typical plots of LVDT data recorded during the month of April 1986. These data can be used to study the curling of the slab due to temperature changes during the day.

All the data collected on these items are available in Project 460 files at the Center for Transportation Research.

(3) FWD and Dynaflect Data. Figure 4.6 shows the positions of FWD and Dynaflect equipment on the test slab when recording deflection data for assessing the load transfer across the joint. The data collection started in January 1985 and records are stored in Project 355 files. In July 1986, a plan for testing the slab using the FWD was developed in connection with Project 460. A copy of this plan is included in Appendix B. The summary of data collected at the test slab through July, 1986, is also enclosed in Appendix B.

A typical plot of data obtained from measurements at test slab is shown in Fig 4.7. This figure shows the variation in deflections as measured by seven sensors of the FWD at different times of the day.

(4) Surface Wave Data. Surface wave data have been collected at the test site in connection with Project 437. The equipment as well as the analytical procedures are described in a research report on this project to be published soon. Data from this test are available in Project 437 files at the Center for Transportation Research.

Test arrays were marked and installed on the test slabs at the BRC site, as shown in Fig 4.8. A total of six locations were thus established. The details of a typical test array

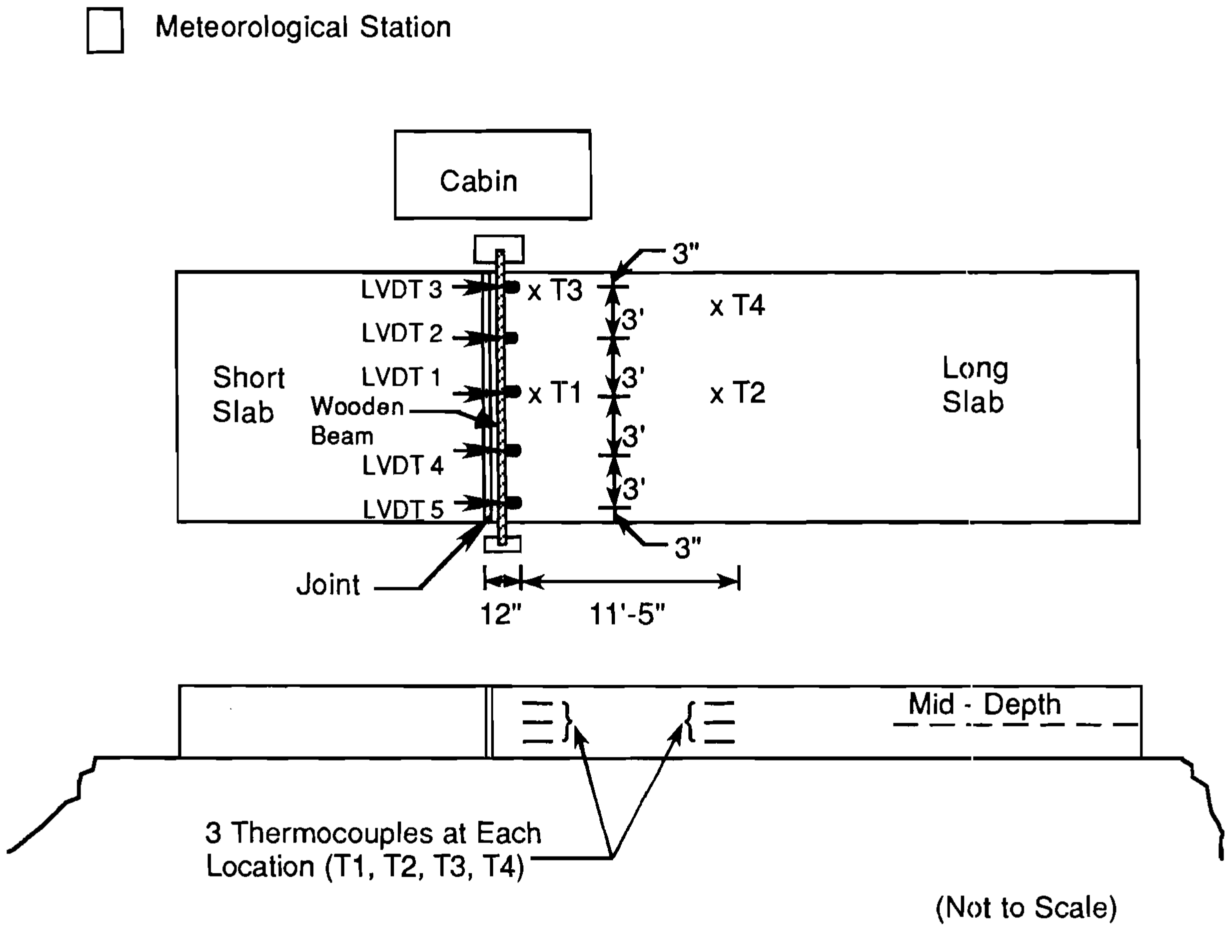


Fig 4.2. Location of the thermocouples and disposition of the LVDTs.

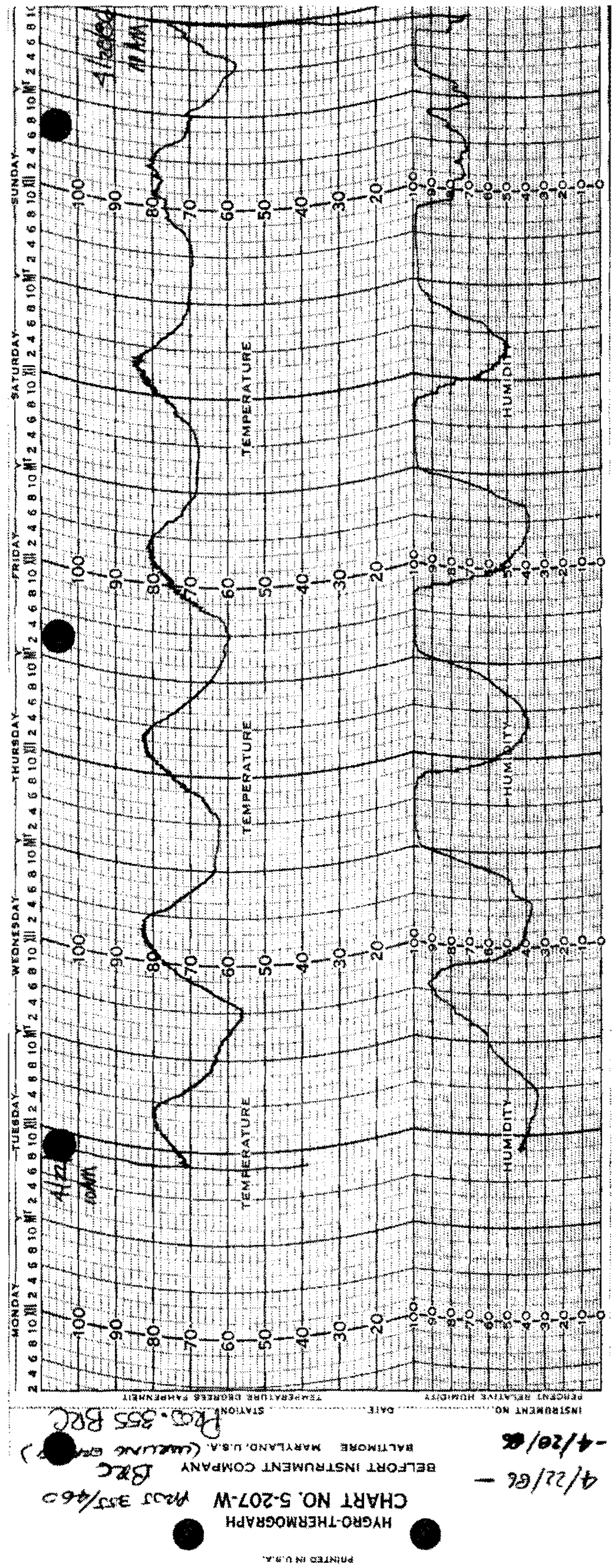


Fig 4.3. Example of the strip chart of the metrological station.

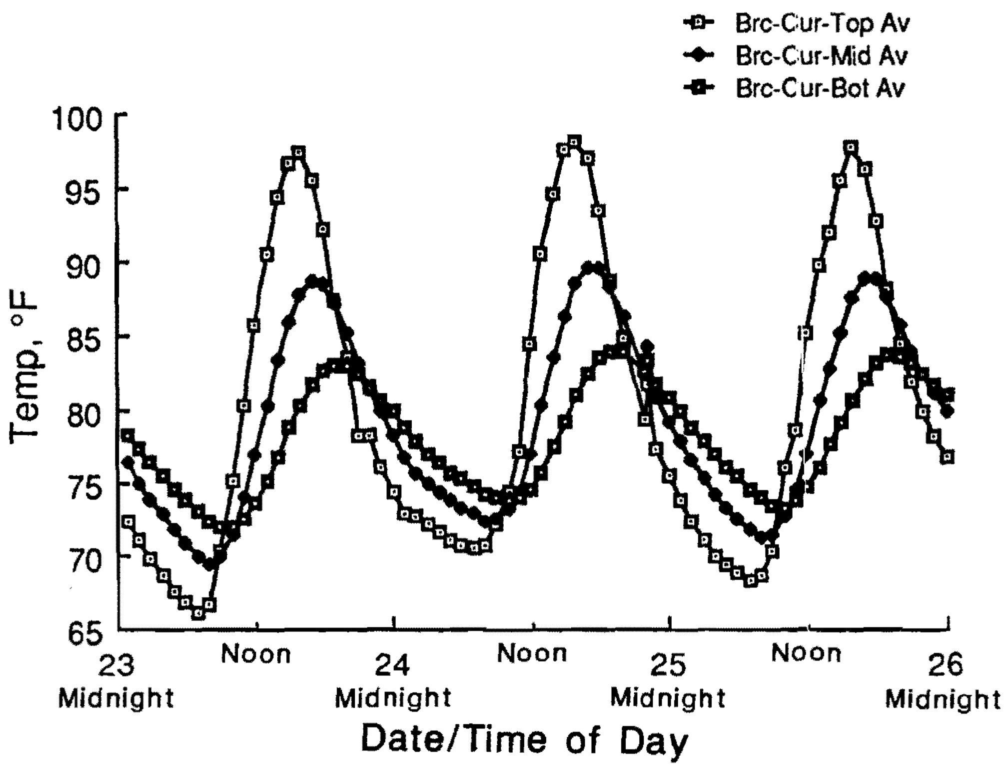


Fig 4.4. A typical plot of thermocouple data recorded during the month of April 1986 (BRC test slab).

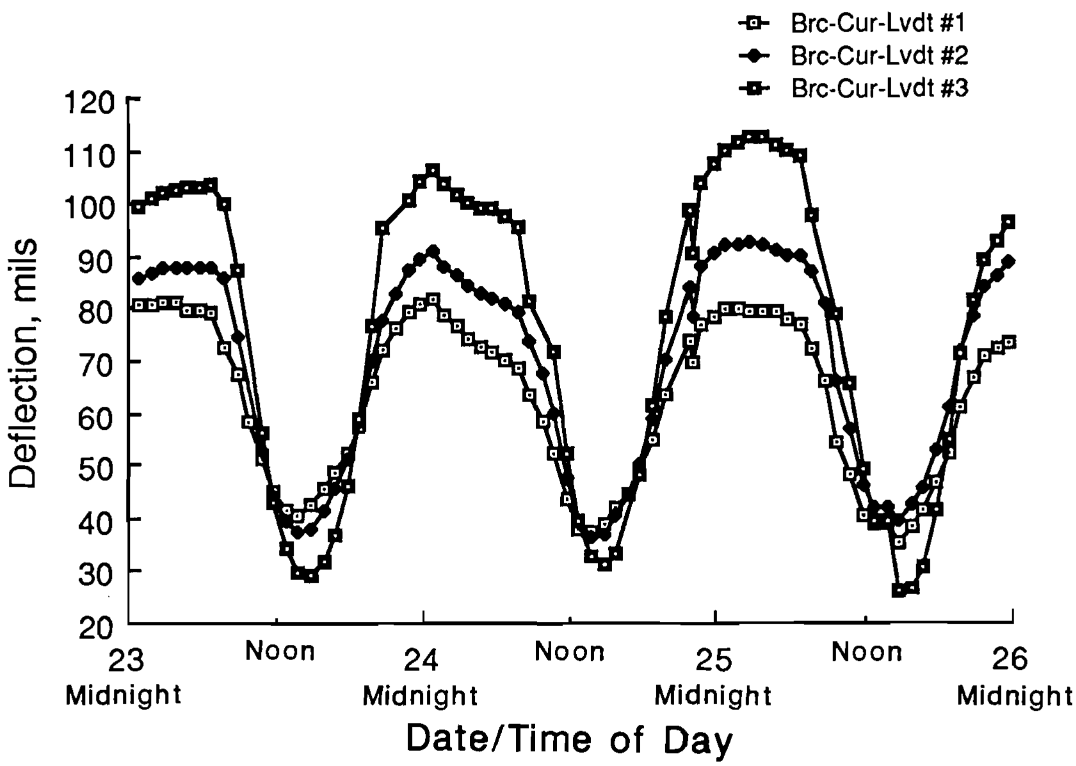


Fig 4.5(a). A typical plot of LVDT data recorded during the month of April 1986 (LVDT Nos. 1, 2, and 3) to measure the deflections caused by curling of pavement (BRC test slab).

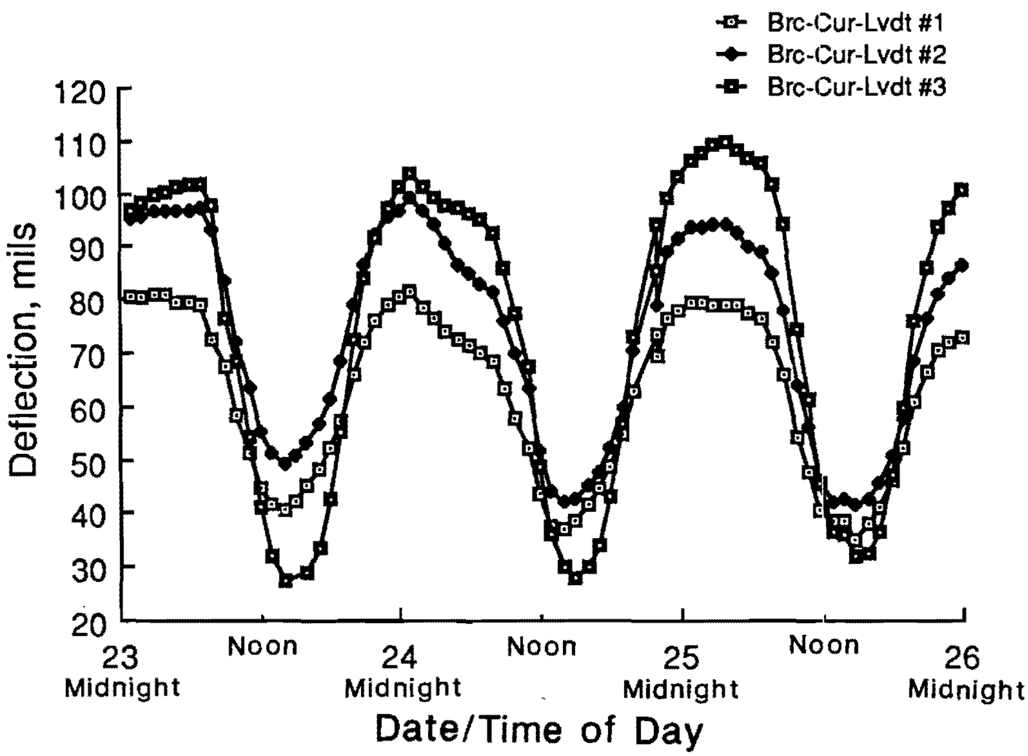


Fig 4.5(b). A typical plot of LVDT data recorded during the month of April 1986 (LVDT Nos. 1, 4, and 5) to measure the deflections caused by curling of pavement (BRC test slab).

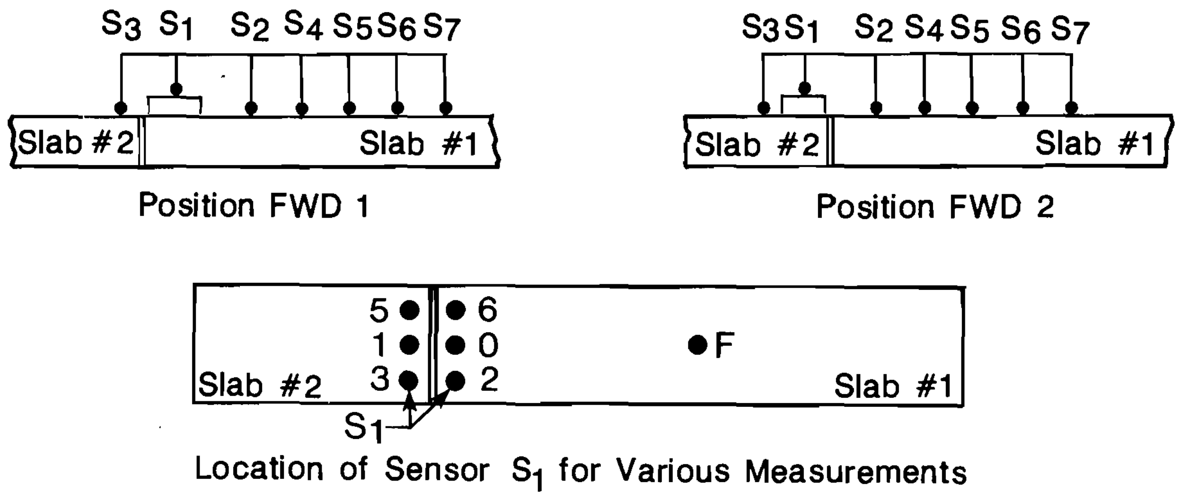


Fig 4.6. Typical positions of FWD and Dynaflect equipment to measure pavement deflections.

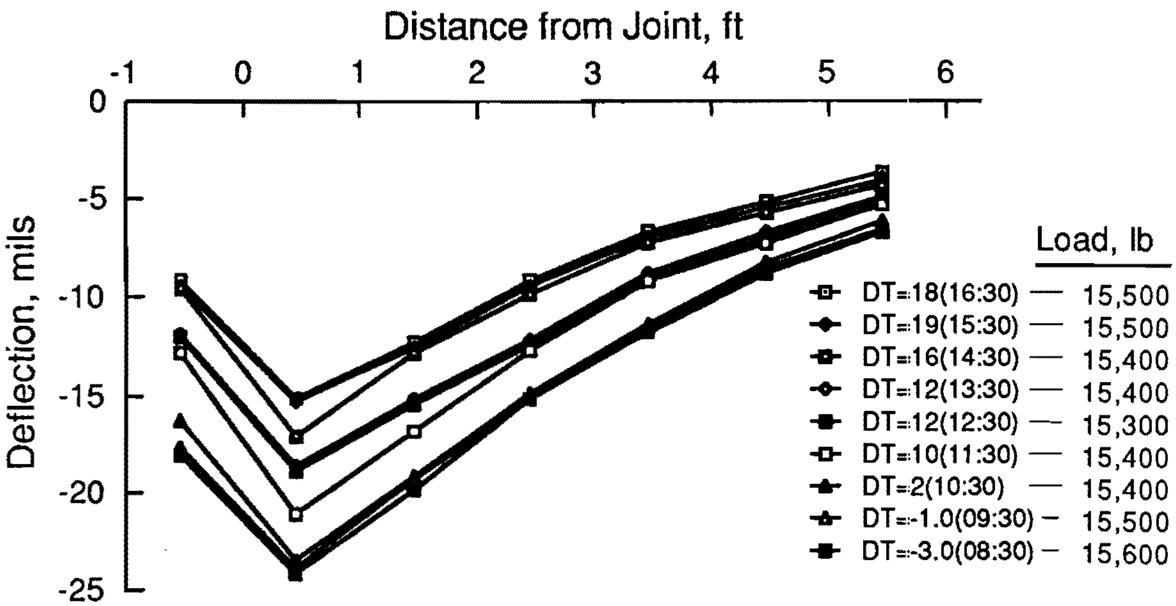


Fig 4.7. Typical plot of FWD data at various times of the day (BRC test slab, FWD location # 2 as shown in Fig 4.6).

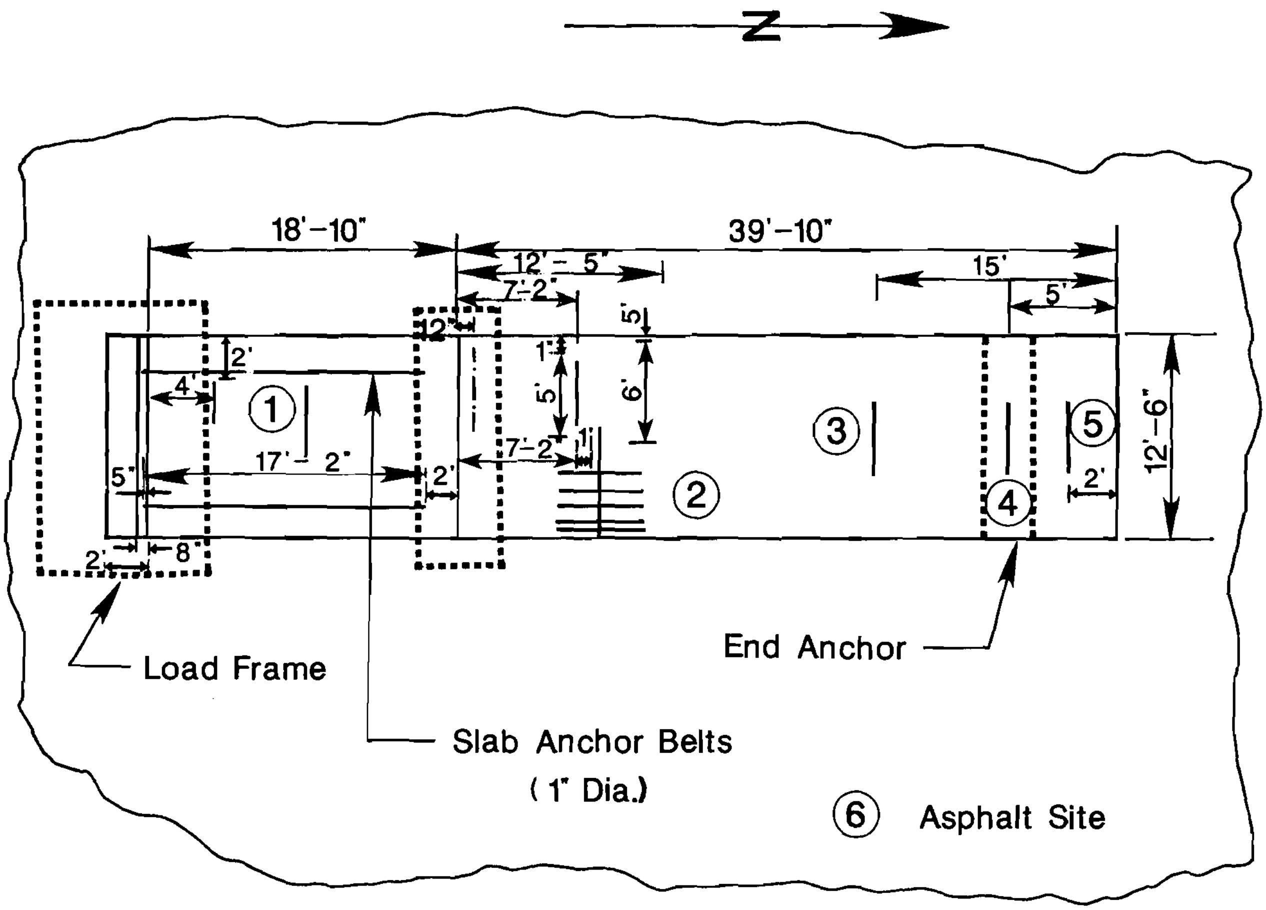


Fig 4.8. Six locations of test arrays on BRC slab and embankment for measuring layer characteristics using Surface Wave method.

(location number 2) are shown in Fig 4.9. The results of measurements taken at these locations will be reported in the research report on Project 437.

(5) Meteorological Data. A weather station was installed at the test slab site to collect air temperature, relative humidity, rainfall, and solar radiation data. These instruments are generally operated whenever there is the need, and consequently specific data on these items are generally recorded with the data items of primary concern.

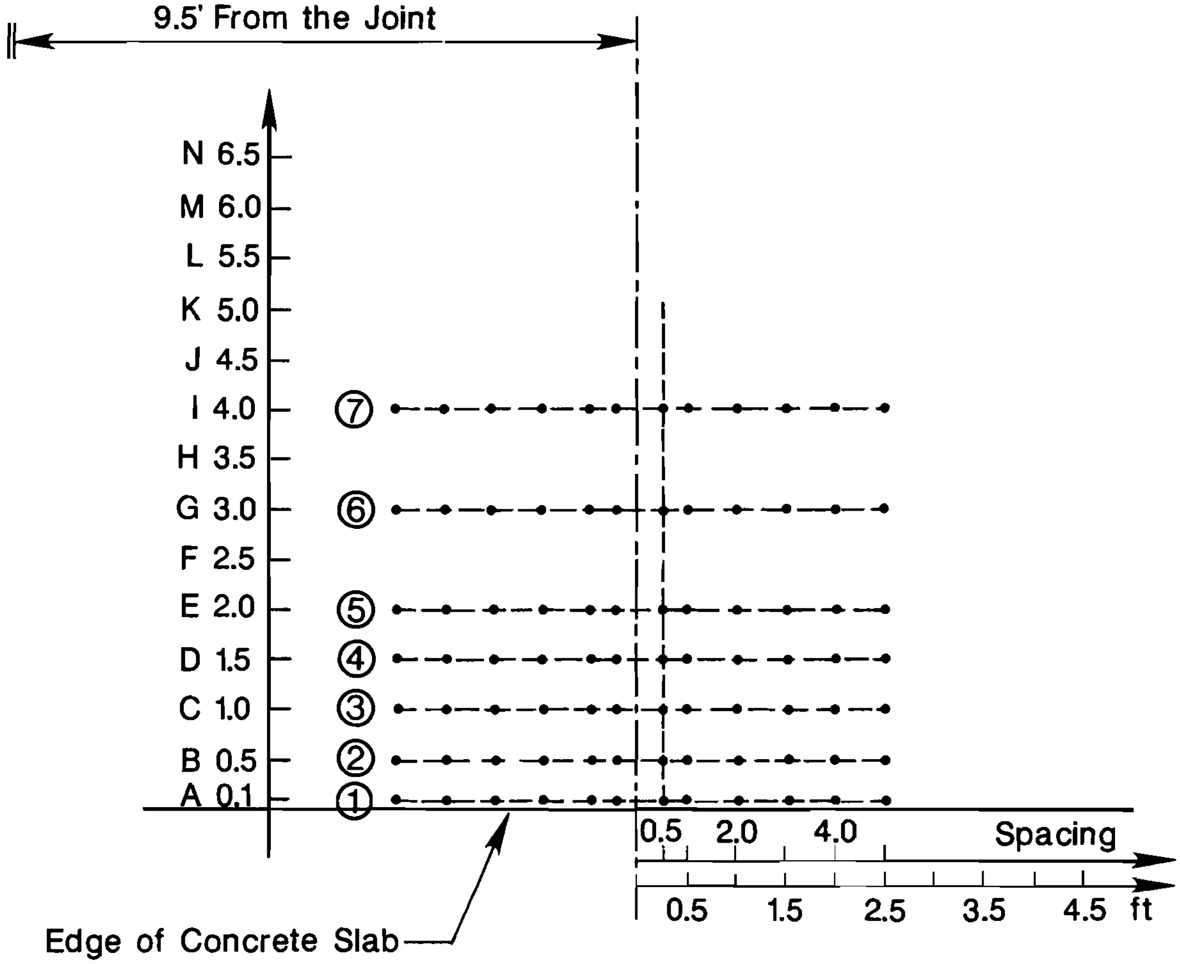


Fig 4.9. Detailed layout of location 2.

CHAPTER 5. SUMMARY

There is a wide variety of non-destructive instruments for evaluating portland cement concrete pavements. Each of these devices is claimed by its manufacturer to have excellent capabilities. However, no really good way of comparing the results of equipment testing against the expectation has been available for use by the State Department of Highways and Public Transportation.

This research report describes a test facility which has been designed and constructed as a part of Research Project 3-8-83-355, entitled "Pavement Slab for Deflection Device Testing." This test facility provides the capability for measuring the actual deflection of the slab using buried deflection reference rods and LVDTs while providing the capability for monitoring pavement temperature and moisture conditions within the subgrade. This capability makes it possible to examine the true deflected shape of the slab and compare it to various outputs of available equipment for surface deflection measurements. This report describes the instrumentation available and describes the use of the slab through its first year, which ended August 31, 1986. The results today are quite promising and the results are already being implemented by the State Department of Highways and Public transportation.

The facility has also served as a useful study for other projects by giving researchers the opportunity to improve on their ideas, look at instrumentation, and analyze important variables that may have a bearing on their future full-scale work. A number of pilot tests have been conducted for measurement to help estimate the magnitude of certain field variables.

> Project 401 -- "Prestressed Concrete Pavement Design and Construction of Overlay Applications." For this project, a small prestressed concrete test slab was constructed on the south part of the facility and used to test the functioning of instrumentation equipment to be implemented at Waco, the overlay project, and to verify predicted strengths of concrete against zone failure.
>
> Project 387 -- "Purchasing and Adapting a Falling Weight Deflectometer for Non-Destructive Evaluation and Research on Rigid Pavements in Texas." This project has been intensely using the research facility, collecting data with the FWD and Dynaflect for load transfer efficiency and for structural characterization of the soil properties.

Project 459 -- "Development of Subbase Friction Information for Use in Design of Concrete Pavement." This project has been building a small slab (Fig 5.1) and using the data acquisition system and the project personnel. Instead of the traditional push-off test to measure subbase friction, this experiment will measure subbase friction indirectly under actual behavior due to temperature variations. Movements, change in temperature, modulus of elasticity, and the coefficient of thermal expansion will be measured; then these variables will be input into a computer program and the friction-force profile will be adjusted until the generated movements match the actual movements. The change in temperature will be obtained artificially using a kerosine heater inside a small temperature chamber. One end of the slab is pinned to an anchor below to, in effect, double the size of the slab. Vertical movements will also be measured to monitor curling effects.

Project 460 -- "Assessment of Load Transfer Across Joints and Cracks in Rigid Pavements Using the FWD." The testing facility at Balcones Research Center is being used extensively by this project to:

(1) study the effect a temperature differential in on the pavement slab has on the deflections measured with the FWD (curling effects).

(2) evaluate longitudinal joints by means of the FWD.

Figures 5.2, 5.3, and 5.4 show the FWD being operated at the testing facility with the purposes already mentioned, as well as the interior of the FWD van.

The testing facility is being used for both aspects of the project as it offers an excellent testing site for such studies and has the following features:

(1) Thermocouples buried in the slab (located at four different locations and at three different depths within each location), that measure the slab temperature at all the locations.

(2) Devices and corresponding instrumentation that measure the temperature of the slab (at each of the already mentioned thermocouples), the ambient air

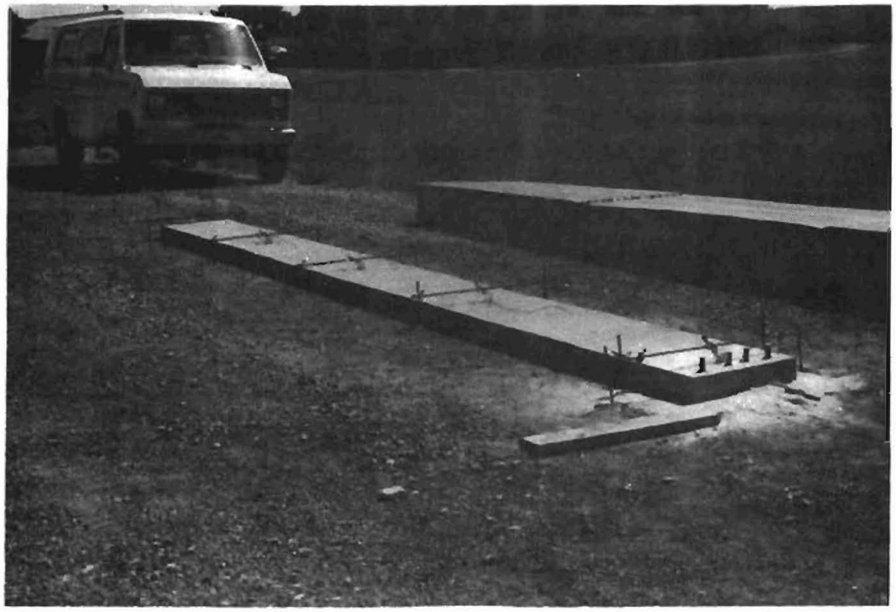


Fig 5.1. Project 459 pilot concrete slab to measure base friction.

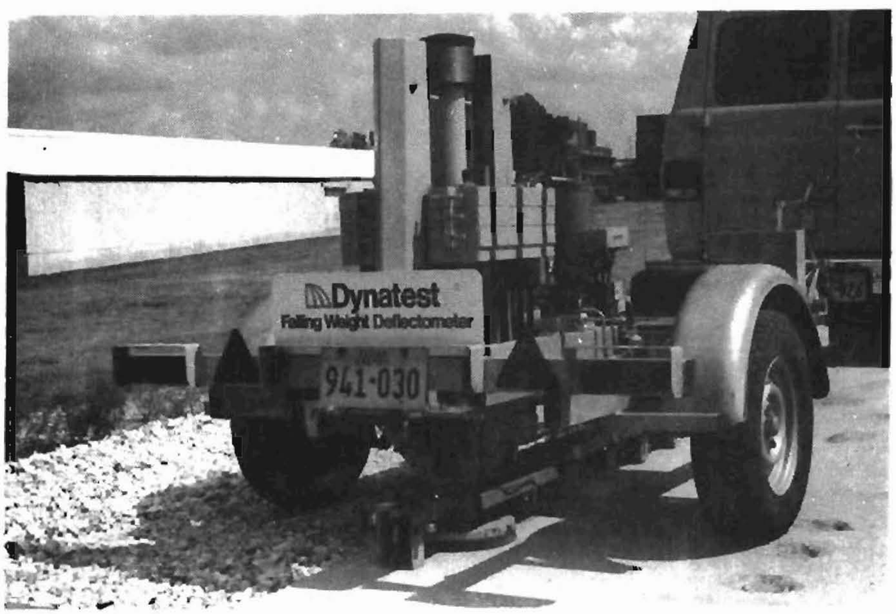


Fig 5.2. FWD in operation for curling effects on Project 460.

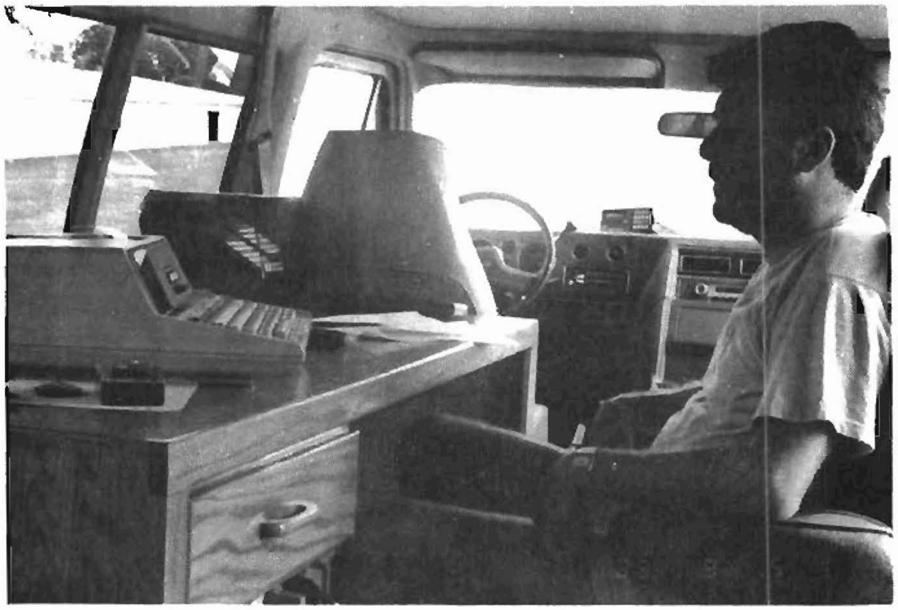


Fig 5.3. FWD computer system inside the van.

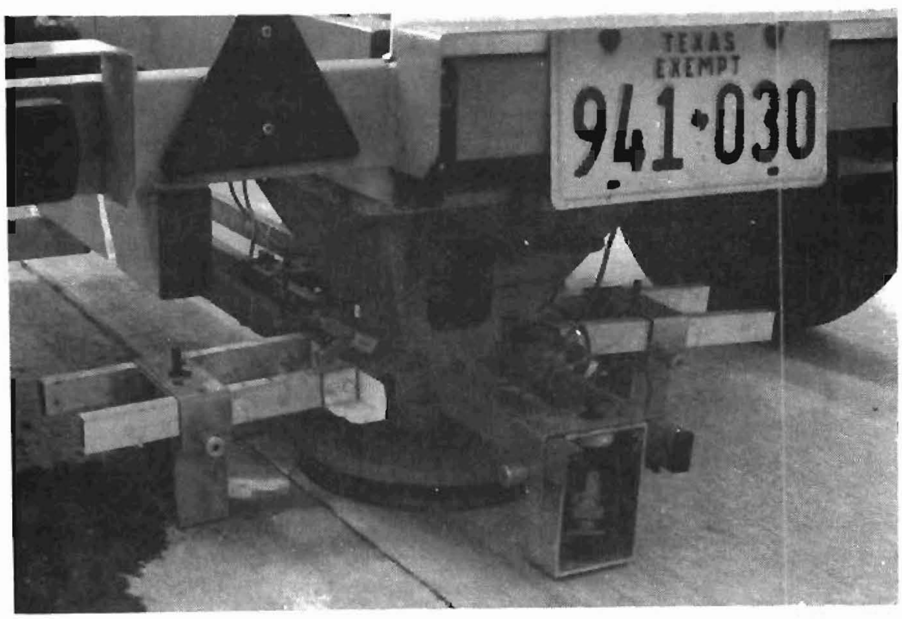


Fig 5.4. FWD being used with four sensors around the loading plate in order to measure joint efficiency at the longitudinal joint.

temperature, and the relative humidity, as well as the solar radiation and wind velocity at the site.

(3) A joint that can, by means of an hydraulic ram system, represent different load transfer conditions.

(4) A pavement slab with a void at one side and none at the other.

Summarizing, the rigid pavement testing facility at BRC is being very widely used for several types of research on rigid pavements because it provides a permanent testing site which is heavily instrumented. It is expected that use of the facility will continue although the current project to design, construct, instrument, and initiate the facility is now completed.

REFERENCES

1. White, R., W. R. Hudson, A. H. Meyer, and K. H. Stokoe, II, "Design and Construction of a Rigid Pavement Research Facility," Research report 355-1, Center for Transportation Research, The University of Texas at Austin, September 1984.
2. "The AASHO Road Test: Report 5 - Pavement Research," Special Report 61E, Highway Research Board, 1962.

APPENDIX A

ENGINEERING CONSTRUCTION DATA

APPENDIX A. ENGINEERING CONSTRUCTION DATA

During the construction the project personnel performing the supervision executed several tests to ensure construction quality control. The following is the summary data or each layer of the pavement structure.

Concrete Pavement Data

Portland Cement Concrete:

Portland Cement Type I
Aggregate: Limestone

Flexural Strength of Concrete Test Procedure:

Texas Highway Test

Spec #	F_s psi
1	910.
2	920.
3	920.

Compressive Strength:

Spec #	F_s psi
1	3715.
2	4317.
3	5007.

Asphalt Concrete Base Properties Data

Asphalt Concrete Base Type C

Asphalt Mixture Characteristics

Asphalt Cement by Weight: 4.7%

Aggregate: Limestone

Sieve Analysis:

Sieve Number	Percent	Specifications
7/8"	0.0	0
7/8" - 5/8"	0.0	0-5
5/8" - 3/8"	22.6	16-42
3/8" - 4	19.4	11-37
4 - 10	19.5	11-32
+10	61.5	54-74
10-40	15.1	6-32
40-80	6.9	4-27
80-200	11.1	3-27
Pass 200	5.4	1-8

Elasticity Modulus:

Spec #	Temperature	E_R psi
D-5	75	632,213
D-13	75	403,846
D-21	75	533,266

Flexible Base Material Properties Data

Soil Description:

Unified Soil classification: SM

Base Material Type A, Grade 1 (Item 249 SDHPT 1982)

Soil Characteristics:

Liquid Limit:	18%
Plastic Limit:	- -
Plastic Index:	NP
Maximum Density:	126.0 PCF
Optimum Moisture:	10.5%

Sieve Analysis:

Sieve Number	% Retained	Specifications, % Retained
1-3/4"	0	0
7/8"	11	10-35
3/8"	31	30-50
#4	45	45-65
#40	73	70-85

Select Fill Material Properties Data

Soil Description:

Unified Soil Classification: SC light brown clayey gravely sand

Soil Characteristics:

Liquid Limit:	30%
Plastic Limit:	20%
Plastic Index:	10%
Maximum Density:	118.5 PCF
Optimum Moisture:	13.7%

Sieve Analysis:

Sieve Number	Percent Passing
2"	100
1-1/2"	90
3/4"	83
3/8"	76
#4	68
#10	59
#20	54
#40	50
#60	45
#100	40
#140	37
#200	34

Subgrade Material Properties Data

Soil Description:

Light grey and black, clayey, gravelly sand with limestone cobbles

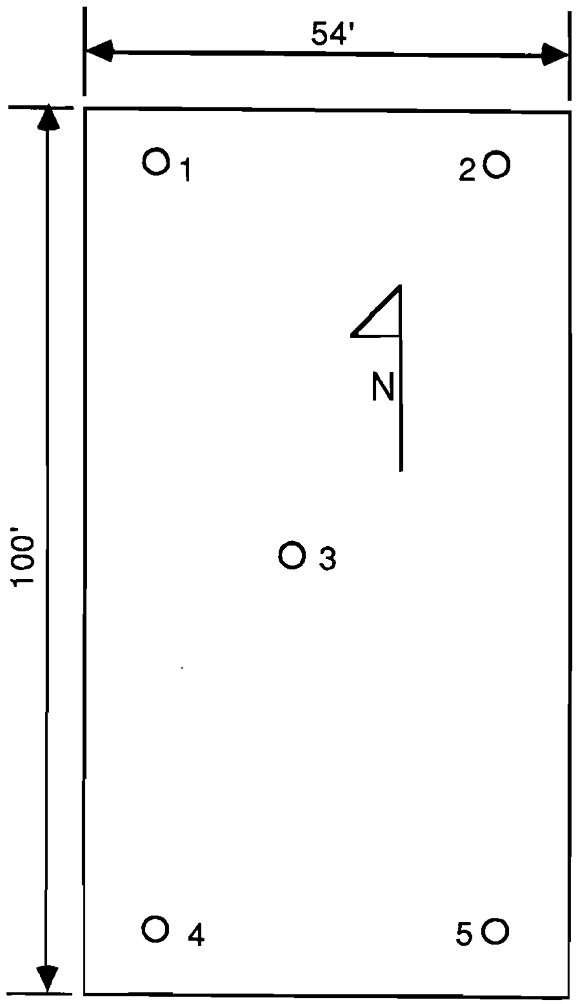
Soil Characteristics:

Liquid Limit:	37%
Plastic Limit:	21%
Plastic Index:	16%
Maximum Density:	114.1 PCF
Optimum Moisture:	14.0%

Sieve Analysis:

Sieve Number	Percent Passing
1-1/2"	100
1"	91
3/4"	88
3/8"	84
#4	78
#10	72
#20	65
#40	60
#60	52
#140	38
#200	34

Compaction Test Results



Select Fill

Test	% Moist.	Dry Dens.	% Comp.
1	14.6	108.8	91.8
2	18.8	112.5	94.9
3	20.1	111.1	93.7
4	13.3	108.0	91.1
5	14.9	110.4	93.1

Flexible Base

Test	% Moist.	Dry Dens.	% Comp.
1	5.8	123.3	97.9
2	8.0	128.6	102.1
3	8.3	130.5	103.6
4	5.9	121.5	96.4
5	7.3	126.7	100.6

All tests performed by District 14 SDHPT, using nuclear density gauges. Tests were measured in the top 6 inches of the select fill and flexible base.

APPENDIX B

FIELD STUDY OF THE EFFECT OF TEMPERATURE ON THE FWD DEFLECTIONS

APPENDIX B. FIELD STUDY OF THE EFFECT OF TEMPERATURE ON THE FWD DEFLECTIONS

WORK PLAN OF THE TESTING WITH THE FWD AT BRC - (WEEK OF JULY 21)

First day of Testing (7/18/86) Initial Set-Ups

10:00 Take the HP system from UT to BRC (Carl and Gustavo).

10:30 Hook up the HP and set it up to take readings from thermocouples at locations T1, T2, and T3, which are shown in Fig B.1 (Carl). First reading at 11:00 and following ones every 30 min. until the end of testing.

-Set-up the metereological station (Gustavo).
-Set-up the Max-min thermometer (locate it next to the metereological station) (Gustavo).

11:00 Hook up the hydraulic ram system (shown in Fig B.1), apply 5000 psi and check that it stabilizes at that pressure.

12:00 Park the FWD in position A, shown in Fig B.2.

Run the FWD in order to check that it is working OK. The test will be done using the cassette "FIELD PROGRAM (BACK-UP COPY)", and 3 pairs of weights, dropping them from each of the 4 dropping heights that the FWD provides.

Turn off everything (except the HP system), check to see if the pressure is at 5000 psi, and, if not, pump in order to get it.

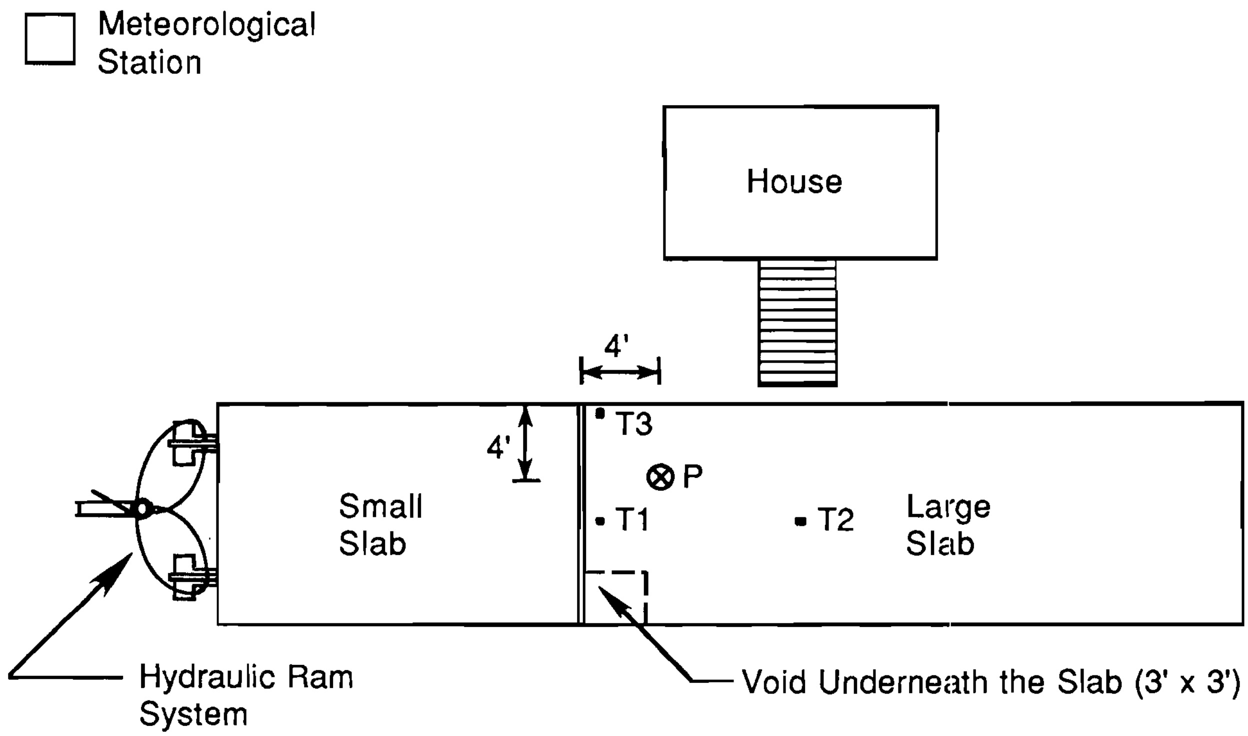
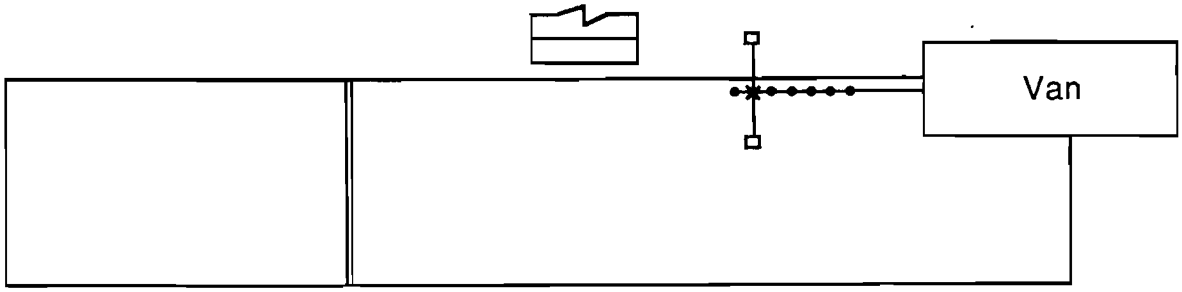
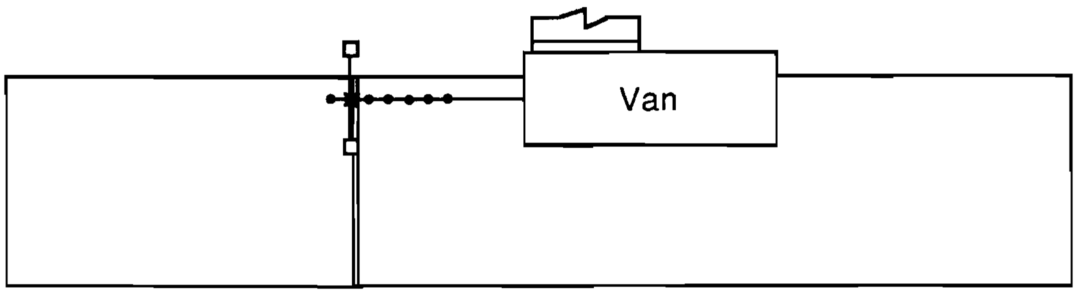


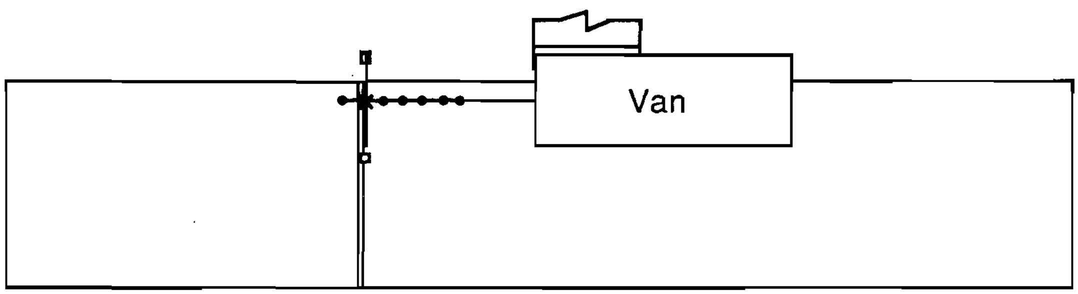
Fig B.1. Layout of the testing facility at BRC.



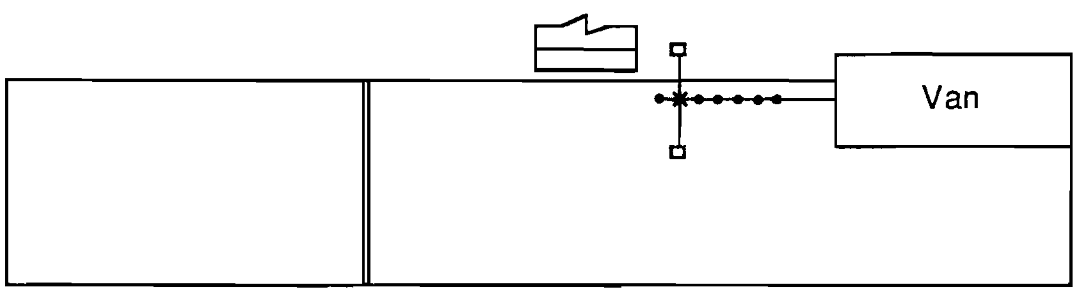
Position A



Position B



Position C



Position D

Fig B.2. Testing postions at side of the slab without void underneath.

Second and Third Days of Testing (7/21/86 & 7/22/86) Testing at the Side of the Slab Without Void Underneath

07:55 Turn on the Van and let it warm-up.

07:57 Check to see if pressure is equal to 5000 psi. If not, pump.

Read and record the Max-min thermometer, reset it, and put it back where it was.

Zero the wind meter.

08:05 Insert the cassette "FIELD PROGRAM (BACK-UP COPY)".

While the program is being loaded, write down, on the print-out paper, the date and the identification of the test ("Side of the slab without void", in this case), as well as the conditions of the day (sunny or not, clear or cloudy, and windy or not). If at any time of the day there is an unusual change in any of these conditions, write down the change including the time of the observation.

The following steps constitute the procedure which will have to be repeated every 60 minutes at the times indicated in Table B.1, included at the end of this procedure.

(1) Check to see if the pressure is equal to 5000 psi. If not, pump to get it.

(2) Move the FWD from position A to D (shown in Fig B.2).
Be sure to have it in the desired position (with the geophones between 6 and 12 inches from the edge, and as parallel to it as possible).

(3) Put the surface thermometer on the slab surface, at the position indicated in Fig B.1.

(4) Read and record:

-Air temperature, from the metereological station
-Wind speed, from the wind meter
-Solar radiation, from the solar meter
-Slab surface temperature, from the surface thermometer
-Pick up the surface thermometer.

TABLE B.1. BRC SLAB TESTING SEQUENCE

Test Step	1st Hour	2nd Hour	3rd Hour	4th Hour	5th Hour	6th Hour	7th Hour	8th Hour	9th Hour
1	08:13	09:13	10:13	11:13	12:13	13:13	14:13	15:13	16:13
2	08:15	09:15	10:15	11:15	12:15	13:15	14:15	15:15	16:15
3	08:17	09:17	10:17	11:17	12:17	13:17	14:17	15:17	16:17
4	08:18	09:18	10:18	11:18	12:18	13:18	14:18	15:18	16:18
5	08:22	09:22	10:22	11:22	12:22	13:22	14:22	15:22	16:22
6	08:24	09:24	10:24	11:24	12:24	13:24	14:24	15:24	16:24
7	08:26	09:26	10:26	11:26	12:26	13:26	14:26	15:26	16:28
8	08:28	09:28	10:28	11:28	12:28	13:28	14:28	15:28	16:30
9	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:32
10	08:32	09:32	10:32	11:32	12:32	13:32	14:32	15:32	16:34
11	08:34	09:34	10:34	11:34	12:34	13:34	14:34	15:34	16:36
12	08:36	09:36	10:36	11:36	12:36	13:36	14:36	15:36	16:38
13	08:38	09:38	10:38	11:38	12:38	13:38	14:38	15:38	16:40
14	08:40	09:40	10:40	11:40	12:40	13:40	14:40	15:40	16:42
15	08:42	09:42	10:42	11:42	12:42	13:42	14:42	15:42	16:44
16	08:44	09:44	10:44	11:44	12:44	13:44	14:44	15:44	16:46
17	08:46	09:46	10:46	11:46	12:46	13:46	14:46	15:46	16:48

(5) Run the FWD with 3 pairs of weights dropped from each of the 4 dropping heights.
After the dropping is finished, input the air temperature read in step (4) and the number of the station (4, in this case), and the results will be printed out.

(6) Move the FWD from position D to B (shown in Fig B.2).
Be sure to have it in the desired position (with the loading plate as close as possible to the transverse joint, and the bar with the geophones close to between 6 and 12 inches from the edge, and as parallel it as possible).

(7) Run the FWD in exactly the same way as in step (5) but input 1 as the number of the station.

(8) Move the FWD from position B to C (shown in Fig B.2).
Be sure to have it in the desired position.

(9) Run the FWD in exactly the same way as in step (5) but input 0 as the number of the station.

(10) Release the pressure in the hydraulic ram, completely.

(11) Run the FWD in exactly the same way as in step (5) but input 2 as the number of the station.

(12) Move the FWD from position C to B (shown in Fig B.2).
Be sure to have it in the desired position.

(13) Run the FWD in exactly the same way as in step (5) but input 3 as the number of the station.

(14) Move the FWD from position B to D (shown in Fig B.2).
Be sure to have it in the desired position.

(15) Run the FWD in exactly the same way as in step (5) but input 5 as the number of the station.

(16) Move the FWD from position D to A (shown in Fig B.2).

(17) Pump the hydraulic ram in order to get the 5000 psi pressure again.

Repeat steps 1 to 17 at the times shown in Table B.1 (*).

(*) The Sling hygrometer should be used in order to measure the relative humidity at 9:00, 12:00 and at 15:00.

16:44 Do this step only if the side with the void underneath the slab is going to be tested the next day; otherwise skip this step. Move the FWD from position D (shown in Fig B.2) to position E (shown in Fig B.3).

17:00 Before leaving turn off everything (except the HP system), and check to see if the pressure is at 5000 psi, and, if not, pump in order to get it.

Fourth and Fifth Days of Testing (7/23/86 & 7/24/86) Testing at the Side of the Slab with Void Underneath

The testing on these days will be exactly the same as on the Second and Third days of Testing, with the following changes:

-The identification of the test is "Side of the slab with void".
-Instead of refering to positions A, B, C, and D, shown in Fig B.2, refer to positions E, F, G, and H, as shown in Fig B.3.

Sixth Day of Testing (7/25/86) Testing at the Center of the Slab

The testing on these days will be exactly the same as on the Second and Third days of Testing, with the following changes:

-The identification of the test is "Center of the Slab"
-Instead of refering to positions A, B, C, and D shown in Fig B.2, refer to positions I, J, K, and L, as shown in Fig B.4.

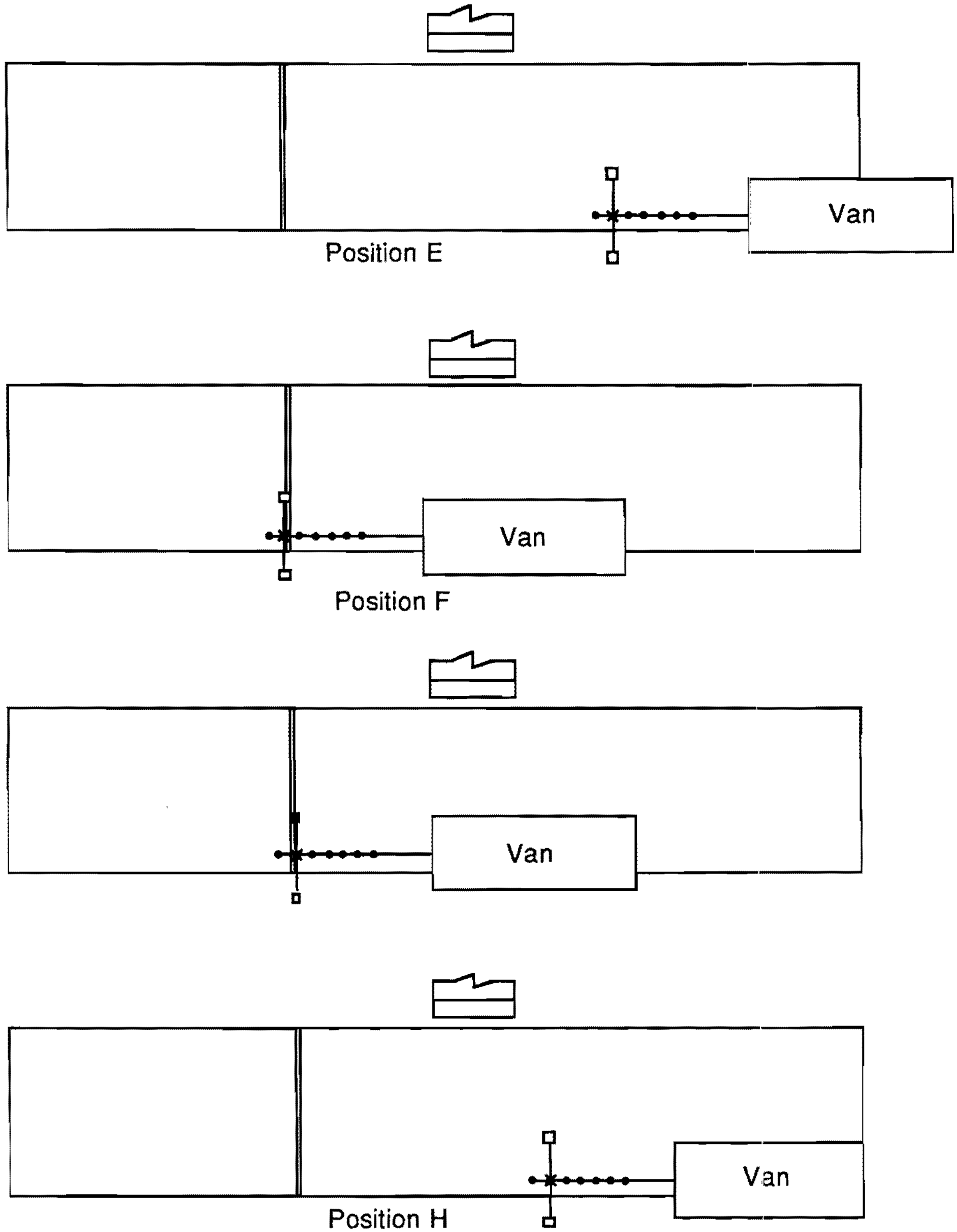
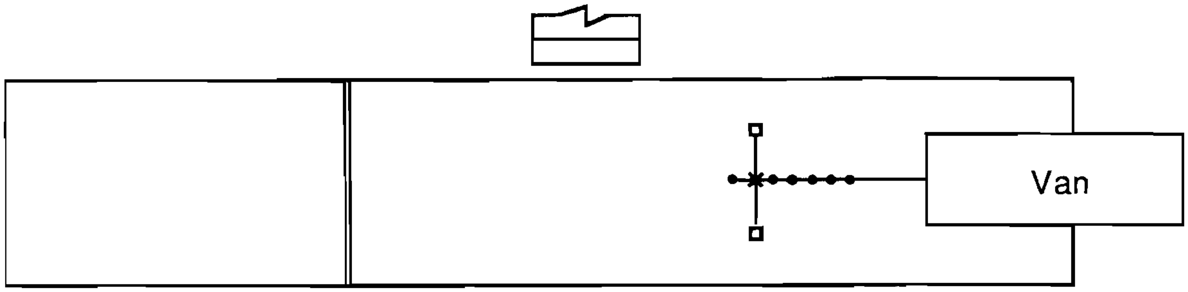
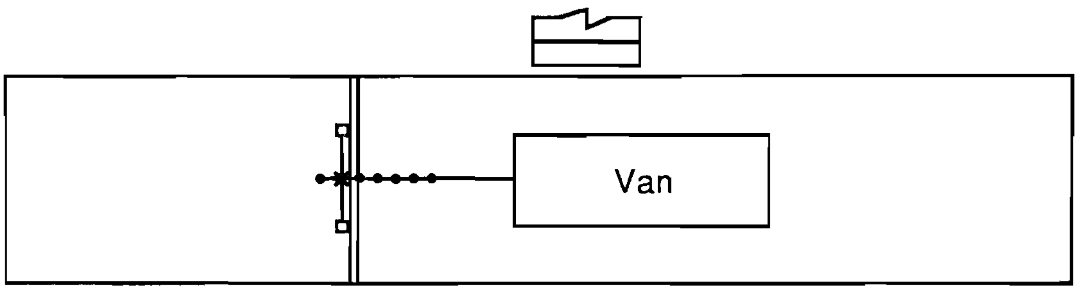


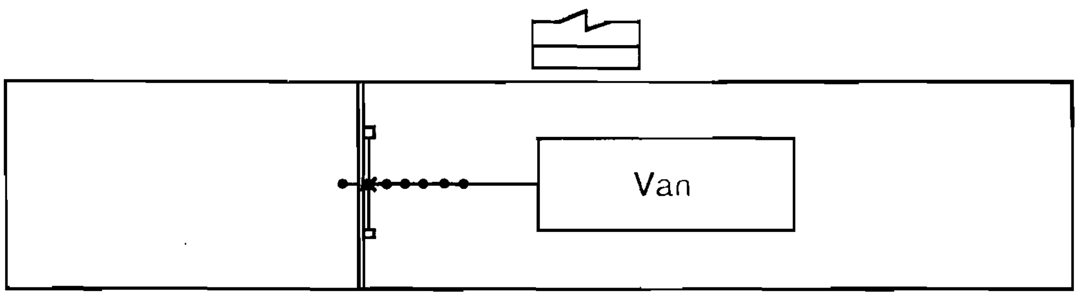
Fig B.3. Testing positions at side of the slab with void underneath.



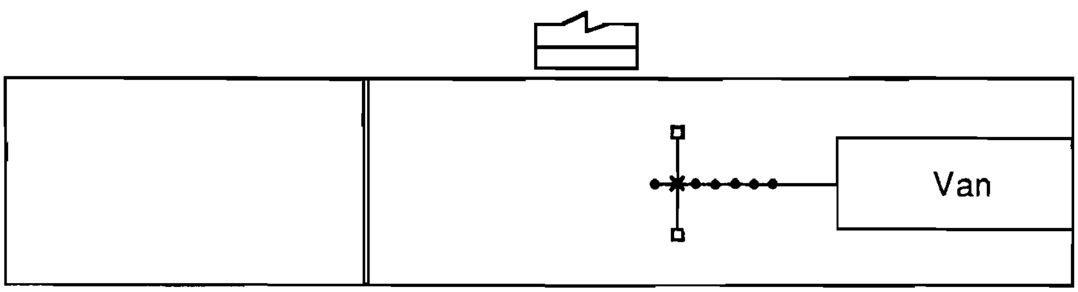
Position I



Position J



Position K



Position L

Fig B.4. Testing positions at center of the slab.

Seventh Day of Testing (7/28/86) Closing the Experiment

09:00 Shut down the reading of the thermocouples (Carl).

-Pick-up the Max-min thermometer, and leave it in the house (Gustavo).

-Pick-up the Metereological Station's strip chart, and leave the instrument itself inside the house (Gustavo).

09:20 Unhook the hydraulic ram system and put it back in the house (Carl and Gustavo).

10:20 Unhook the HP system and bring it back to UT.

SUMMARY OF THE DATA TAKEN AT BRC UP TO JULY 18, 1986

DATA	DATES	COMMENTS
LVDTs and Thermocouples	2/27-2/28/86	Bad Data (problems with the data acquisition system).
LVDTs and Thermocouples	3/5-3/7/86	Bad Data (problems with the data acquisition system).
LVDTs and Thermocouples	3/19 & 3/21/86	Bad Data (problems with the data acquisition system).
FWD and Thermocouples	3/20/86	Bad Temperature Data (problems with the dataacquisition system). Acceptable FWD Data (OK) (FWD w/o void side,w/o pressure, w/o movingthe FWD, downstream position).
LVDTs and Thermocouples	4/2-4/4/86	Bad Data (problems with the data acquisition system).
LVDTs and Thermocouples	4/22-4/28/86	OK.
Thermocouples	4/28-5/2/86	OK.
FWD	4/29/86	Acceptable FWD Data (OK) (started in the light rain, then heavy rain during the rest of week-FWD w/o void side, w/o pressure, w/o moving the FWD, downstream position).
Thermocouples	5/19-5/23/86	OK.
FWD	5/20/86	Acceptable FWD Data (OK) (FWD w/o void side, w/o pressure, w/o moving the FWD, downstream position).
FWD	5/21/86	Acceptable FWD Data (OK) (FWD w/o void side, w & w/o pressure, w/o moving the FWD, downstream, upstream and downstream positions).