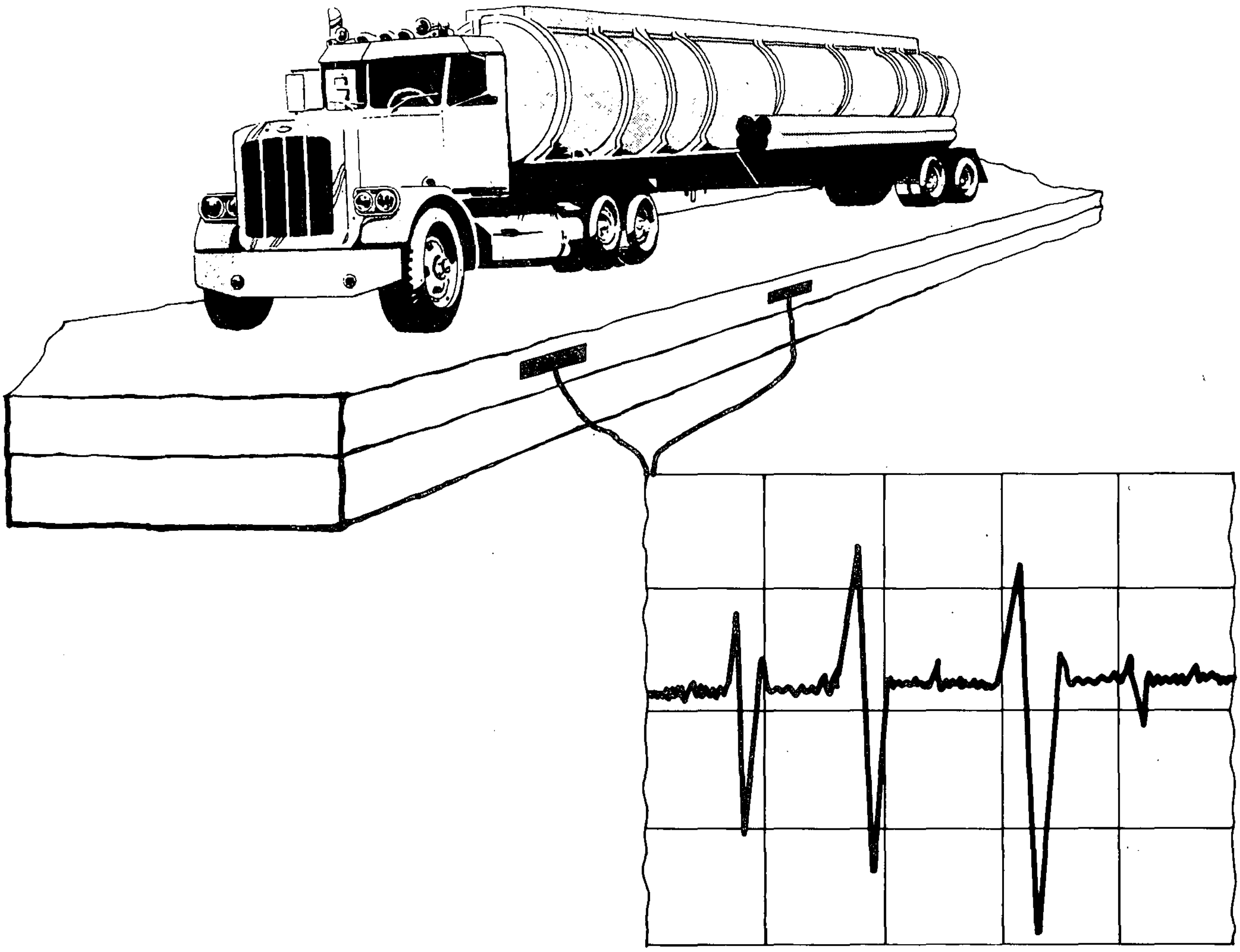
U.S. Department
of Transportation

Federal Highway Administration

Demonstration Projects Division

Pavement Instrumentation



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March 1988

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16. Abstract

The report documents the development and installation of an instrumented pavement on I-80 in Iowa for the purposes of demonstration and answering current pavement questions. Its two primary objectives include documentation of the installation and verification of existing design procedures through monitoring of the continuous traffic stream reactions in the pavement.

Some 120 instruments were installed in a forty foot segment of reconstructed pavement. The instruments included concrete strain gages, weldable strain gages on dowels, LVDT-deflection gages and temperature sensors in the concrete and base material. Five tubes were placed under three joints and two midslabs to measure the relative moisture and density at the interface between the pavement and base with atomic equipment. The instruments were placed ahead of the paving and over 92% of the instruments responded after paving. Planning requirements, problems encountered and costs of installation are presented. The site will use piezo electric cables in a weigh in motion arrangement to trigger the data collection, a microcomputer controlled data acquisition system to analyze multiple sensors simultaneously, and telemetry to monitor the site remotely.

Details provide the first time user of instrumentation with valuable information on the planning, problems, costs and coordination required to establish and operate such a site.

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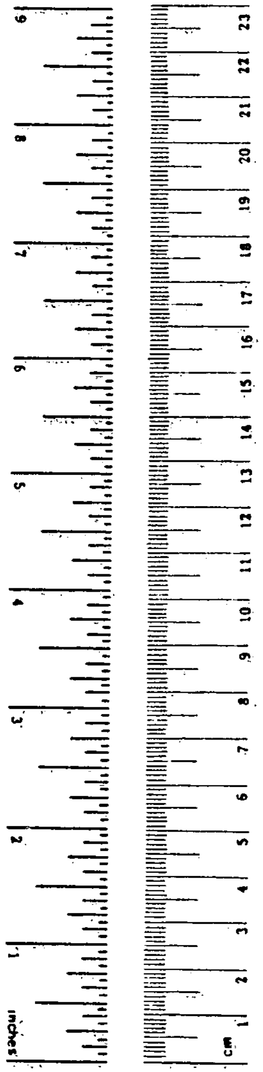
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

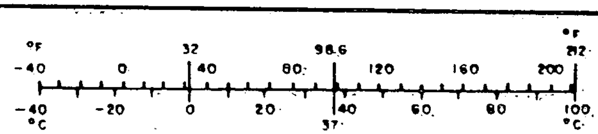
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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



FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT NO. 621

PAVEMENT INSTRUMENTATION

IOWA HIGHWAY RESEARCH BOARD
PROJECT 293

Prepared by:

James K. Cable, P.E.

Dr. John R. Rohde

Dr. D. Y. Lee

Dr. F. Wayne Klaiber

Civil Engineering Department

Iowa State University

Ames, Iowa

Under Direction and Funding by:

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March 1988

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The authors wish to express appreciation to the many personnel in the Offices of Maintenance, Transportation Inventory, Materials and Purchasing of the Iowa DOT for making the project a reality. Without the help of the Council Bluffs Construction Residency personnel and the Central Paving Corporation, the installation would not have been possible. We are also grateful to Professor W.W. Sanders, Jr., and other staff of the Engineering Research Institute at Iowa State University for financial management and editorial services related to this project.

EXECUTIVE SUMMARY

The project was initiated to achieve two primary objectives and several secondary objectives. The primary objectives include the demonstration of pavement instrumentation installation techniques and the verification of design procedures in an effort to improve rigid pavement pavement performance in Iowa. Secondary objectives include the evaluation of magnitude and frequency of dynamic loads vs static loads on rigid pavements, and the relationships of pavement strains to pavement loads under various base moisture and density conditions. This report deals primarily with the selection and installation problems, and costs involved with development of the field site and associated analysis equipment.

A forty foot long section of twenty four foot ten inch wide by eleven inch thick, joint reinforced pavement, part of I-80 in Pottawattamie County, Iowa was instrumented with some 120 instruments. They included weldable strain gages on selected dowel bars at three consecutive joints, and concrete strain gages at selected locations across the slab at two mid slab and two exterior corner locations. The strain gages were installed prior to the placement of the new eleven inch thick pavement. The site also includes some sixteen deflection gages at locations near the joints and midslab in the wheel path areas. Metal pipes were placed under each of three consecutive joints and in the two midslab locations, in the base material. Temperature sensors were placed near the surface of the pavement, at top of the variable thickness base material, and 6 inches into the subgrade. An additional single unit was placed outside the slab to measure ambient air temperature. Over 90% of the instruments were found to provide a completed electrical circuit when measured after construction of the pavement.

The system is set up to be triggered by a weigh-in-motion piezo-electric arrangement in each of the travel lanes. The collection of strain, deflection, and temperature data is accomplished by a micro computer controlled data acquisition system at the site and transmitted via telephone to a central site for analysis. The weigh in motion site when installed will provide information on axle and gross weights, axle spacing, vehicle classification, speed and lateral location within each lane. Monthly moisture and density measurements of the base in the base and subgrade are currently being performed through the metal pipes installed concurrently with the instrumentation system.

During installation, a study was made comparing the output of the common pavement software analysis programs of ILLISLAB, JSLAB, SLABPACK, and FEACONS. Part of the analysis was directed at comparing the effects of the skewed joints vs rectangular joint patterns in strain and deflection results. This data will provide the starting point for the second part of the study.

Details of the installation found in this report provide the first time user of instrumentation with information on the planning process, costs of the materials required, problems encountered, and the coordination required to place the instruments in the pavement during paving operations.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The reaction of pavement structures to traffic loads and the environment has been studied in many ways in the laboratory. With the exception of the AASHO Road Test and the other previous test track studies, little has been done to test the performance of the pavements under field traffic and environmental conditions.

The Strategic Highway Research Program is designed to answer some of the highway research needs that states are unable to meet on their own due to the time, manpower, or funding constraints. The Federal Highway administration is assisting in the sponsorship of this project to demonstrate the "state of the art" in pavement instrumentation as one way of helping to answer those questions. Iowa's involvement in the SHRP and other national highway research efforts is providing an opportunity to tie that effort to a better understanding the performance of portland cement concrete pavements under actual traffic and environmental conditions.

DEMONSTRATION OBJECTIVES

Project Objectives

The study has two primary objectives and several secondary objectives to be achieved through the primary research effort.

A primary objective of the study is the demonstration of pavement instrumentation techniques for use in portland cement concrete pavements for use in the Strategic Highway Research Program Study. The study is expected to provide information on the methods for placement of instruments, their reliability, and hardware and software needs, instrumentation costs and the types of results that can be obtained. The research offers a chance to verify and evaluate the laboratory work in the design and the performance of pavements. It also serves to assist the efforts of AASHTO in the development of emperical/ mechanistic design procedures which closely match the anticipated laboratory pavement performance that can be achieved in the field.

The second primary objective of the study is the evaluation of the magnitude and the frequency of the dynamic loads applied to the portland cement concrete in relationship to the static loads for which the pavement was designed. Depending on the design procedure used, the design may be based on the static analysis calibrated for dynamic traffic such as was the case in the AASHO Road Test. The current design theories developed by Westergaard are based on the application of a static or slow-moving load across the pavement slab. The study is designed to provide information on the actual dynamic loads and strains being introduced into the slab by the traffic stream. This relationship can provide for a better understanding of the performance of pavements and a way of predicting the impact of changes in the weight laws in Iowa.

Secondary objectives of the study include the evaluation of the behavior of the pavement in relationship to the loads under various temperature and moisture conditions in the subgrade. This type of result is aimed at improving the design of the subgrade, pavement slab, drainage systems and the administration of the highway weight embargo legislation.

Initial Report Objectives

The objective of this report is the fulfillment of the first primary objective. It is designed to provide SHRP and other state highway agencies with information on the selection, installation, and costs associated with instrumentation of the I-80 site in Iowa. Items such as site selection and preparation, instrument selection and preparation, data processing equipment selection and installation, and the costs involved with each phase of the installation are discussed. The report identifies the problems associated with such an installation by persons with no prior experience in this type of research effort.

APPLICATION AND SCOPE OF PAVEMENT DATA

Theory

The application of instrumentation data should be compatible with one or more of the current theories of materials and mechanics to be useful. With the current shift in the AASHTO pavement design to mechanistic design, the data should support one of the elastic, visco elastic, or plastic theories of design. The linear elastic theory of mechanistic design would suggest that the responses of the pavement are proportional in the increment of strain or deflection for both low and high values of traffic loadings. When the loads are removed, the strain and deflection will both return to zero.

The nonlinear elastic theory states that the increments of strain and deflection induced by various increments of load are different. It is assumed that the strain and deflection will still return to zero when the load is removed.

Visco elastic systems are affected by time or circumstances of loading. In this type of system, both the increment of response and the limits of the recovery are modified during the life of the materials.

A material that shows increases in strain at a constant stress and no recovery of strain when the stress is reduced to zero, is termed to be plastic in nature.

Each of the materials discussed is found in the pavement layers and mechanistic models should relate how the various pavement layers react to loads and interact with one another. Each of the models shown above is limited by criteria associated with an analysis based on the number of load repetitions necessary to produce a certain type of distress function. The individual distress may be accumulated in a linear manner in equal increments for each load application or a non linear manner based on a variety of loads and magnitudes. The latter better represents the situation that is anticipated by the actual pavements due to the traffic mix and environmental effects.

The limiting criteria or distress function for each pavement system is obtained from calculating the deflection or strain associated with a known load application and then extrapolating the result to one for a pavement response to millions of load applications. This type of activity has previously been accomplished at test tracks and road tests such as the AASHO Road Test. Laboratory tests have been used to fill in missing data and define "safe" limits of elastic response.

The laboratory cannot duplicate the construction, material, traffic and environmental variables present in the actual pavements. Field instrumentation of actual pavements seeks to provide data to verify theoretical calculations based on one or more of the theories along with defining the type and magnitude of the transformation functions associated with relating the laboratory tests with the field performance. The data can also be used to determine load equivalencies of various known loads under selected conditions when accompanied with distress measurements.

Responsive Attributes

Data that can be collected by instrumentation includes the response of pavement materials, pavement layers, and special features of the pavement cross section. External factors such as load can provide responses such as strains, stresses, deflections, pore pressures, and deformations. For the current study the factors of strain and deflection are the primary responses collected. Several components of the rigid pavement can be studied with this data. In this study they include the slab (edge, corner, center, and joint interaction), reinforcement (dowels, tie bars), base, and layer interfaces (slab to base and base to subgrade).

Contributory Factors

Sufficient supporting data is necessary for the analysis of the response attributes for each of the pavement features. Load must be defined in terms of magnitude, character and amount of traffic, contract tire pressures and position of loading for the specific response measurement. In this study all of these items except the contact tire pressures can be measured. Consideration is being give to an attempt at measuring the contact tire pressure with a Weigh in Motion (WIM) device associated with the site.

In situ moisture and density in the various layers of the pavement and especially at the interface between the slab and the base are important in the quantification of the strength of the pavement system. The variance of moisture over time and across the slab base can have definite effects on the performance of the slab.

Background Data

Certain background data on the condition of the base and subgrade of the test site are needed to establish the state of the foundation at the time of installation, data collection, and the time of any noted failure. This includes moisture and density of the base and the subgrade and information on the thickness of the pavement and mix design.

Pavement Condition

Pavement condition in Iowa and in most of the states is measured in terms of the AASHTO Present Serviceability Index (PSI). This is a measure of the roughness in terms of longitudinal profile and is adjusted by a measure of the relative amounts of cracking, rutting and patching. It is designed to correlate the subjective rating of the public to a mechanical and manual observed objective rating of the roads functional adequacy. Collection of PSI data provides a measure of pavement condition and a valuable input into the link between mechanistic analysis and distress functions required in the development of a mechanistic-emperical design procedures.

EXPERIMENTAL DESIGN

The researcher must develop the overall design of the experiment in an effort to determine the detailed instrumentation needs and the methods that will be used to achieve the goal of the project. The goals of this project are both short and long range in nature.

Short Range

1. Installation of instruments in a new pavement during paving operations.
2. Development of a data acquisition system including hardware and software appropriate to the instruments installed.
3. Installation of a communications link for remote monitoring of the site traffic.

4. Sensor response calibration to the known static and dynamic load situations and ranges.
5. Installation of the moisture/density instrumentation equipment.

Long Range

1. Monitor pavement responses to mixed traffic loads during:

   varying base moisture conditions

   varying times of the day
2. Monitor the changes in density and moisture at the interface of the pavement and the base material.
3. Analyze the response frequency and magnitudes to determine the pavement performance in terms of equivalent axle loads.
4. Compare the rate of pavement loadings to that predicted by the pavement design formulas used in the construction.
5. Develop load equivalencies for this pavement design for the traffic using the section highway prior to any identifiable distress in terms of cracking or joint deterioration.
6. Develop relationships between the observed strains and the measured moisture/density at the pavement/base interface.
7. Define the drainability of the base material and the performance of the longitudinal subdrains.

With the short and long range goals in mind, the researcher should next determine what is to be measured and how it will be measured. The Iowa project will measure the following items of information:

1. Strain

   a. Concrete pavement

      1. Longitudinal strain

   b. Reinforcement

      1. Longitudinal strain

2. Temperature

   a. Concrete pavement

      1. Near slab surface 2. Near base interfaces

   b. Subgrade

   c. Air

3. Deflection

   a. Concrete pavement

4. Moisture/density

   a. Relative changes in moisture and density of the base and subgrade materials.

5. Vehicles

   a. Weights

      1. Axle, gross

      2. Static, dynamic

   b. Axle spacing

   c. Speed

   d. Lateral location

   e. Classification

6. Road surface profile

   a. Initial and periodic review

We chose to measure the items shown above in the following locations and manner:

1. Concrete strains will be measured at the top and bottom of the slab. Since maintenance of such an installation would be difficult at the surface of the slab, the sensor was embedded approximately one inch. The bottom sensor was elevated in the same manner to provide concrete cover and assure that the two sensors are equally distant from the computational neutral axis. This should provide nearly equal and opposite compression/tension values at each location.

   Sensors were placed longitudinally at the midslab locations in equal transverse spacing increments across the slab. The outer most sensors on each side are inset six inches to reduce the impact of the shoulder material reactions to temperature and allow the paving equipment to pass by. Three sensors are located in an exterior corner on a diagonal line. The placement of the sensors allows the researcher to verify the strains that occur at the edge, middle and corner of the slab as used in the design equations of previous research.

   Redundancy of the sensors is accomplished in two adjacent slabs.

2. Reinforcement strains will be measured on the bottom of selected joint dowel bars. Strain gages were attached to the bottom of the dowel at a location at the center so they are under the intended concrete joint saw cut. Gages were mounted underneath to offer protection from

paving and pavement joint sawing operations. This should measure the maximum strain on the bar due to loads from above.

Instruments are to be placed on selected bars under the wheel paths, near the centerline joint location, the transverse midslab, and near the edges of the pavement section in each lane.

Also of interest in considering the dowel loading is the shear stress in the dowel bar at the joint. Measurement of this shearing stress will require a small strain gage assembly mounted exactly in the center of the pavement joint. While this was impossible under conditions existing in this project, future projects may include precise surveys to allow for the positioning of joints. By using multiple strain gage sets, the joint position requirement could be approximately ± 0.5 inches.

3. Temperature in the pavement and the subgrade will be measured by sensors mounted on a reinforcing bar that can be inserted vertically into the base to provide sensors at locations one inch below the pavement surface, one inch below the base surface, and two inches above and nine inches below the subgrade surface. The sensors will be located six inches inside the pavement edged and near the centerline to measure the gradient between the center and edges of the pavement.

   The ambient temperature will be measured at a sensor mounted on a similar reinforcing bar near the control cabinet and exposed to the natural elements.

4. Deflection of the pavement will be measured with the aid of transducers located in vertical housings placed in the pavement under the wheel paths and on each side of a transverse joint or at the midslab location. Measurements of the pavement movement will be referenced to a rod, protected from the subgrade and base course in an oversized casing, driven into the soil five feet below the base of the pavement. Redundancy of the installation will be achieved at two consecutive joints and midslab locations longitudinally.

5. Relative moisture and density will be measured using a nuclear density system that can be pulled through a pipe, at the interface of the pavement and base layers. Because the reading is the average about the entire circumference of the pipe, aluminum irrigation type pipes shall be placed six to seven inches below the base surface. Five such pipes will be placed under each of three consecutive transverse pavement joints and the midslab locations of the included pavement slabs. Aluminum or a similar material that does not absorb the atomic instruments output can be used. Care should be taken to seal all joints and dry the interior of each pipe prior measurement.

6. Vehicles to be observed will include only the single axle trucks or larger. Cars are of little impact in the design of pavements compared to trucks and in an effort to make maximum use of available data storage. They will be omitted from the collection effort.

Piezo electric cable installations will be used to both trigger the data collection and measure the weight, speed, lateral location and axle spacing of the vehicles traversing the site. This will be accomplished through the installation of two layouts in each of the lanes in front of the instrumented slabs.

The first installation will be located ahead of the instrumented slab some 360 or more feet to provide information to the control unit in time to trigger data collection on the desired vehicles. The distance shown is based on allowing for three to four seconds of time between the initial sensing of the vehicle and collection of instrument data for proper vehicle identification. The configuration of this installation in each lane is shown in Figure 1. It consists of two twelve foot lengths of cable embedded in the surface of the pavement perpendicular to the centerline and spaced ten feet apart. A third cable, eighteen inches in length is located in the outer edge wheelpath to assure that the vehicle is wholly within the lane. The longitudinal dimensions shown on the diagram are designed to keep the cables away from the transverse joints and provide an offset between adjacent lane installations that can cause electronic interference.

Axle spacings and vehicle speeds will be measured with the Figure 1 installation layout. The measurement will include a calculation of the vehicle type by axle spacing in accordance with current FHWA classifications. The gross weight of the vehicle and the individual axles will measured with the same of the piezo cables. Initially

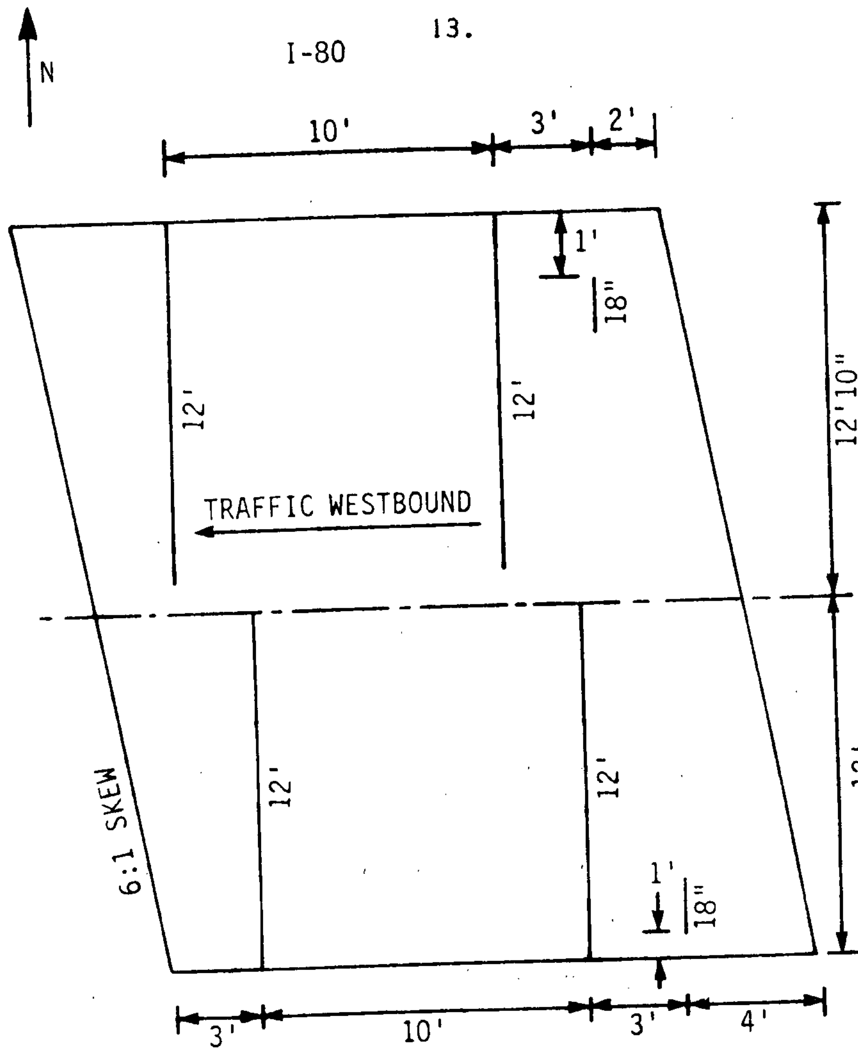


Figure 1 Vehicle Identification Piezo Cable Configuration

consideration was given to the use of the bridge as a Weigh in Motion device. Technology advances in the piezo installation and accuracy make it a better choice at this time.

The second installation, illustrated in Figure 2, is located immediately in front of the instrumented pavement section. The layout includes two twelve foot lengths of cable in each lane spaced fourteen feet apart and sparated transversely only by the centerline. The added separation distance is provided to allow for the diagonal twelve foot length placed on an angle of 60 degrees from the transverse cable. The diagonal cable is placed equally distant from the transverse cables with one end in placed near the edge of the pavement. The dimensions are controlled by the fact that this slab contains a perpendicular joint at one end and the skewed joint at the other end near the instrumented slab. This layout will be utilized to measure the location of the vehicle tires relative to the edge of the pavement as the vehicle enters in instrumented area. This installation can also be used to gather the weight, speed, and axle spacing data gathered at the first sites and evaluate the effect of the bridge on the loadings being measured.

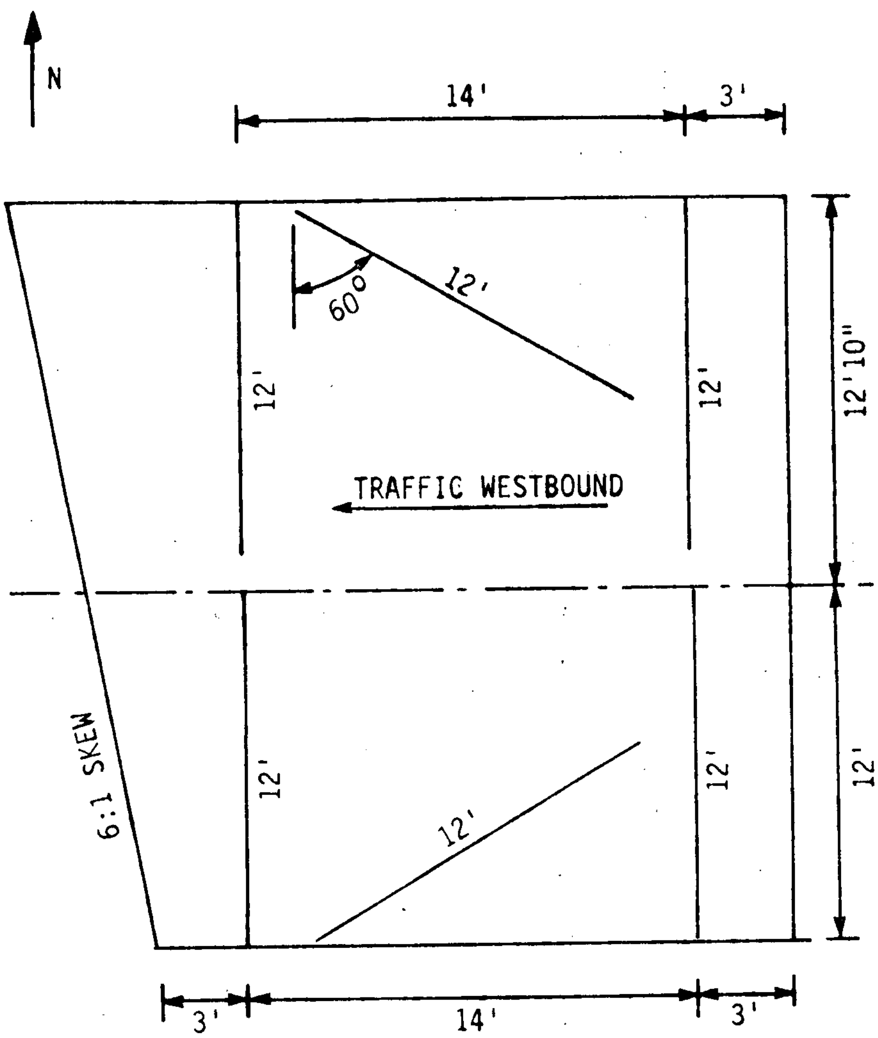


Figure 2 Vehicle Lateral Location Piezo Cable Configuration

The use of separate piezo installations in each lane and at locations on each end of the bridge allows for both the intended function of triggering the data collection and the accurate lateral measurement of vehicle location on the slab. A secondary study is possible to measure the effect of the bridge on increasing the dynamic weight of the axles and vehicle due to the bridge surface vertical alignment.

7. Road surface profile was measured with the profilometer at the time of pavement construction and will be measured by the IJK Roadmeter at the end of the study to determine changes over the research period.

Based on the characteristics of concrete and steel, sensors were selected to meet the needs of loads applied by the largest truck expected. In Iowa some trucks in the 100,000 + lbs. gross load have been weighed. The sensors discussed later in this report were selected to provide sufficient strain range to meet or exceed those associated with the expected loads.

Initial specifications for the data collection system included the capablity of monitoring/scanning each of the gages or any combination of the gages in the site at any time at a rate of 1,000 times per second per gage. This allows for a reading every one inch of vehicle movement (assuming 60 mph). This specification increased the cost of the data acquisition system by a factor of three to four times over the system that was ultimately chosen with the capability of data acquisition at 300-400 readings per second per gage for each of the gages in two consecutive joints (full pavement width) and the strain gages in the slab between the joints. At the same time it is capable of monitoring the deflection gages in the same area and respond to the traffic counting, classification and triggering unit. This data acquisition system is obviously a compromise due to cost, and will allow for readings approximately every three and one half inches of vehicular movement. It is realized from the on set that determination of strain/deflection vs load position relationships will be much more difficult to determine with this setup.

The system includes the necessary micro computer, monitor, and storage units with the data collection manager hardware to collect and store data on two or more hours of traffic passing by the site. The traffic data collected only applies to single axle or larger trucks. The output of the system will be in the form of a graphical display and numerical list of data for each vehicle that is selected for data collection. It is capable of identifying the strains associated with the loading at any of the individual sensors and identify which lane the vehicle is traversing. Such data will be placed in a format capable for transmission via telephone to the central office location in Ames upon telephone demand.

The central office portion of the system serves as the detailed analysis area. The hardware includes a microcomputer with color graphic monitor, modem, and a plotter and printer to display the analysis results.

Software for the data collection and analysis used in the study will be obtained from that provided in the hardware management package subroutines, available spreadsheets and communications packages. The subroutines shall be utilized in the following required programs that must be developed by the project staff.

1. A program that initiates, stops and directs storage of the data from each individual or series of vehicles. The program will selectively trigger appropriate gages and divide the data obtained from the various gages into bins equal in size to a floppy disk capacity.
2. A program to zero each instrument (at predetermined intervals) and collect temperature data at the same time. The program should provide for preset intervals of collection or approximately 30 minutes between zeroing.
3. A program to allow the operator to change the identity of selected sensors being monitored at any time from the central office via the modem.
4. Documentation for each of the programs shall be provided by the programmer.

Commercially available communications and spreadsheet software will be used for the majority of the analysis of the data. Other pavement related software available in the areas of pavement design and finite element analysis will be used to verify the pavement design theories.

Data storage on any computer system is limited. In this program the funding and relative value of the data guided the research to limit the active time of data collection to that when the truck is on the site. The collection of the strain gage data (dowel and concrete) will be triggered by weigh in motion piezo electric cables located some 300-360 ft. upstream of the test site in each approaching lane as described earlier in this report.

The acquisition equipment can be programmed for data collection rates and times based on the vehicle speed. Collection is of course considered for each axle identified and the software must determine overall vehiclar configuration. Since the computer will be triggering the data acquisition system, relatively low level programming may be required to perform logic operations in real time and down load data from the data acquisition unit. Each lane will be triggered by a separate piezo cable arrangement. Initially the equipment shall be set to collect data beginning three seconds after triggering by the piezo cable and continue for a period of three seconds to allow for the approach and passage of the vehicle over the test slabs at speeds of 50-90 mph. This assumes that the 50 mph vehicle is to be monitored as it approaches the first joint and collection lasts until the rear axles leave the monitoring area. It shall also allow for multiples of the three second collection period if additional vehicles approach in either lane during the initial collection time. If no vehicle enters the area during the three seconds, the collection unit shall be programmed to stop. Based on the vehicle axle classification definitions of the FHWA, only single unit trucks or larger should be used to trigger data collection. Each lane will have separate cables with the trigger cable placed 360 ft from the first test joint measured longitudinally along the lane centerline, to indicate where the vehicle is located relative to measured strains induced.

The weigh in motion device used for this type of experiment should provide accuracies in the following ranges for all vehicles measured including those exceeding the legal weight law limits as follows:

Steering axle - Plus or minus 10% of static weight on at least 80% of the vehicles.

Other single axles - Plus or minus 10% of static weight on at least 80% of the vehicles.

Tandem axles - Plus or minus 10% of static weight on at least 80% of the vehicles.

Gross weight - Plus or minus 10% of static weight on at least 80% of the vehicles.

Originally the bridge was considered for instrumenting with weigh in motion and vehicle classification equipment. The piezo cable technology innovations have negated the need for the bridge. Future installations will consider pavement sites without bridges and with relatively flat grades to reduce the dynamics induced in the vehicle by the bridge approaches and the grades. Additional problems associated with the paving changes associated with the bridge approaches would be eliminated.

Data storage in the field is limited to the hard disk and a single floppy in the micro computer on site. Software decisions will set the number of events that can occur between downloads to the computer in Ames. Initially linited processing will occur in the field so frequent transmission will be required with the increase of on-site software, non-significant data can be deflected and eliminated with an anticipated increase of an order of magnitude in the number of acquisition events in storage on site.

The amount of data collected at any given time shall not be greater than that stored on one floppy disk with 15% of the volume left vacant. The limit shall be set at 247 k based on the capacity of IBM 5-1/4 inch disks (360 k) or HP 3.5 inch disks (247 k). Each series of strains will be identified by the time and date of the entry and the sensor. In the event the maximum capacity is reached, the system shall be compartmented (segmented) to allow for the maximum amount of data to be stored. The system shall be able to store data at the site in increments equal to the noted floppy disk volume until the total hard disk storage is filled. When this happens, the system shall ignore future vehicles until the system is down loaded to the Ames office site. The sensors shall be scanned each 30 minutes to determine the zero reading for each sensor. Zero readings shall be accompanied by a date and time of the readings.

Data from the piezo cables on gross and axle weights, speeds, classification and lateral location of the vehicle can be stored separately. It shall also identify each vehicle in terms of lane, time and date on the record to allow for matching of the vehicle information with pavement response data.

The field site strain outputs and piezo cables will be calibrated periodically with the use of at least five passages of a loaded single and tandem axle maintenance trucks of known weight at static conditions, creep speed, 30 mph and 55 mph in each lane. In addition the accuracy of the piezo equipment will be tested for accuracy using 100 trucks which have been weighed at static scale up the traffic stream from the site some five miles.

The data collected in the field will be transferred via modem at 300-1200 baud using suitable communication software in combination with the appropriate subroutines.

The data collected will be analyzed to determine the maximum and minimum strains, mean values, areas under the strain curves and the length and rate of increase and decreases of strain. The zero or null situation will provide for reduction of the data to a standard for analysis. This data will be correlated to the vehicle classification, weight, speed and location information. It will be used to compare the static and dynamic weights of the vehicles, the weight to strain magnitude, weight to deflection and frequencies of the strains to the expected pavement damage and what is observed. The use of the moisture/density information will aid in understanding the changes in strain and deflection for given loads over time.

SITE CHARACTERISTICS

Site Selection

Site selection for the instrumentation was carried out in the Fall of 1985 as the project was being proposed for the FHWA. It is important that the researcher identify the goals of the study prior to the site selection to insure that the site will provide the necessary background data to allow validation of the results over time. If a good pavement history is not available, the hidden variables of the site may overshadow the results found in the testing. The selection process identified certain site characteristics that limited the options of the researcher. They included:

1. A smooth pavement surface (PSI of 3.5 or greater) is desirable.
2. Four lane section where traffic flows could be directed over one or both lanes in either direction to observe the reactions of the tied slabs to a load in one or both lanes.
3. A horizontal, tangential section of 400-500 feet in front of the instrumentation to reduce the effects of grade and eliminate the centrifugal forces on the vehicle/pavement dynamic interaction.
4. Adjacent to an existing static weight station. It is important to be able to correlate the values of strain and deflection associated with a known load using the weight station and the instrumented site.
5. The pavement should be new, or in such condition that rehabilitation is not anticipated during the study period. Rehabilitation will require additional funding to maintain the Weigh in Motion equipment

and some of the deflection devices. If the existing pavement is used, the history of construction practices used, traffic and loading records, maintenance records and performance measurements should be available to document the history of the pavement prior to instrumentation. A new pavement is highly desirable for observation of the development of pavement failure function responses. If that is not available, existing pavements with well documented pavement condition studies can be used to measure the growth of the failure function responses over time.

6. If the pavement is being reconstructed at the time of installation, what is the construction schedule and how will the installation effect the work? This work must fit in with and not delay the construction project.
7. Pavements that carry large amounts of heavy trucks daily to provide a variety of loadings in relatively short period of time. This type of analysis can also be accomplished by deliberately under designing the pavement to fail. In either the most useable results can be obtained from pavements that represent those currently in use by the highway agency or proposed for use.
8. Accessibility of the site to the researcher, commercial power and telephone, and relatively short distance from the office to the project increase the research efficiency, reduce costs and increase the amount of items that can be studied at one time.
9. Sufficient length of 300-400 feet in front of the site to allow for the installation of Weigh in Motion or traffic loop equipment to act as a trigger for the data collection equipment. The actual distance

is based on the anticipated speeds of the vehicles and reaction time of the data collection equipment. Approximately 3-4 seconds are required to identify the vehicle, decide to collect data and trigger the data collection unit. If bridge weigh in motion equipment is used, the bridge should contain no more than three simple spans with concrete beams being the preferred type with a length of 100-300 feet. The bridge also acts to direct the traffic across the test slabs and minimizes lane changes in the test area. This criteria was not required in the installation due to the improved WIM device development between the planning and installation times.

In years past, Iowa programmed in excess of 100 miles of new or reconstructed portland cement concrete pavement each year. The combination of a nearly completed and mature state highway system, a major need for pavement rehabilitation monies and a general reduction in highway funding reduced the average number of miles of portland cement concrete paving to 50 miles per year in 1985-1989. The reduced number of miles of new pavement being placed and the other criteria limited the project to less than six potential areas that were scheduled for new construction or reconstruction.

The final site selected for the instrumentation is located in Pottawattamie County in Southwestern Iowa in the Westbound lanes of I-80 near the town of Minden shown in Figure 3. The site is part of a seven mile reconstruction project extending from near the I-80 and I-680 interchange (milepost 28.0/station 908+50) easterly to a point on the east end of the Shelby interchange (milepost 35.1/station 1380+85). The instrumented site is located near milepost 30 ±/station 1119 ±) at the west end of the Keg Creek Bridge as shown in Figure 4.

The site was selected for the following reasons:

1. The pavement was being replaced as part of the reconstruction project. This provides an opportunity for good documentation of the base and pavement characteristics of the reconstruction.

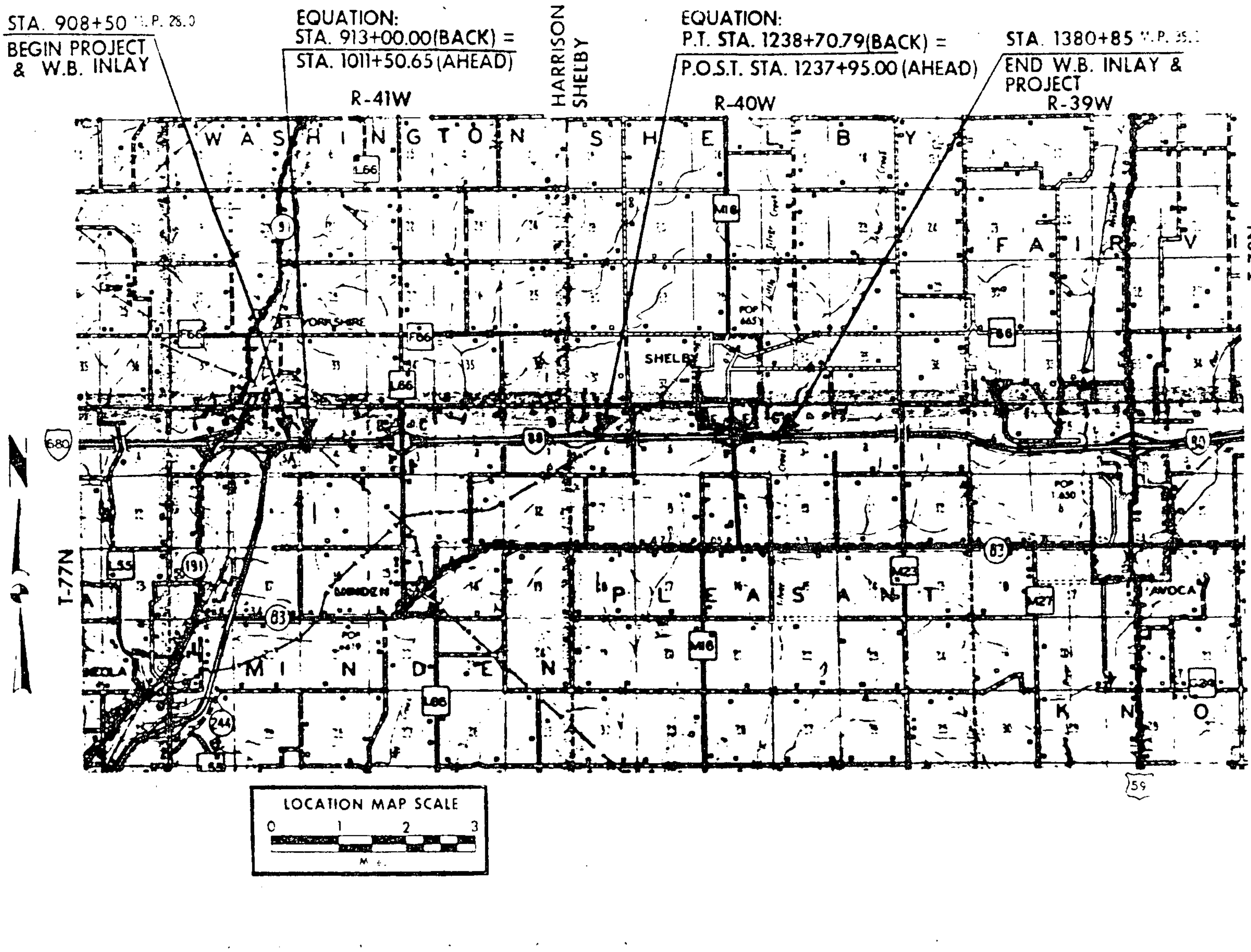


Figure 3 Instrumentation Construction Project Site

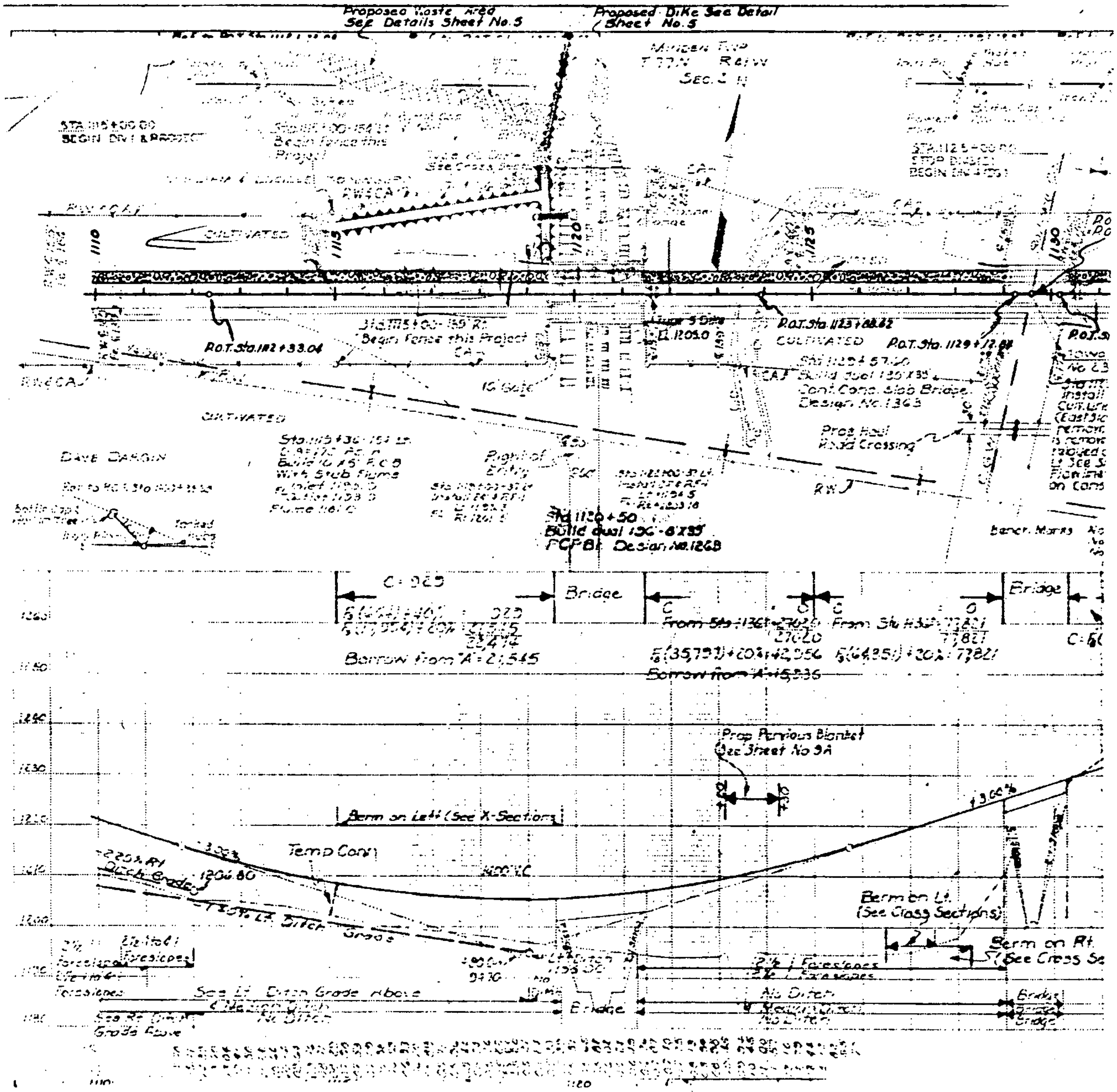


Figure 4 Instrumentation Site

2. The bridge could be used as a weigh in motion site for calibrating the sensors in the pavement to known loads. It also could be used for identification of the lateral location and speed of the vehicles entering the test site and crossing the traffic loops. Lane changing by the vehicles is reduced on the bridge.

3. This route provided the heavy truck traffic and a mix of truck configurations to adequately test the pavement strain theories.

4. The section is near the low point of a 1,400 ft. sag vertical curve providing a relatively flat grade across the test site. The effects of grade are minimized in the the test.

5. The new pavement created a very good chance for smooth pavement profile at the beginning of the test.

6. A static weight station (Figure 5) is located east of the site approximately 15 miles on both the east and west bound lanes and can be use to check the correlation of weights and strains. A continuous traffic recorder is located in the new pavement approximately one mile east of the site in the west bound lanes that can provide ADT counts for pavement wear calculations.

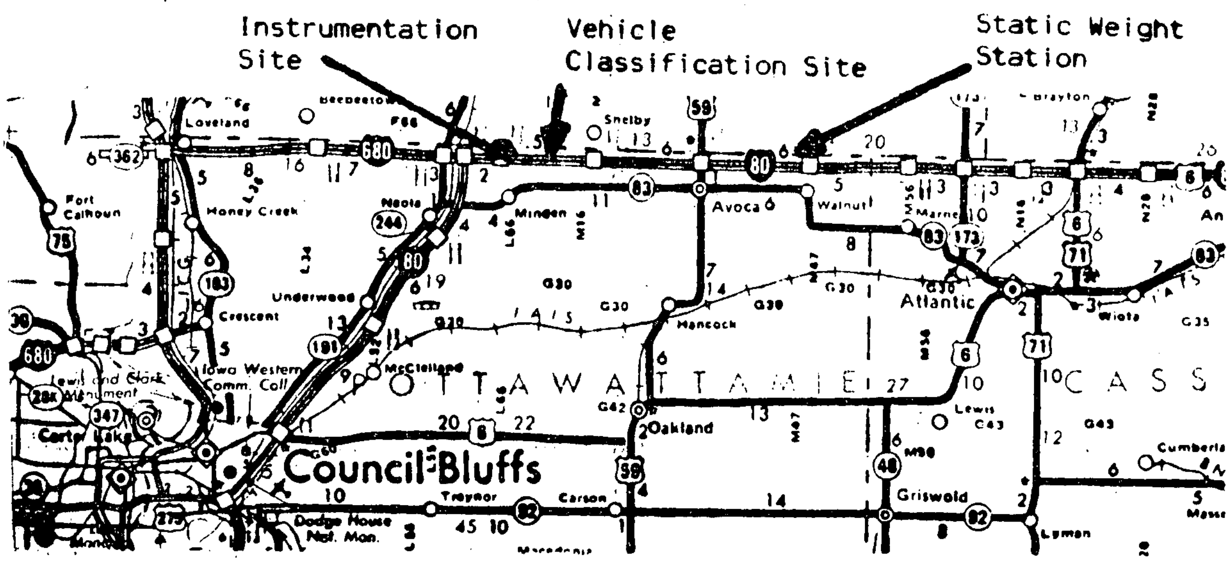
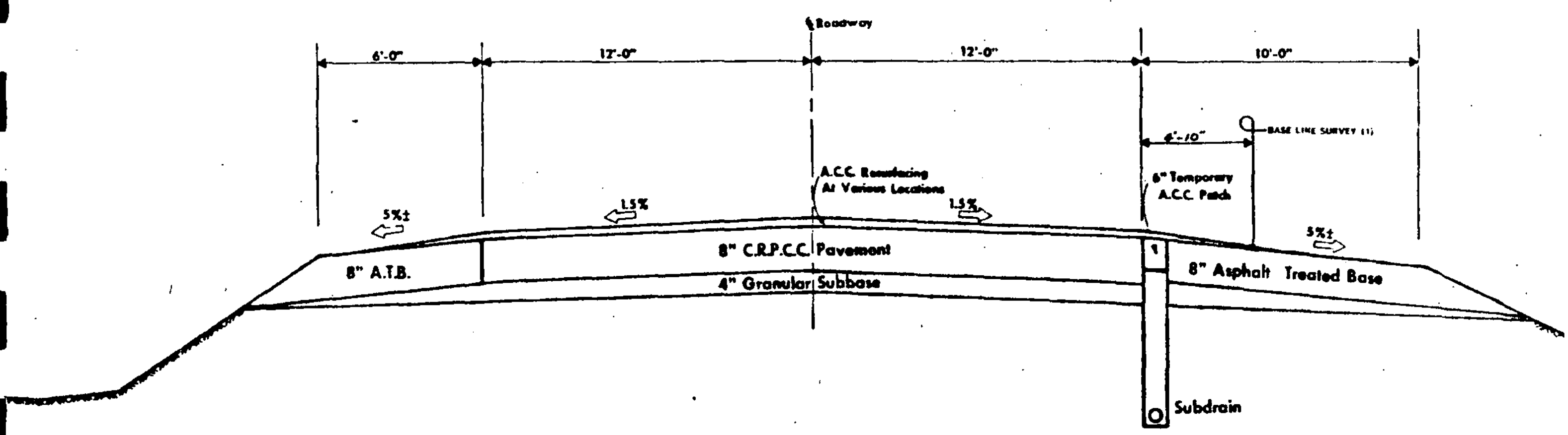


Figure 5 Static Weight Station and Traffic Counter Locations

Site Preparation

The reconstruction project was composed of 7.1 miles of pavement reconstruction in the west bound lanes of I-80 from milepost 28.0 to milepost 35.1. The existing pavement was composed of 8 inches of continuously reinforced portland cement concrete pavement placed over a 4 inch granular base. Full depth 8 inch asphaltic concrete shoulders were built at the time of construction. A four inch diameter flexible plastic longitudinal subdrain was placed in the trench 4 foot below the surface of the pavement along the outside edge of the pavement driving lane prior to the reconstruction. A cross sectional view of the existing pavement is shown in Figure 6.



TYPICAL CROSS SECTION
EXISTING HIGHWAY
(VIEWED IN THE DIRECTION OF TRAFFIC)

Figure 6 Typical Cross Section of the Existing Highway

The reconstruction included the removal of the concrete pavement, base and 3-4 inches of subgrade. The trench was also widened to allow for placement of a 24 foot, 10 inch wide portland cement concrete pavement and allow the equipment to pass by the retained shoulder materials. The existing pavement was crushed and returned to the site to be used as a drainable base. The base varied in thickness from a 6.5 inches at the median side of the driving surface to 9.5 inches at the outside shoulder edge. An 11 inch thick joint reinforced concrete pavement was placed on top the base. The shoulders were resurfaced with 2.5 inches of Type B asphaltic concrete base (class 1) material. The new cross section is illustrated in Figure 7.

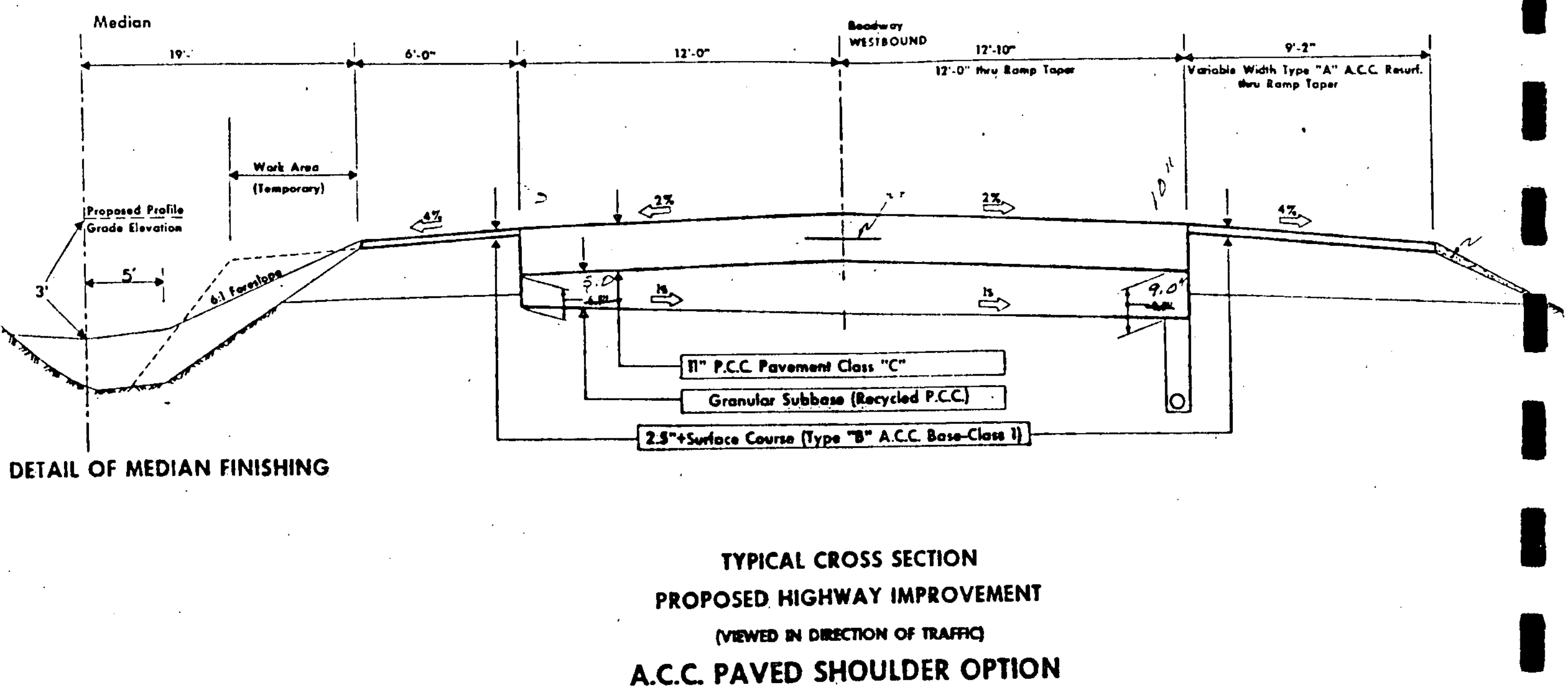


Figure 7 Typical Cross Section of Proposed Highway Improvement

A view of the completed base construction looking west from the Keg Creek bridge is shown in Figure 8. The work of placing the deflection reference conduits is underway in the photo.

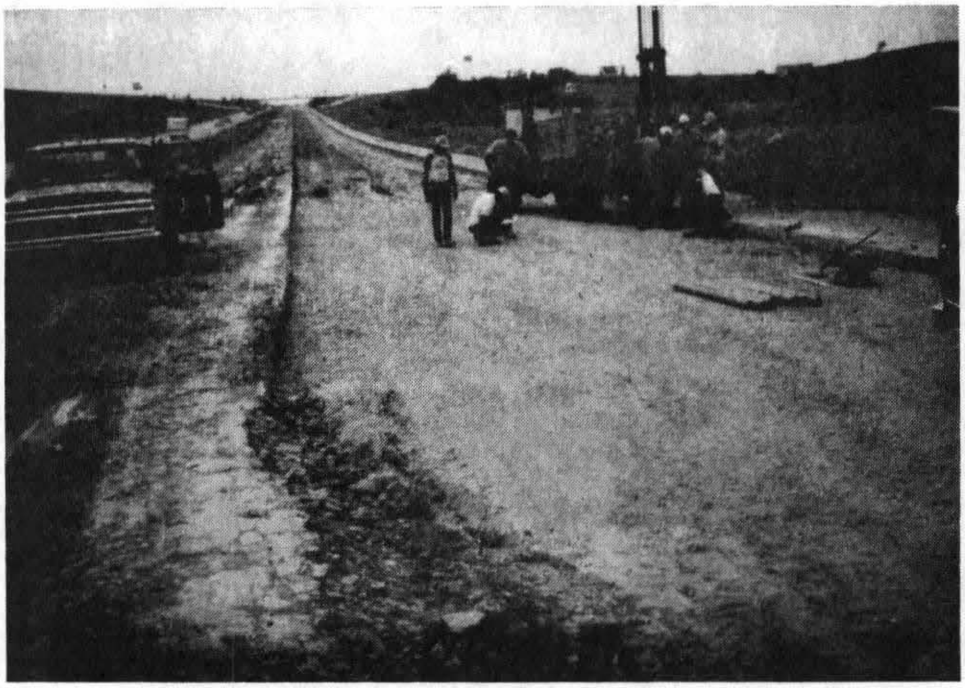


Figure 8 Test Site With Base Material in Place

The construction work took place in the summer months of 1986 in stages to meet the traffic needs at the various interchanges along the project. Installation was anticipated as early as July, but due to weather and other project construction problems, the pavement was placed in September in this location.

The project site is located some 4,000 ft. east of the center of the Minden interchange and all sources of power and telephone. A phone cable and high voltage power line were buried in a common trench along the north right of way line of the Interstate Highway from a pole at the end of the controlled access in the northeast corner of the Minden Interchange. It was trenched out from that line to a point behind the guardrail at the northwest corner of the Keg Creek Bridge in a wingdike (Figure 9) to the control cabinet for the site in Figure 10. The cable was purchased from the local telephone and power

Figure 9 Test Site End of Buried Power Cable

Figure 10 Control Cabinet With Buried Power Source

companies and placed by Department of Transportation staff to reduce the costs. Aerial service in the same location proved to greatly increase the cost and potential for maintenance costs in the future.

Department of Transportation staff were used to cut trenches at five locations across the base material and through openings created by the contractor in each shoulder. Two inch inside diameter aluminum irrigation pipe for nuclear moisture density testing, such as the single pipe at the left of the three types of pipe used in project and shown in Figure 11, was placed through the pavement area and the outside shoulder in 10 ft. lengths on a 1% slope from the median edge of the pavement to the outside edge of the pavement. Pipes were sealed at the joints with joint materials and capped to inhibit water from entering. The last 10 ft of each pipe was placed in the median shoulder after the paving train of equipment had passed on that side to the pavement to protect the pipe structure and the grade of the pipes.

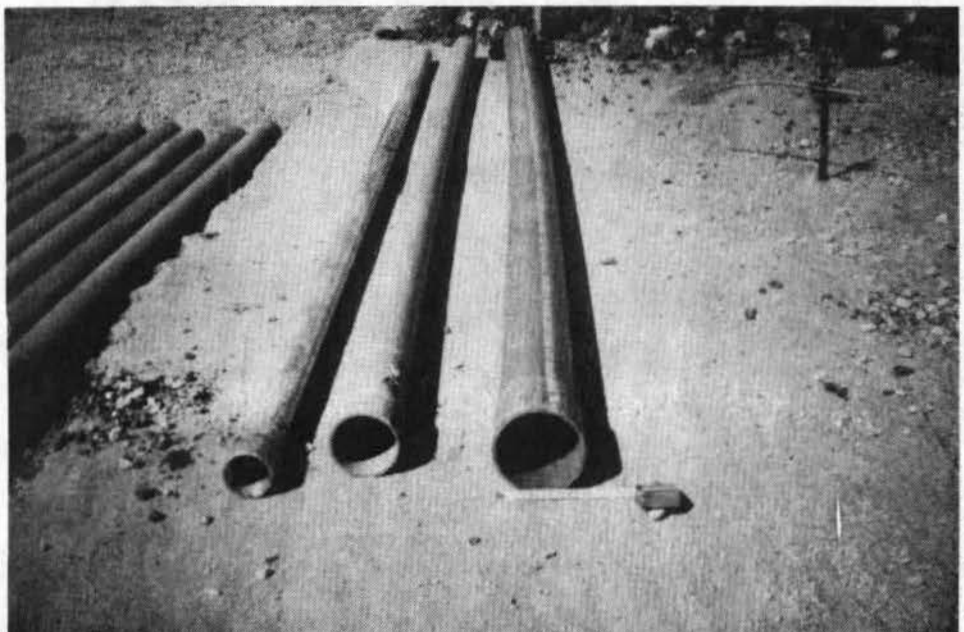


Figure 11 Typical 2 inch Aluminum and 3 and 4 inch Diameter PVC Pipe

A common trench approximately 6 inches wide was cut longitudinally from the the westerly most pavement joint of the test site, easterly on the outside shoulder to the control box site on the wing dike of the Keg Creek Bridge as shown in Figure 12. The concrete for the control cabinet was supplied by the paving

Figure 12 Longitudinal Trench Connection

contractor and placed by Department staff. A control cabinet and base shown in Figure 13 were installed after the concrete placement by Department staff and insulated as shown in Figures 14 and 15. This serves as the command center for the data collection and analysis at the field installation.

A Department of Transportation soils investigation drill unit was used to drill 5 inch diameter holes, 5 foot deep at each of the deflection gage locations. This was accomplished in the completed base and subgrade prior to the paving operation. A five foot section of 3 inch diameter PVC pipe was

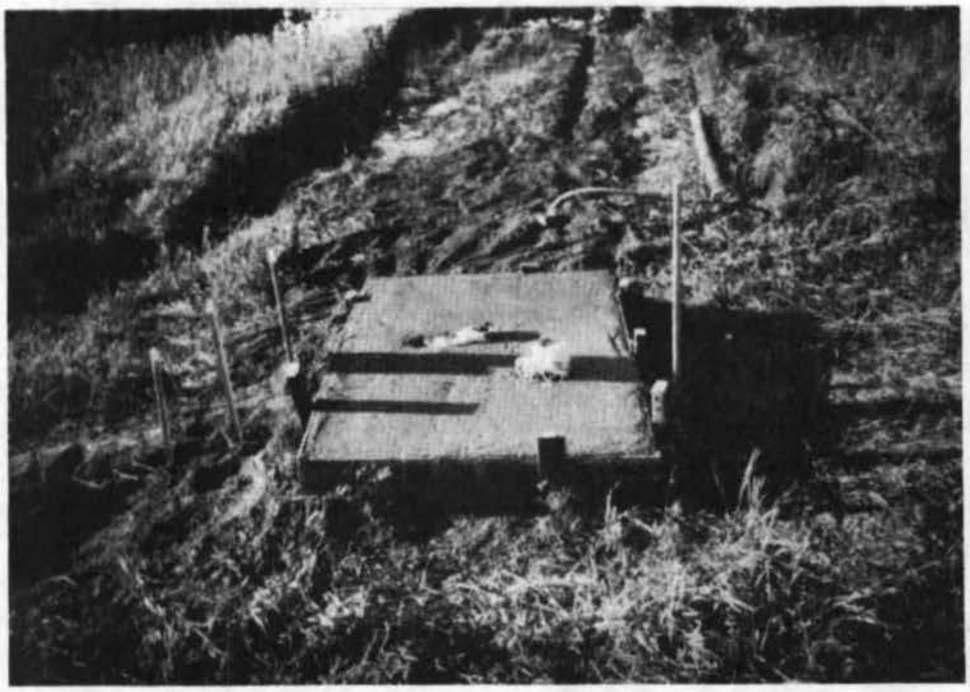


Figure 13 Control Cabinet Completed Base

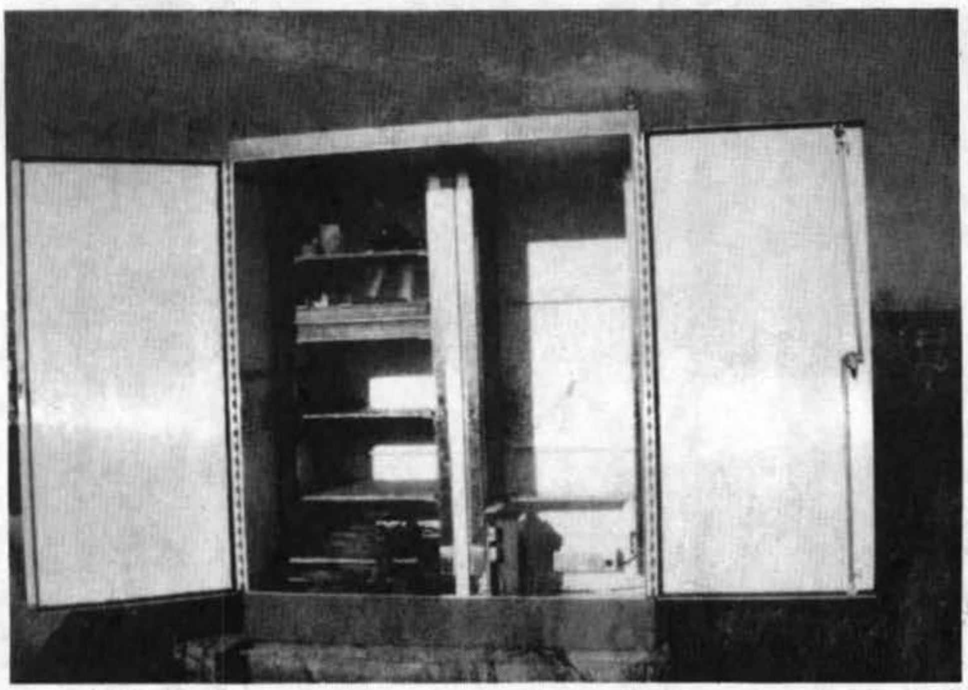


Figure 14 Control Cabinet Interior View

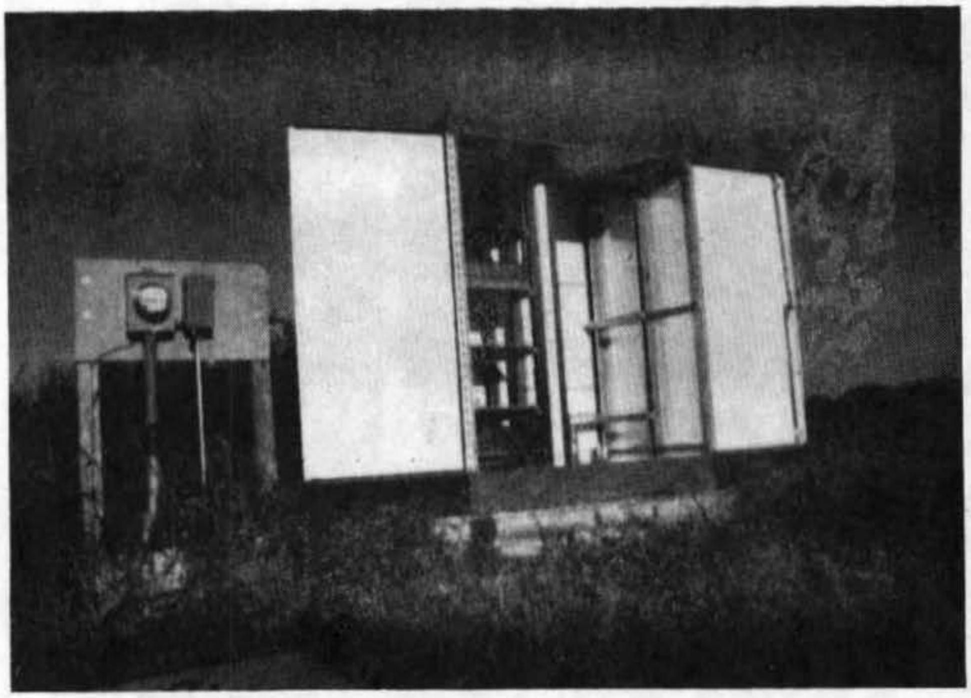


Figure 15 Control Cabinet and Base Exterior View

Figure 16 Deflection Reference Hole Construction

inserted in each of the holes as shown in Figures 16 and 17. This casing provided protection for the reference rod driven later. A one foot square section of plywood (Figure 18) was used to cover each of the holes during concrete placement. The center of each hole was precisely located by the Department of Transportation survey crew for future retrieval purposes. The target plywood section shown in Figure 18 was painted four colors (red, yellow, green and blue) and placed in the same color arrangement over each hole. This was done to insure a way to identify any location changes required in the drilling of the completed concrete to place the housing over the test hole. An example of the target covers in place over the reference holes is shown in Figure 19.

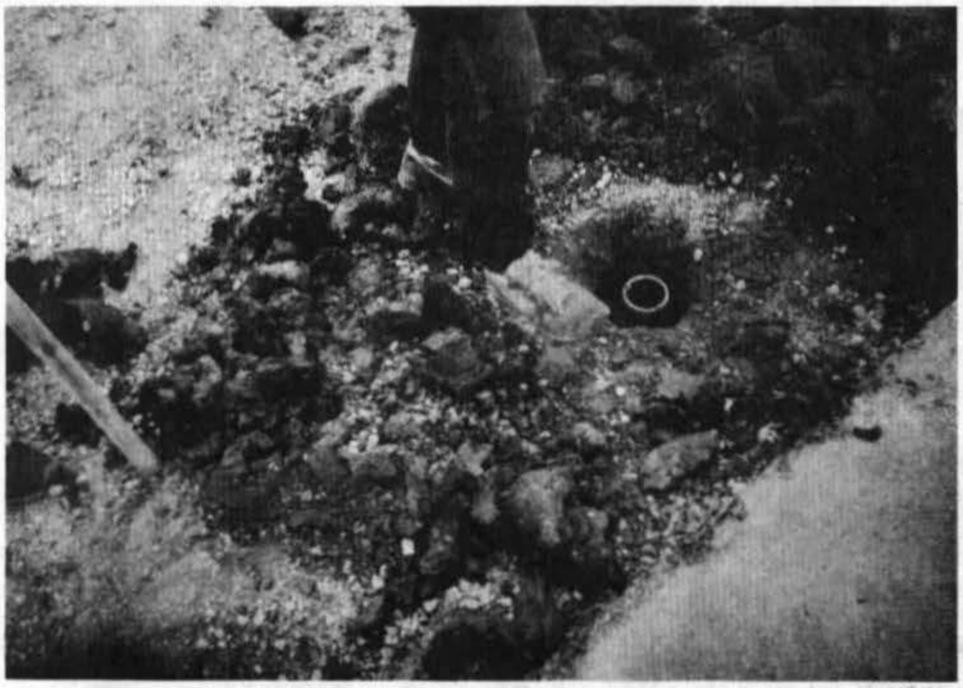


Figure 17 Deflection Reference Hole Conduit in Place

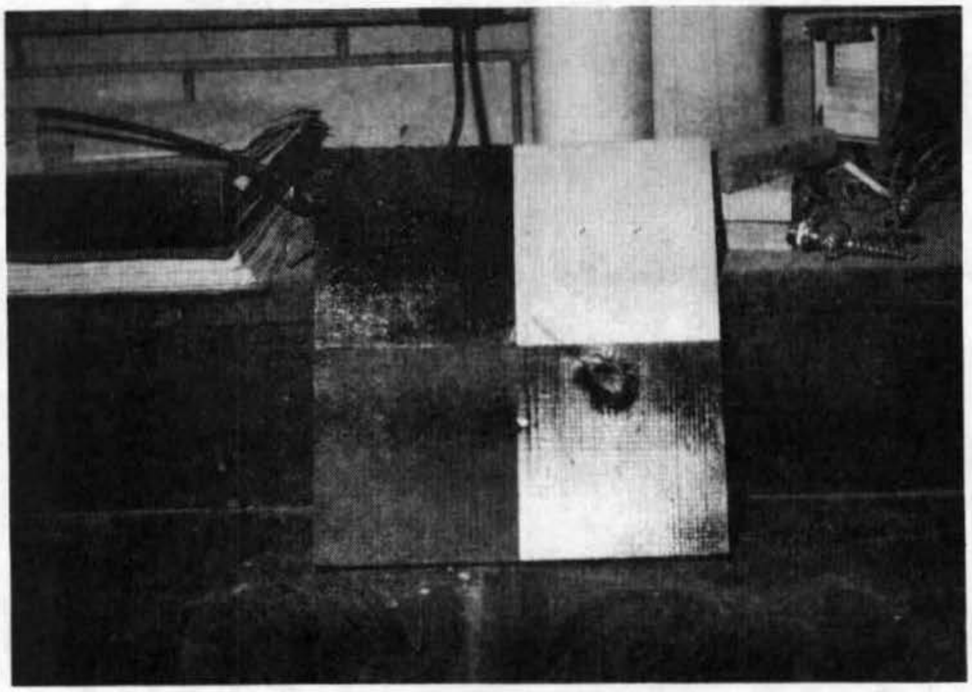


Figure 18 Reference Target

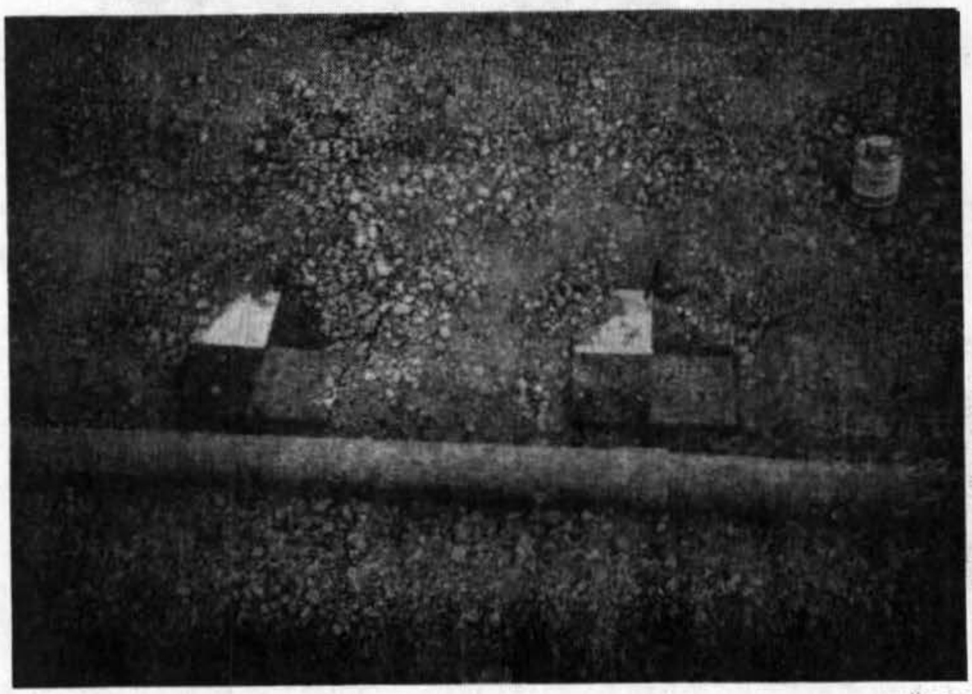


Figure 19 Reference Targets in Place

SITE INSTRUMENTATION

Instrument Selection

It is appropriate at this juncture to consider the costs of purchasing commercially available equipment exactly suited to a given application versus assembling components to the same end. It can be stated that universally it wiser to purchase commercially available equipment if at all possible, because even though the front end cost of the components in the system are lower, the overall costs measured in man-hours, equipment failure, required modifications, and erroneous results will always outweigh any initial cost advantages. While exceptions to this rule certainly exist, the supporting evidence is overwhelming. For this study several commercially available gages were not used due to the cost and availability on the limited time schedule. These include steel encased concrete strain gages with pre-attached cables, diaphram earth pressure cells, and vibrating wire weldable strain gages. The selection of the concrete and steel strain gages for this project was based largely on the experience of the ISU Civil Engineering Staff. This particular staff has completed similar work on the instrumentation of concrete bridge decks, beams and railroad subgrades. The particular instruments were selected on the basis of reliability, cost, ease of installation, and durability under field conditions. The gages selected included the following:

Concrete Strain Measurement: A molded gage manufactured by the TML Tokyo Sokki Kenkyujo Co. Ltd., distributed by the Texas Measurements Inc. company of College Station, Texas and identified as a PML-60 model was installed to measure concrete strains. The length of the concrete gages is an important selection parameter. Longer gages average, of course, over a larger aggregate stress concentration. As a rule of thumb the gage should be three to four times as long as the maximum aggregate size in the pavement. The gage also averages the strain and consequently the stress over its' length as well, so the gage length is a compromise between measurement of stress at a point and accuracy of measurement. The gage measures 60 mm long and 1 mm wide and is imbedded in an epoxy capsule covered with grit that measures 125 mm by 15mm by 5mm. The gage has a nominal resistance of 120 $\pm$ ohms, gage factor of 2.1 and is packaged in groups of five. The gage, shown in Figure 20 can easily be embedded by hand in the concrete or carefully attached as was done in this project to a bar cage to achieve a specific location in the concrete as the the concrete is placed. The operational temperature range of the gage is -30 to +60 degrees centigrade.

Reinforcing Dowel Strain Measurement: A weldable strain gage, model LWK-06-W250B-350 made by Micro Measurements Division of Measurements Group, Raleigh, North Carolina, was used on the selected rebars at each of the three pavement joints. Weldable gages were selected due to the speed of installation versus bonded gages. Surface preparation requirements are significantly lower for weldables than bonded gages. The other primary advantage of these particular gages was the pre-attached lead wires (10 inches long). Solding to gage pads is a time consuming and technically difficult project, where as in solding of the lead wires to the shielded cable was simple and required relatively little techniques. The gage shown in Figure 21 is a precision foil sensor bonded to a metal carrier for spot welding to structures and components. It measures 6.35 mm long by 3.18 mm wide and has a

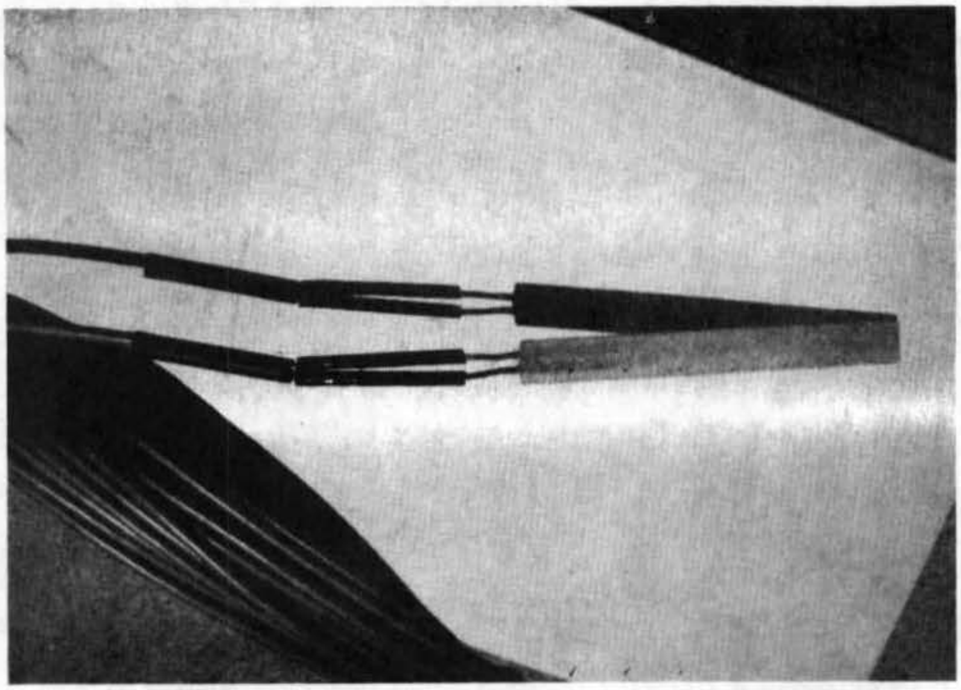


Figure 20 Concrete Strain Gage

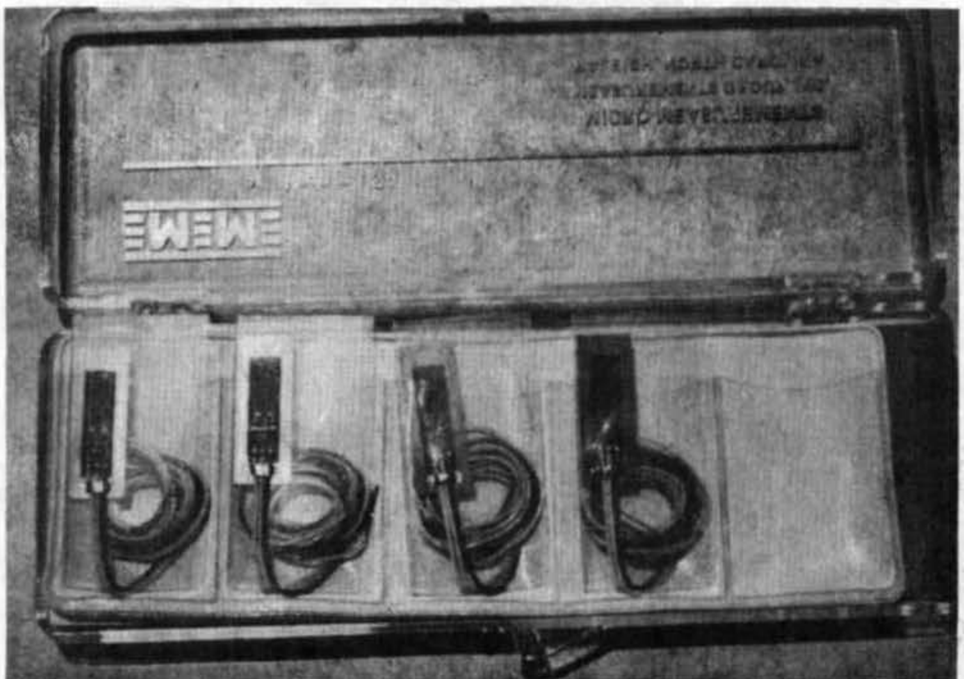


Figure 21 Weldable Strain Gage

nominal resistance of 350 $\pm$ ohms. It has a strain range of $\pm$ 5,000 micro strain meters per meter and a temperature range of -195 to +260 degrees centigrade. The gage is also packaged in groups of five for delivery.

Temperature Measurement: A Micro Measurements model WTG-50C grid sensor was used to measure the concrete, air and base material temperature. The gage is comprised of a strain grid mounted on a thin nickel foil. Temperature is determined by the strain in the nickle foil. The gage is mounted in a similar method to a bonded strain gage, but is is not sensitive to strain. The grid is 6.35 mm by 3.18 mm and is bonded in the resin mold of 9.53 mm by 3.18 mm. The gages have a temperature range of -195 to +260 degrees centigrade and a nominal resistance of 50.0 $\pm$ 0.15 ohms at 23.9 degrees centigrade.

Deflection Measurement: A Trans-Tek Inc. Displacement Transducer DC-DT series 240-000 was used in specially built housings in the wheel paths to measure pavement deflection. The gage, shown in Figure 22, has a working range of $\pm$0.500 volts.

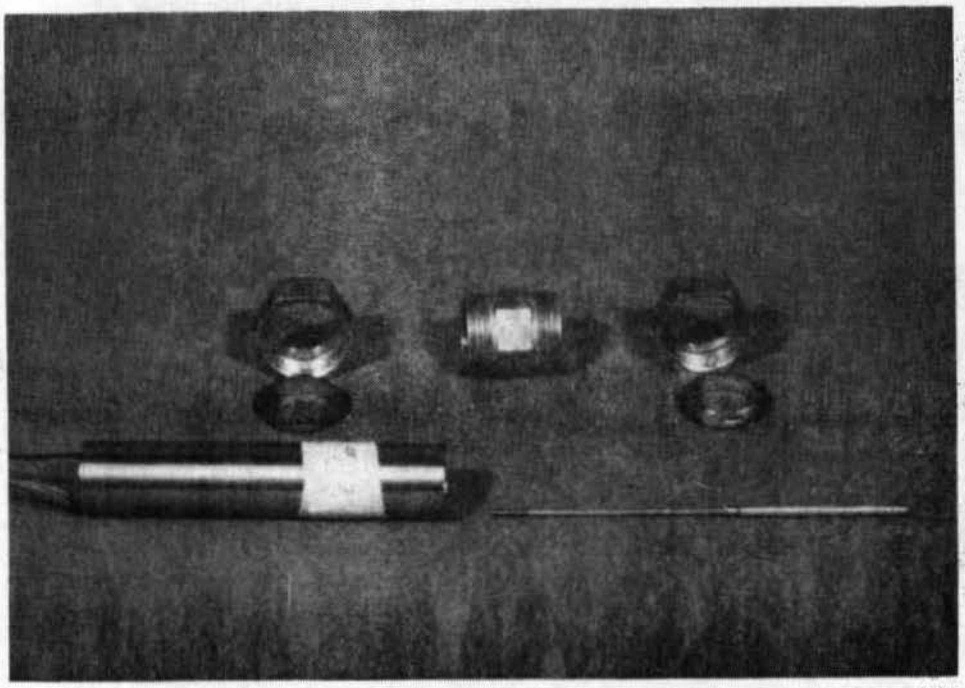


Figure 22 Deflection Gage

Moisture and Density Measurement: Troxler equipment was selected to perform measurements on the relative moisture and density in the base and subgrade material. A density gage model 1352 (Figure 23) with scaler unit and moisture gage model 3321 (Figure 24) were used for the testing. Special 90 and 100 foot hoses were obtained for the units to allow passage completely across the road under the pavement. Such units have not been tested under these type of conditions before and are experimental when used in this in operational mode. The test probe shown in Figure 25, that is pulled through the conduits to assure no obstruction, was specially fitted with a chain on each end for retrieval in the case of an obstruction.

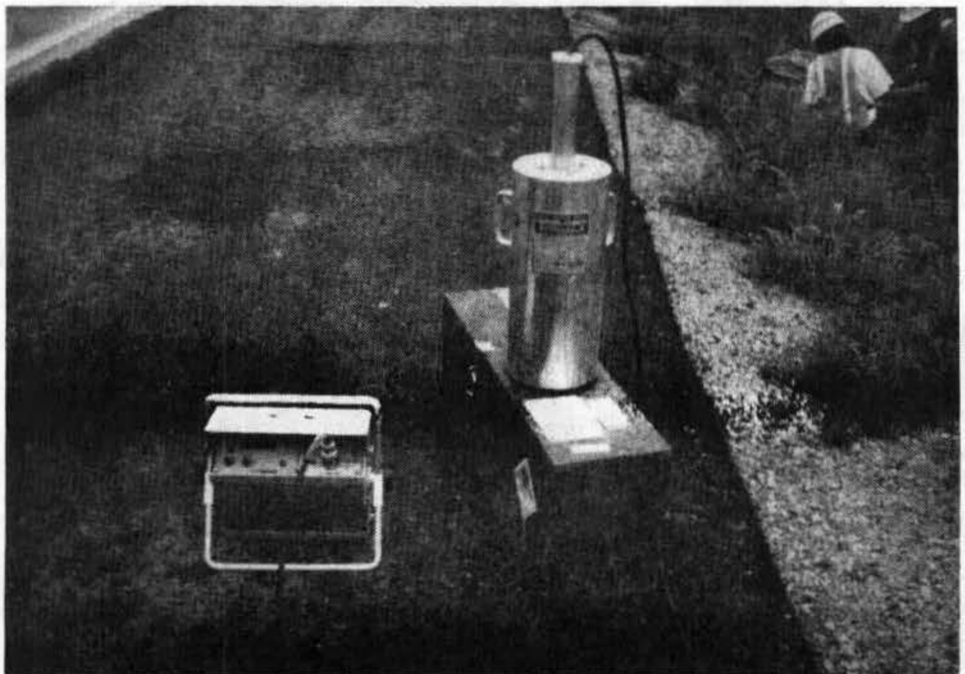


Figure 23 Troxler Density Gage With Scaler Unit

Figure 24 Troxler Moisture Gage

Figure 25 Troxler Test Probe

Gage Preparation

The gages were prepared for installation in the laboratory at ISU. A staff of three graduate students was used to prepare the wiring, attach the weldable gages to the dowel bar assemblies and test each gage.

A layout of the site from the construction road plans was established to determine the location of each sensor (Figures 26-29) and the length of wire needed to connect it to the control cabinet. Belden #8723, four conductor wire in 1,000 foot spools was used for this purpose. This wire selection was based principally on economic considerations. Durability of insulation is an important consideration during installation as well as the long term and should always be considered versus cost. All wire lengths were grouped to optimize the number of sections obtained from each 1,000 foot spool. A sample is shown in Figure 30. Each connecting wire was cut for a specific gage connection. No splices beyond the gage were made in the connecting wires to avoid possible resistance change in the line. Some 18,000 ft. of wire was required for this project.

Each of the concrete gages was tested in the laboratory to insure that there were properly connected. The concrete gage lead wires were cut to a short length and soldered to the Belden wire according to a predetermined standard three wire color code configuration. This operation should be accomplished in the laboratory to reduce the chance of gage damage. Each of the wire welded connections was first coated with M-coat B and encased with a special heat shrinking tubing (Surface Irradiated Polyolefin #Fit-300-wire diameter in inches) with a meltable interior wall to seal the connection. This material is used to seal, strengthen and waterproof the joint. Shown in Figure 31, the material is placed on the wire prior to the welding, moved over

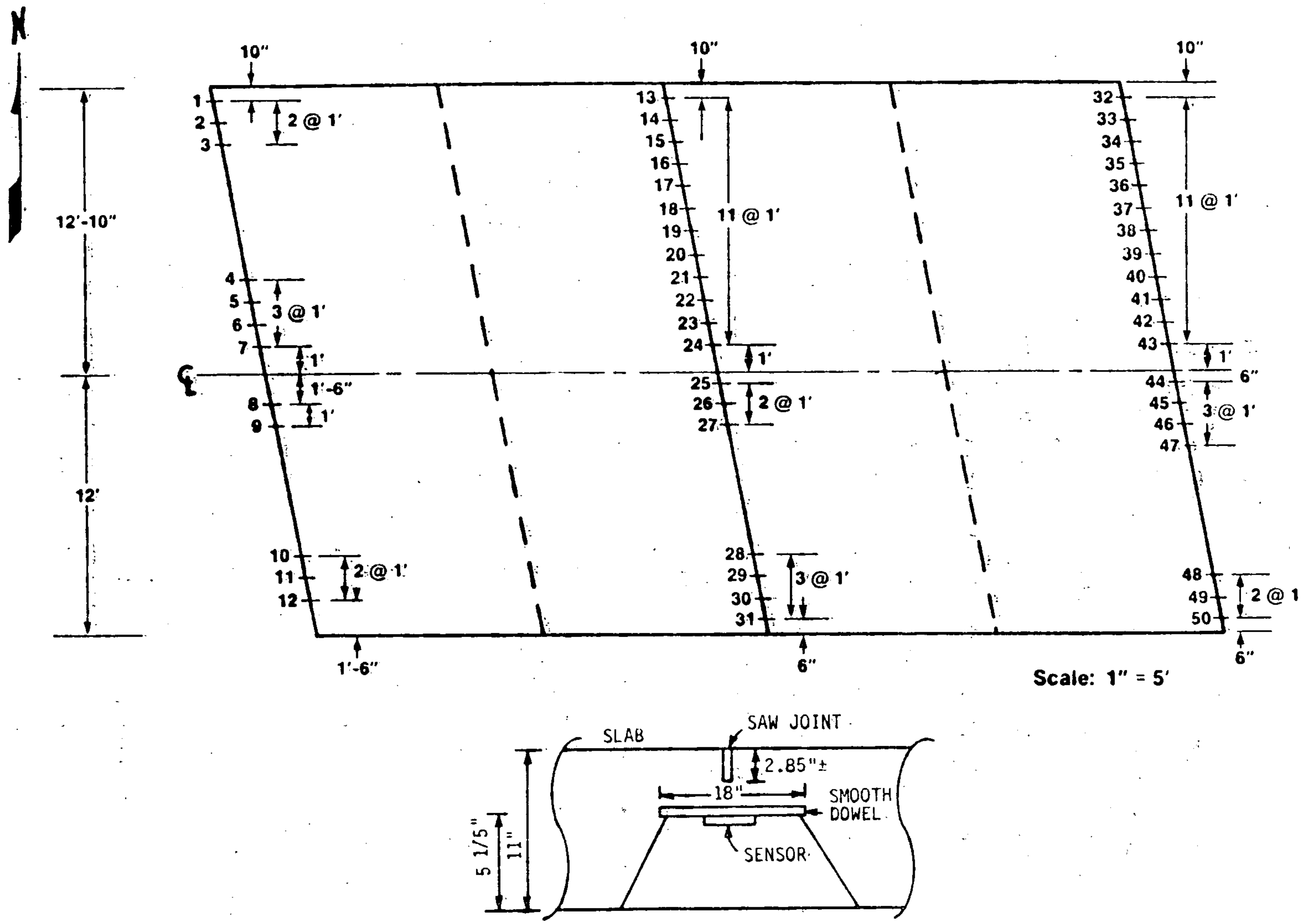
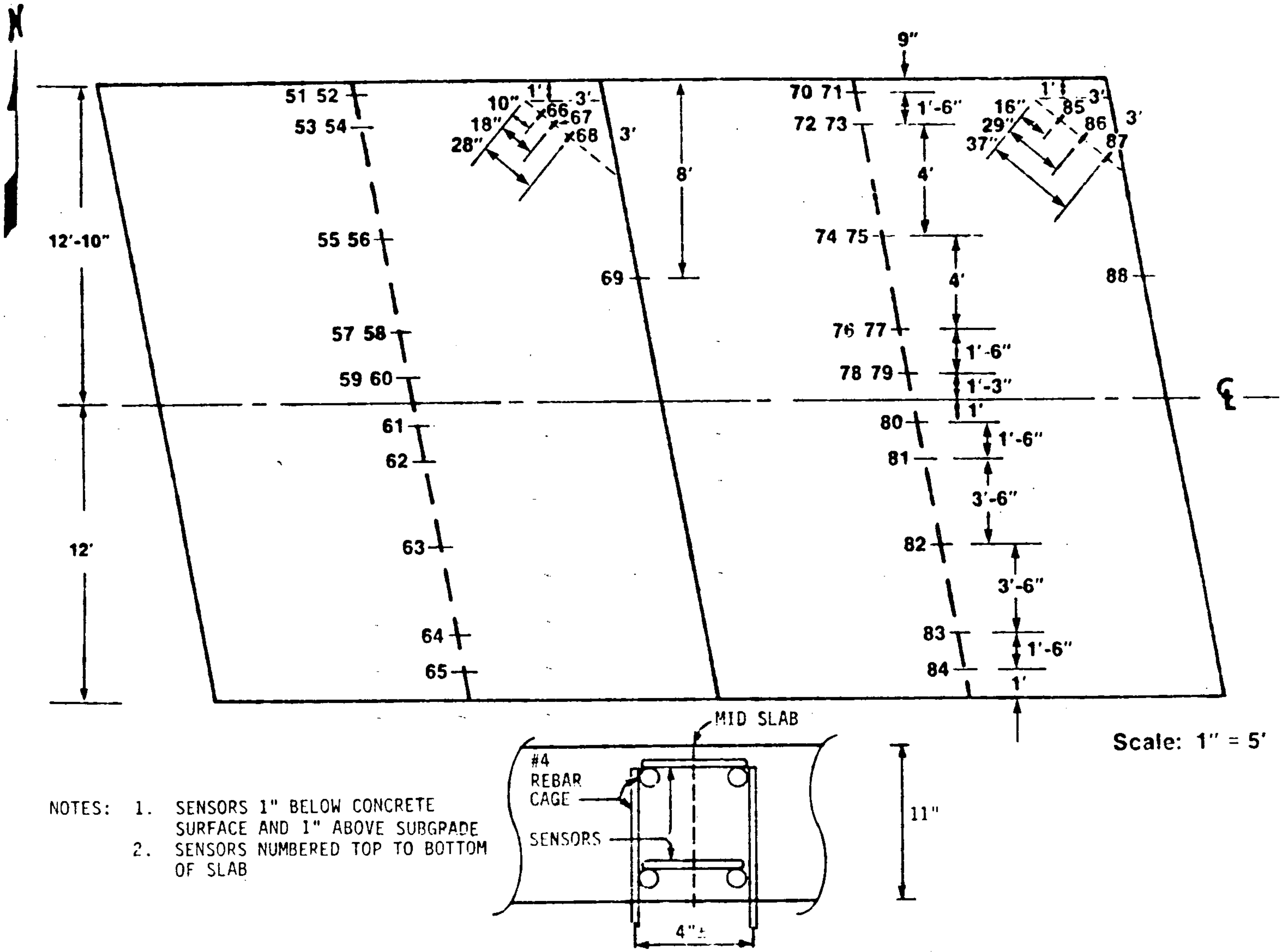
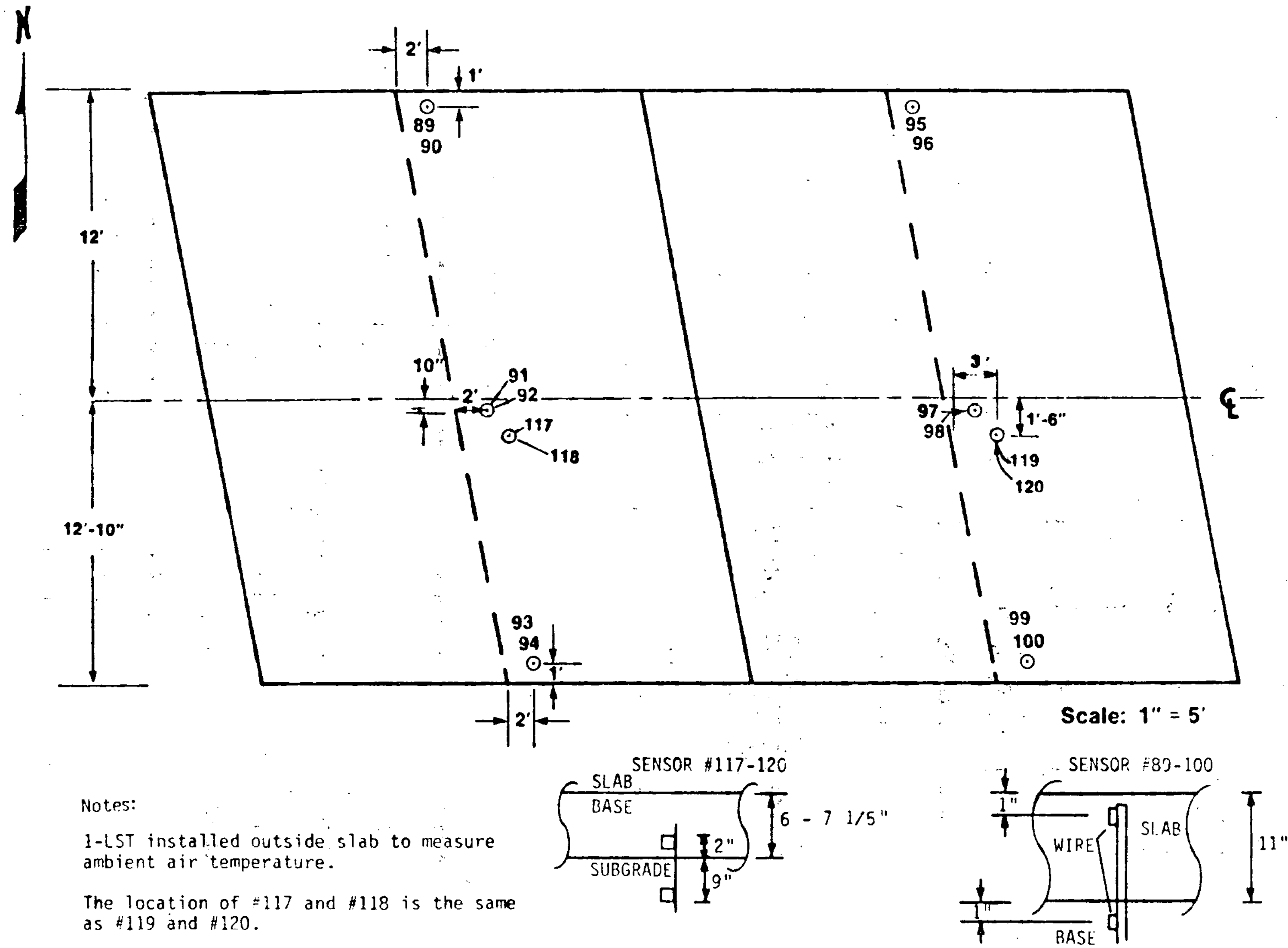


Figure 26 Dowel Bar Sensor Location

Figure 27 Concrete Sensor Location



NOTES: 1. SENSORS 1" BELOW CONCRETE SURFACE AND 1" ABOVE SUBGRADE
2. SENSORS NUMBERED TOP TO BOTTOM OF SLAB

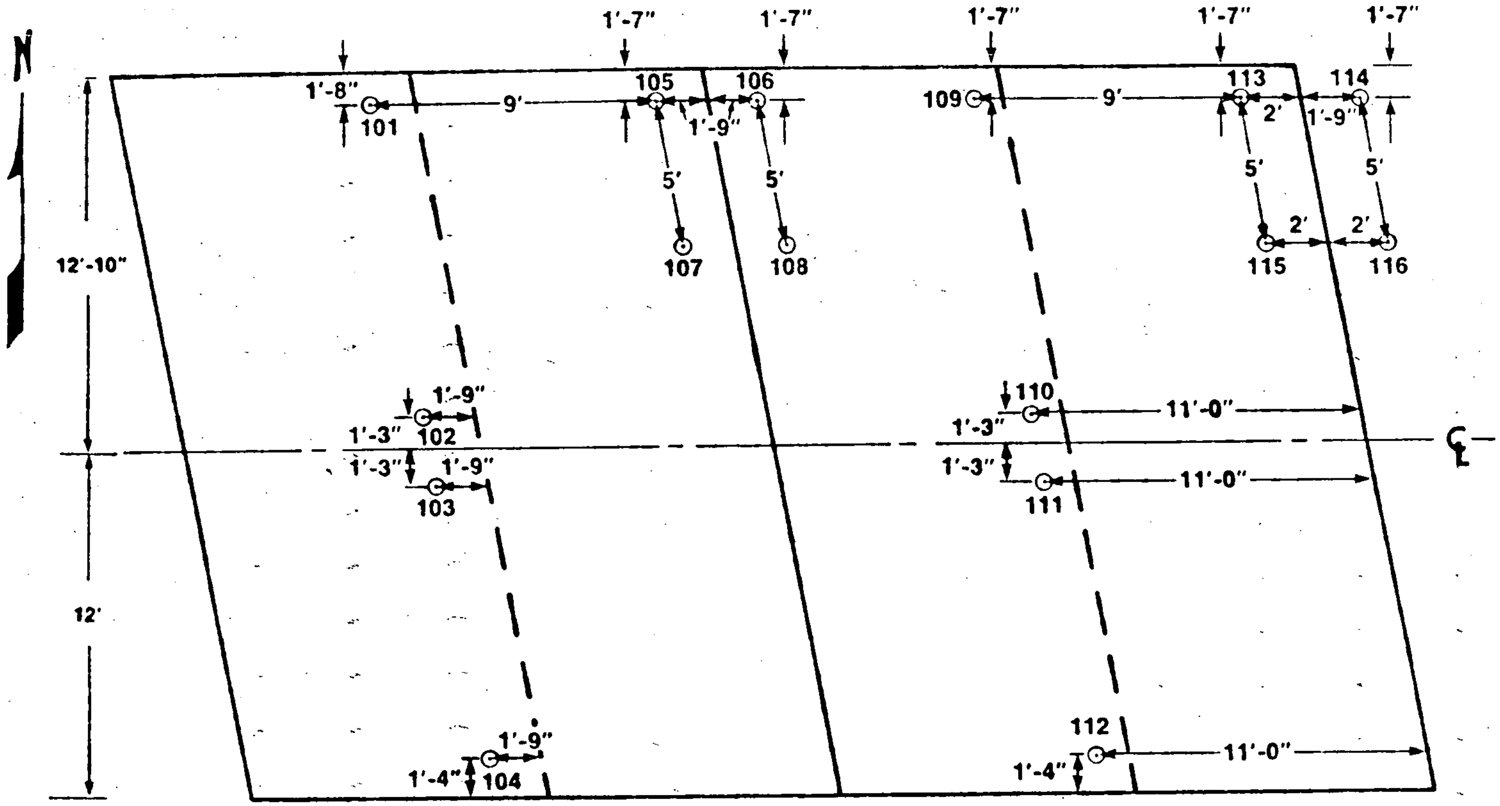


Notes:

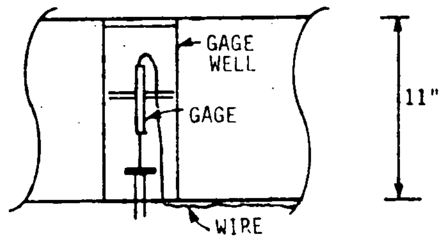
1-LST installed outside slab to measure ambient air temperature.

The location of #117 and #118 is the same as #119 and #120.

Figure 28 Temperature Sensor Location



Scale: 1" = 5'



NOTE: 1. GAGE WELLS #102, 107, 116 ARE EMPTY DUE TO WIRE LOSS DURING CONSTRUCTION

Figure 29 Deflection Sensor Location

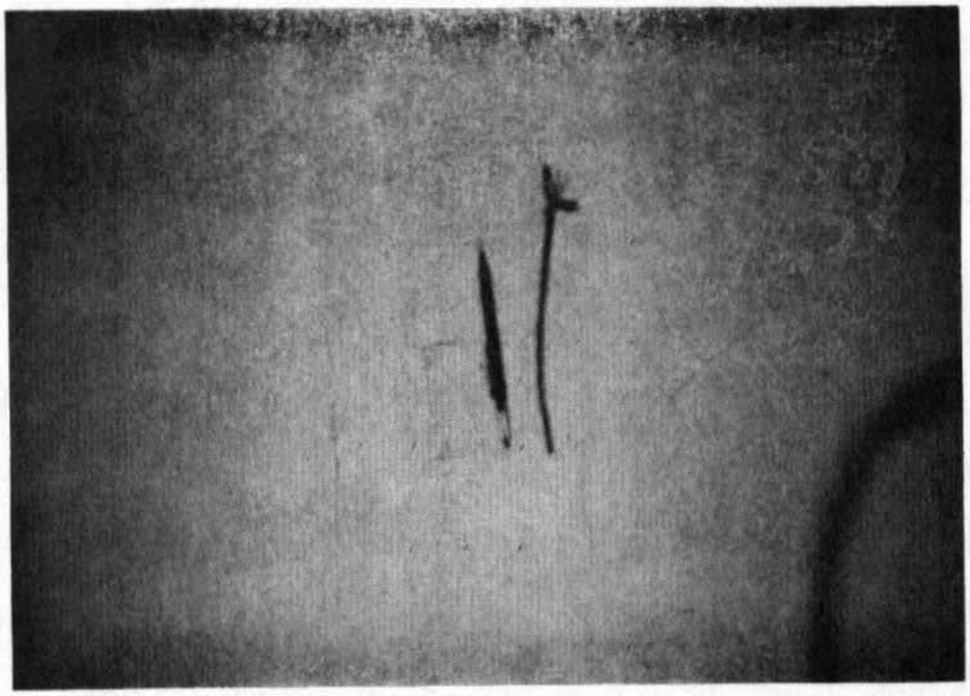


Figure 30 Belden Wire Conductor

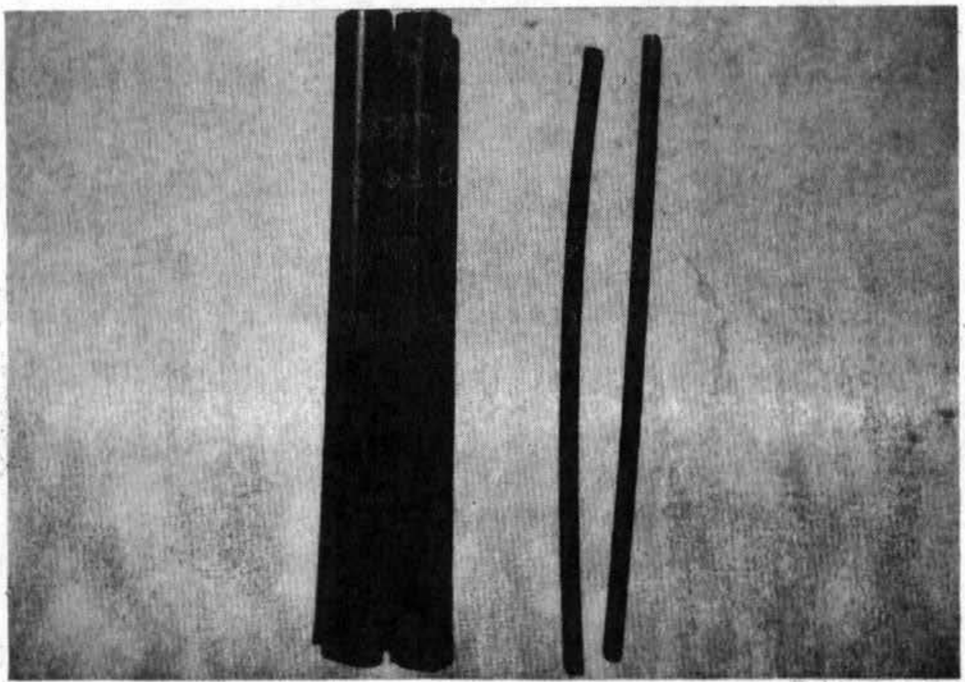


Figure 31 Surface Irradiated Polyolefin Material

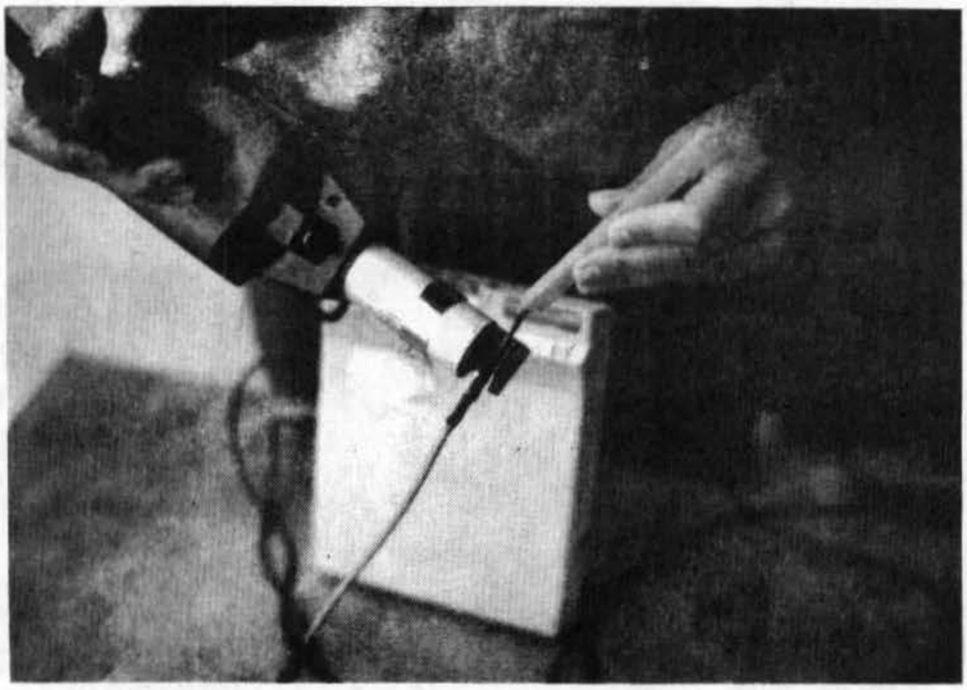


Figure 32 Heat Gun Used in Sealing Wire Connections

the completed joint and heated to shrink around the joint as shown in Figure 32. This material was used to seal all sensor to control wire connections. The insulation of the solder connections is the foremost factor in the longivity of the gage installation, therefore it should be treated with the upmost care. Different insulations adhere differently to various sealants, so the combinations should be carefully considered.

The dowel bar assemblies for the project were supplied to the contractor in 12 foot lengths with the first of the 1-1/4 inch diameter dowels spaced at 1 foot intervals along the bar chair assembly. The investigators decided to measure strain on the bottom of the dowel bars, to affore the gages the maximum physical protection during installation. To provide redundancy of measurements three of the joints in the passing lane and one of the joints in the driving lane were equipped with strain gages on the bars under the wheel paths, and distributed accross the slab. Each of the transverse joints and midslab locations is numbered in Figures 26-29 from west to east (locations 1-5). On joint number one, three bars at each end of the joint in both the driving and passing lane were instrumented. In the case of joint locations three and five, each of the dowels in the driving lane was instrumented for redundancy. Joint number one of the passing lane was instrumented on three dowels along the median edge and the second and third dowels to the right of centerline. Three sensors were planned at this location, but one sensor was lost in the fabrication process. Joints three and five of the passing lane are laid out in identical, but opposite patterns using three and four bar combinations again in the wheel paths. All of the Belden cables were marked at the control cabinet end by a Shrinkable Wire Cable Marker #MRK-C-LS using a letter, number or combination of letters and numbers to identify the sensor connected to each cable.

The dowels assemblies were supplied to the laboratory by the Department of Transportation staff. Each was coated with a black epoxy compound specified for the construction contract. The coating for a distance of approximately one inch was removed at the center of the specified bars on the bottom of each bar. The intent of this location is to record the maximum strain under the sawed joint in the pavement. This was first accomplished by grinding with the use of an abrasive disc grinder and then the use of a hand held Dynafile #11021 Stroke Sander with special #11258 contact arm shown in Figure 33 and demonstrated in Figure 34. This technique was precipitated by the selection of weldable strain gages with preattached lead wires. Grinding techniques would have been far more rigorous if bondable gages had been selected. In this case the cost of labor for gage bonding would have far outweighed the difference in the cost of the gages. About one half man hour was required for grinding and surfacing of each gage location. Quality control was a major consideration even though weldable gages are significantly less sensitive to surface aberations. Each ground surface was carefully degreased and etched using Micro Measurements cleaning procedures. Care was taken to clean an area at least one quarter inch larger than the gage in all directions to assure bonding of the protective coatings. Welding was done with a specialized spot welder from Micro-Measurements. The gages were coated with M-Coat A for sealing, and M Coat JL-3 for physical protection (Figure 37). Wire leads were coated with M-Coat B (Figure 36), for sealing and meltable heat shrink tubing was utilized to cover lead wires to the cable connections. Again a three wire connection was utilized. Cables were epoxyed to the dowel bar sets and further reinforced with cable ties to prevent stress on the gage lead wires. Due to the number of gages on a single dowel set, the package became unwieldy in a short time, so great organizational wherewithal was required to assemble and transport the cage assembly. The cables were identified in the same manner as those on the concrete gages.

Special housings for the deflection gages were constructed in the Department of Transportation Machine Shop from stock materials. The housing shown in Figures 38-42 is constructed from 4-1/2 inch O.D. drill casing conduit and cut to eleven inch lengths. Each was threaded at one end and a special cap of bar stock was machined to fit the opening as shown in Figure 38.

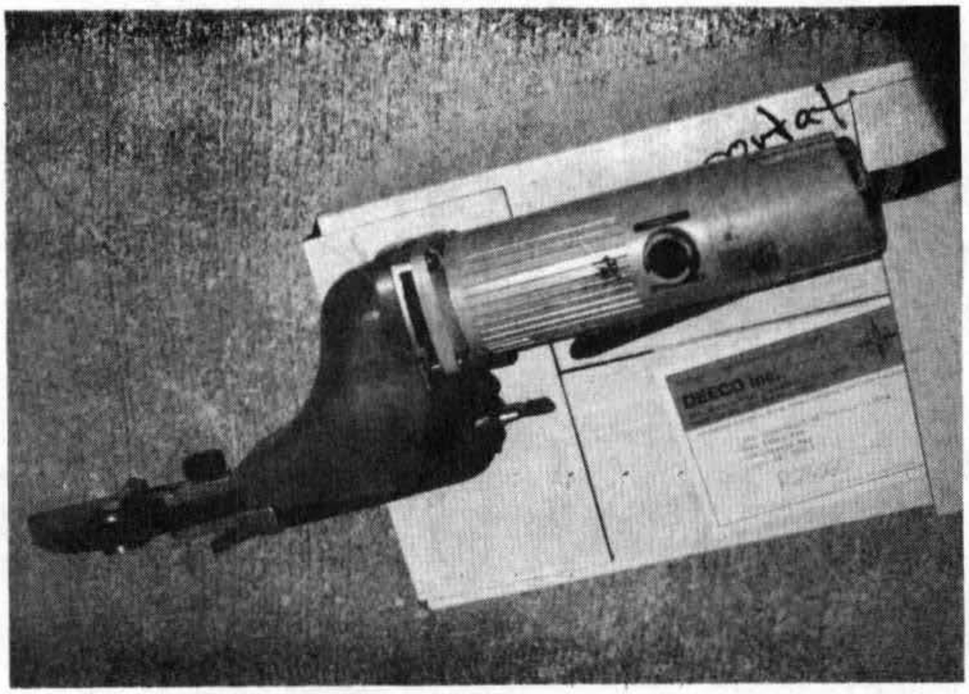


Figure 33 Dynafile Stroke Sander and Contact Arm

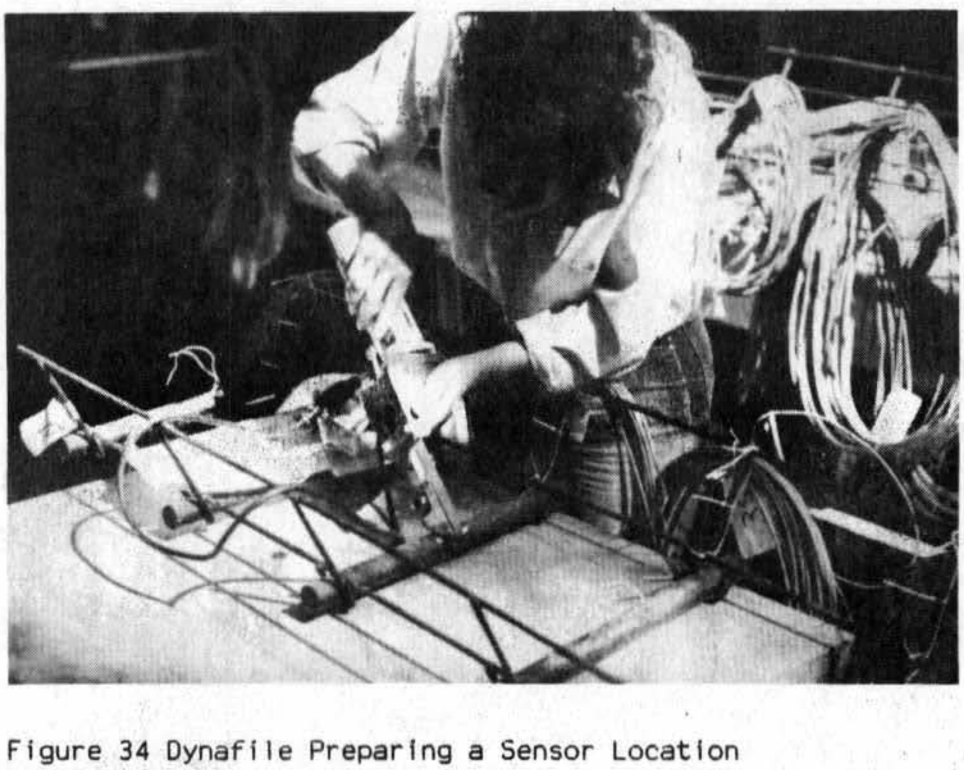


Figure 34 Dynafile Preparing a Sensor Location

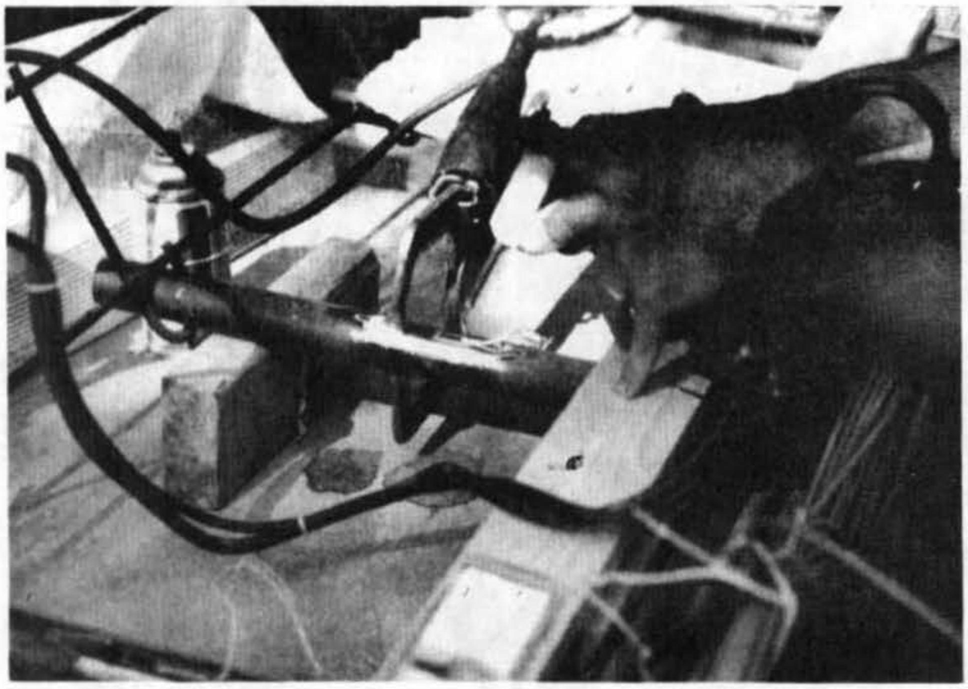


Figure 35 Welding a Sensor to the Dowel Bar

Figure 36 M Coat B Sealer

Figure 37 M Coat JL Sealer

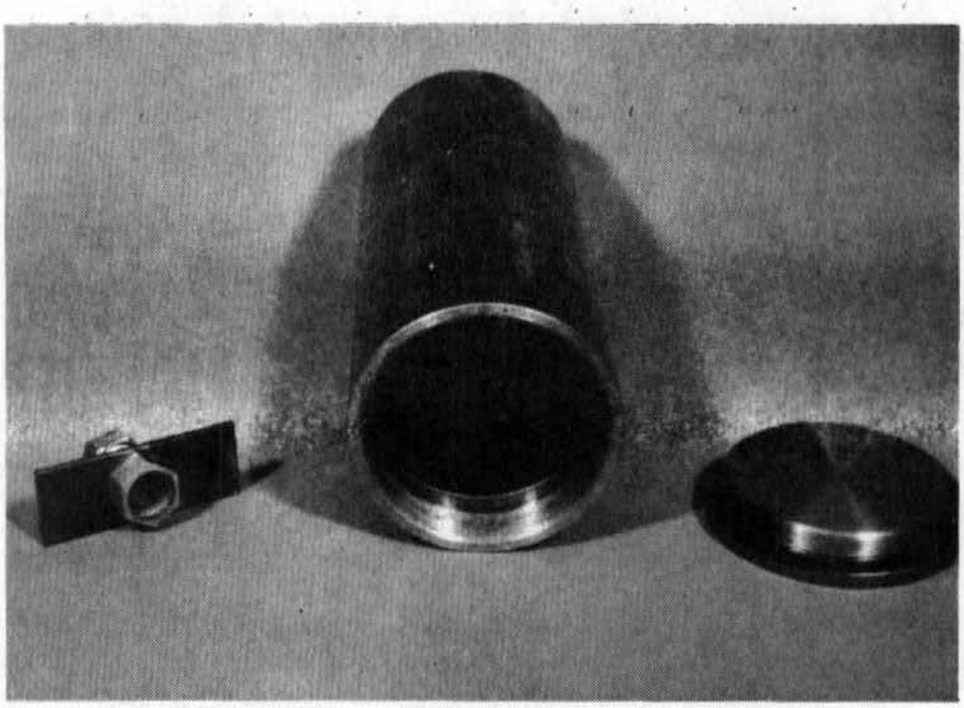


Figure 38 Deflection Housing and Cap

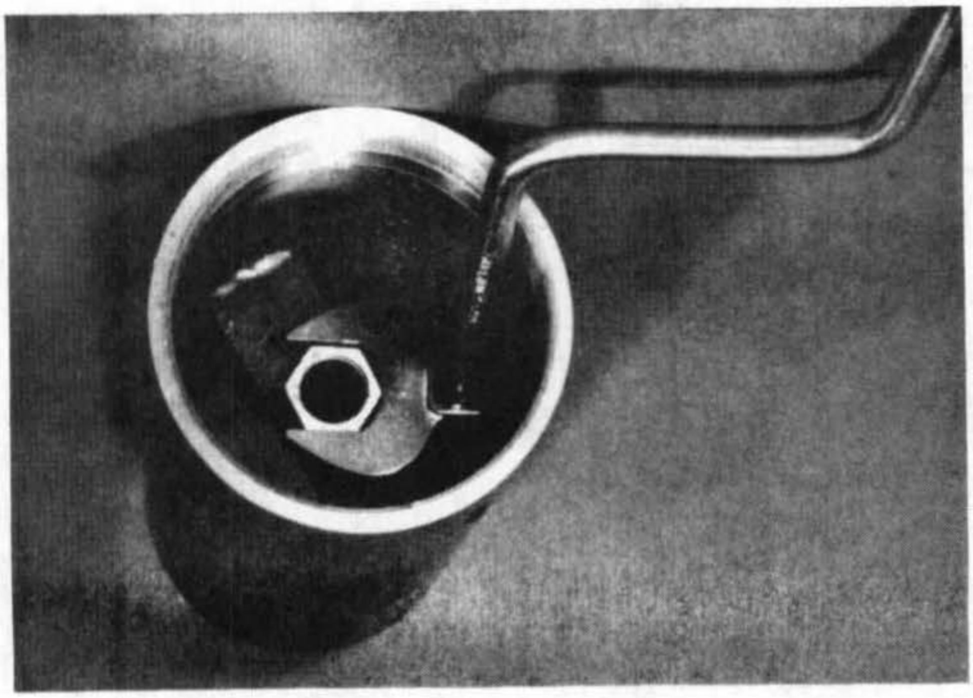


Figure 39 Deflection Housing Adjustment Assembly

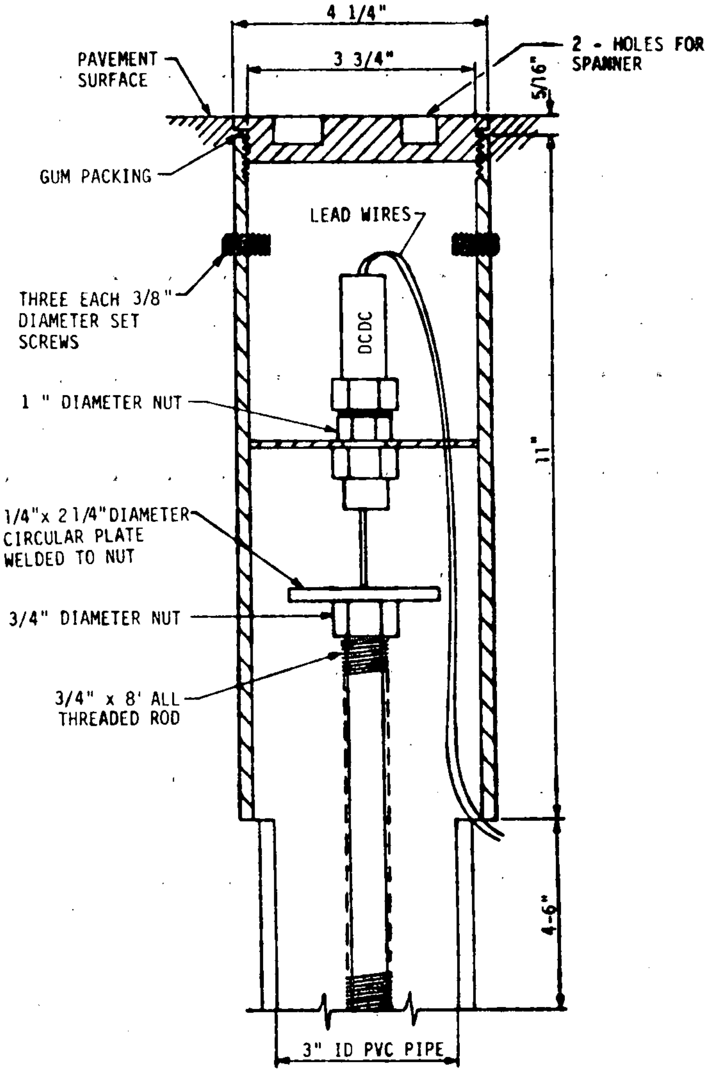


Figure . Layout of vertical displacement measurement instrumentation.

Figure 40 Sectional View of the Deflection Housing

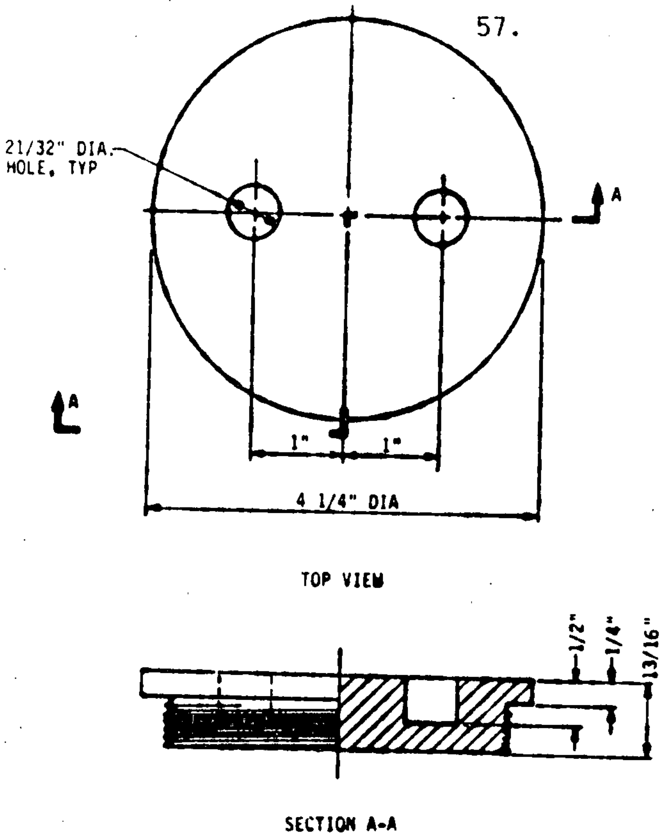


Figure 41 Sectional View of Deflection Housing Lid

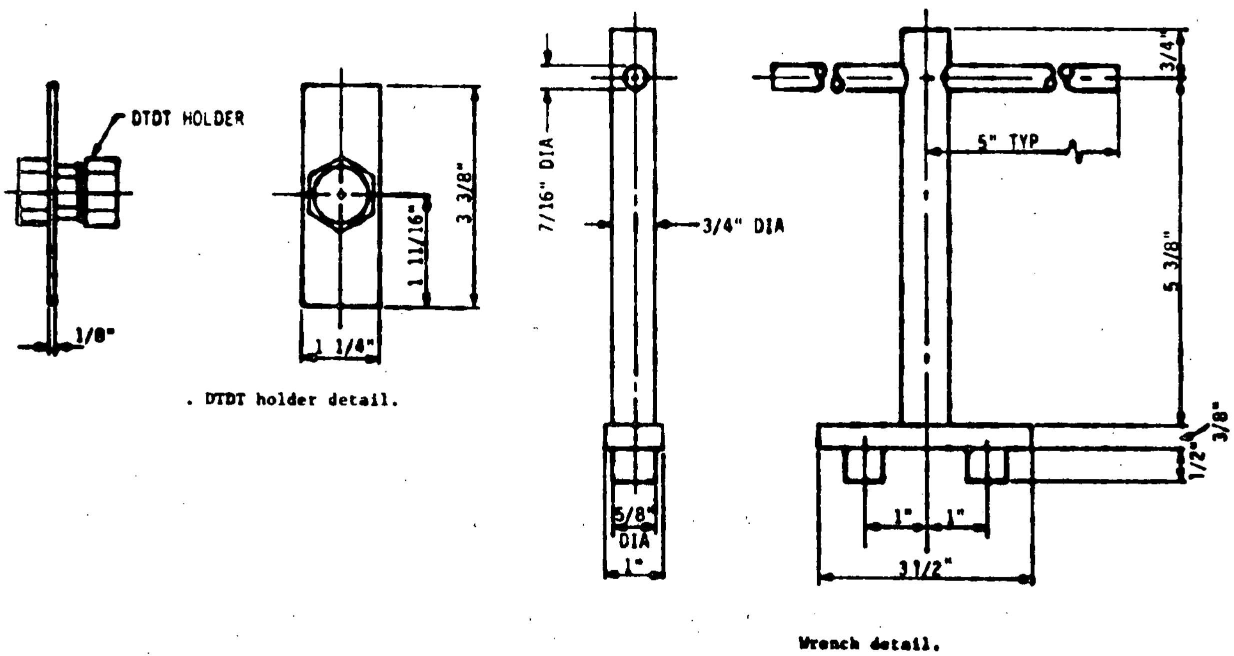


Figure 42 Sectional View of Deflection Housing Adjustment Assembly

A rubber O-ring was used to allow for opening and resealing of the lid. The assembly is held in place in the concrete by three set screws mounted near the top of the assembly for access by the appropriate wrenches. Two holes were drilled partially through the lid to form a place for a specially designed wrench to be used in opening the assembly.

Inside the deflection housing, a horizontal brace was used to support a self locking nut device which will support the actual deflection sensor. The device allows the sensor to be inserted, position changed vertically, and removed from the site without removal of the housing. A one inch crows foot head for a 3/8 inch drive set is used to tighten and loosen the locking device while it is in place as shown in Figure 39. The wiring for the deflection devices was connected in the field to wires placed under the concrete slab and into the three inch PVC housing the deflection reference rods.

The temperature sensing devices were mounted on # 4 deformed reinforcing bars such as shown in Figure 43. The Micro Measurement temperature sensors were treated identically to a bondable strain gage, so flats on the reinforcing bars were finished to a 400 grit surface before gage mounting. The installation also required bonding pads because lead wires were not preattached. The gages were protected in the same manner as the weldable strain gages. The sensors were located in such a manner as to place the top sensor approximately 1 inch below the pavement and base surfaces, and two inches above and nine inches below the subgrade surface. A single sensor was attached to one bar to be placed outside the control box to measure ambient air temperature. Each of these sensors and connections were sealed and the cables identified by wire markers. A circuit element is available to connect the temperatures sensor directly to a standard wheatstone bridge, but in this application the connections near the gage were impossible. The calibration would not be possible. The data acquisition for the temperature sensors will therefore have to use a different circuit on the analog side.

Each of the electronic senors/gages was tested prior to installation and after they had been installed on the dowels or reinforcing bars for circuit continuity and strain registration. It is important to note that these devices are very fragile and require extreme care in the connection of the device to a reference material and the connection of the wire leads to the

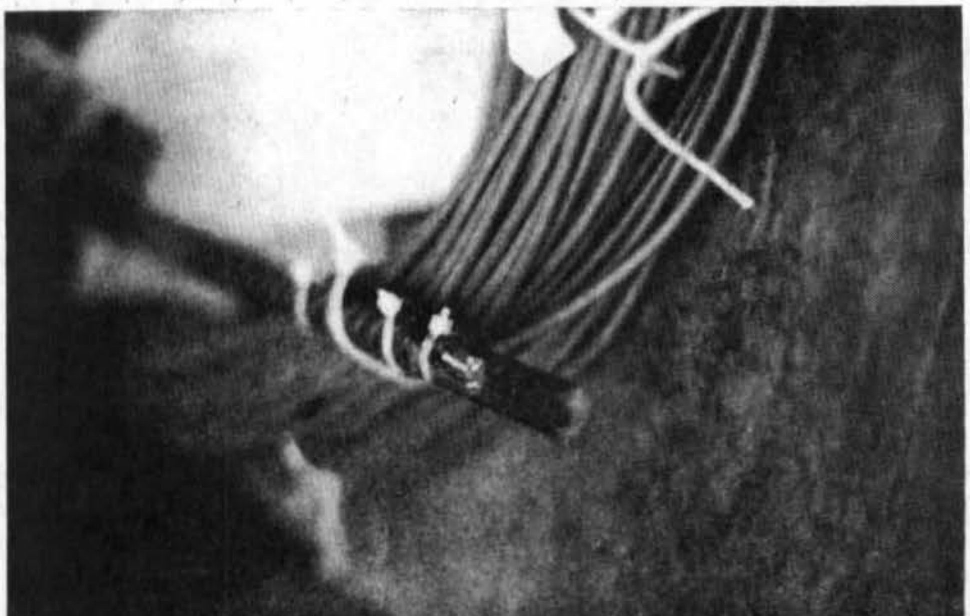


Figure 43 Reinforcing Bar Mounted Temperature Gage

wire cable connecting the control unit and the sensor. Care taken in the connection and the use of the continuity and resistance response check prior to the installation phase will improve the success rate of response when the installation is completed. The researcher should maximize the use of the laboratory for preparation of the instruments to improve the reliability of the instruments installed.

Each sensor and its connecting wire cable was identified with the cable markers at the control box end and a tag was used to identify the entire unit for placement during installation. The cable for each sensor was cut to a predetermined length to run from the installation point to the control cabinet with no intermediate splices. In some installations this can increase the amount of lead wire required, but it is essential in the survival of instrumentation after installation.

While the gages were being prepared in the laboratory, field installation of power and telephone progressed. The cost of installation of phone and power to a remote site can be considerable and should be carefully considered in the budget preparations of the project. In some cases such as this, it was necessary to secure utility permits to cross or work within given highway Rights of Way.

Gage Installation

The goal of the installation was to place the instruments in the pavement area immediately in front of the paving operation. This meant a great deal of coordination with the construction company and the University staff. The fact that the site is some 150 miles from the University added to the coordination problems. Coordination began with a meeting between the research staff and the contractor soon after award of the bid to gain the support required to meet the deadlines of the construction and effect the instrument installation.

Original estimates of early to mid July for the time of installation were made at the time of the first meeting. This coupled with the required delivery time for the instruments and the dowel bar assemblies to the lab required the University staff to utilize large amounts of overtime to prepare and test the instruments.

The site construction plan called for the removal of the existing pavement and base material and the placement of a compacted layer of recycled portland cement concrete. In addition, the existing bridge approach had to be removed, a new subdrain installed and the backfilling completed prior to the pavement placement. Each of these operations required the use of heavy equipment in the instrumentation site. Through close coordination, the transverse pipes for the measurement of the moisture/density were installed immediately after the compaction of the replaced base materials. Contractor forces were used to trench through 15 inch thick asphaltic concrete shoulders (Figure 44) for placement of the pipes in the existing shoulders rather than try to push the pipes through the existing subgrade. A ten foot section was left off the median end of each pipe during the paving to allow the contractor to use the median as a haul road and complete the finishing of the median shoulder prior to the installation of the final sections of pipe.

Associated with the installation was the use of the University students to effect the installation during the summer months. Rains and conflicting contractor schedules delayed the installation until early September of 1986. At this time the student labor had been stretched to the time limits and the contractor was getting very close to being in a penalty situation on contract time. As a result, approximately 48 hours notice was received by the researchers from the project inspection staff.

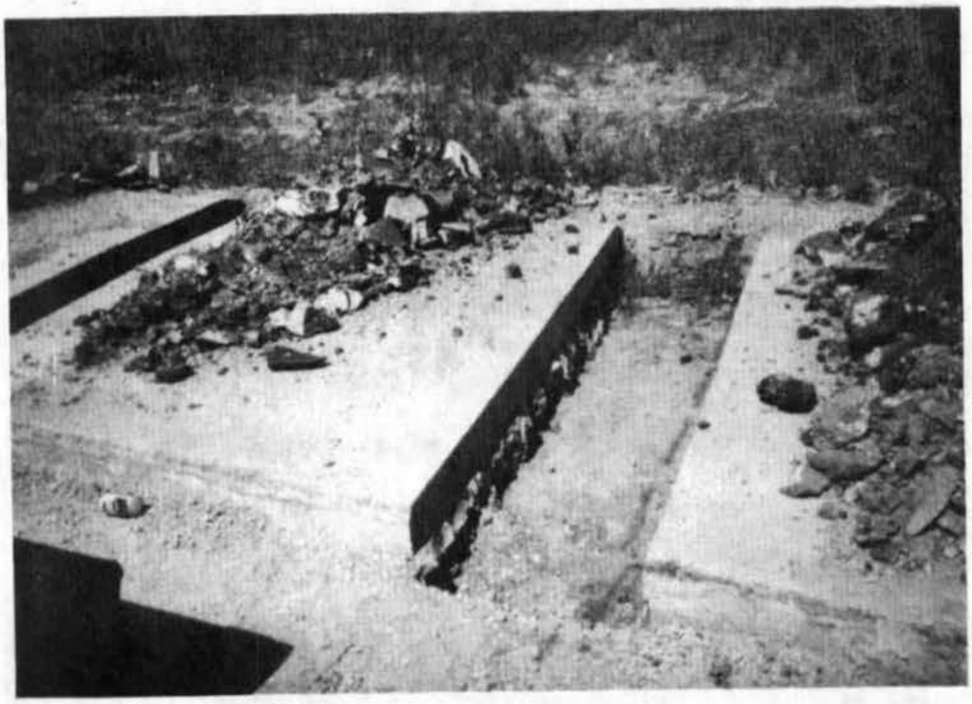


Figure 44 Road Shoulder Conduit Trenches

The installation of the bar support cages and wiring for the concrete, dowel bar, and temperature gages was accomplished in a matter of less than five hours by a crew of four researchers, six Department of Transportation staff and various others associated with the contractor or the highway agencies observing the installation. Work began at 7AM and was completed at 12AM as the paving equipment reached the site. Figures 45 through 61 illustrate the operations involved in the construction from the start to final concrete placement at the site. In each midslab or joint location the rebar or dowel assemblies were set in place, the wires stretched down the road toward the bridge and then fed into the conduits and out to the shoulder. Joints were sealed and the concrete placed. It is important to understand the rate of paving anticipated if one is to coordinate such an effort. We chose not to place any of the instruments at the site the prior evening due to the uncertainly of the weather and possibility of vandalism.

Care must also be taken in the installation planning to understand the operation of the paving equipment. The sensors must be placed in such a location that will not interfere with the vibration equipment, strike off blade (Figure 59), or side forms of the paver as it passes by. In this case some of the support bar cages had to be shortened at the last minute by the use of a torch to allow passage of the paver.

Figure 45 Instrumentation Site at Installation

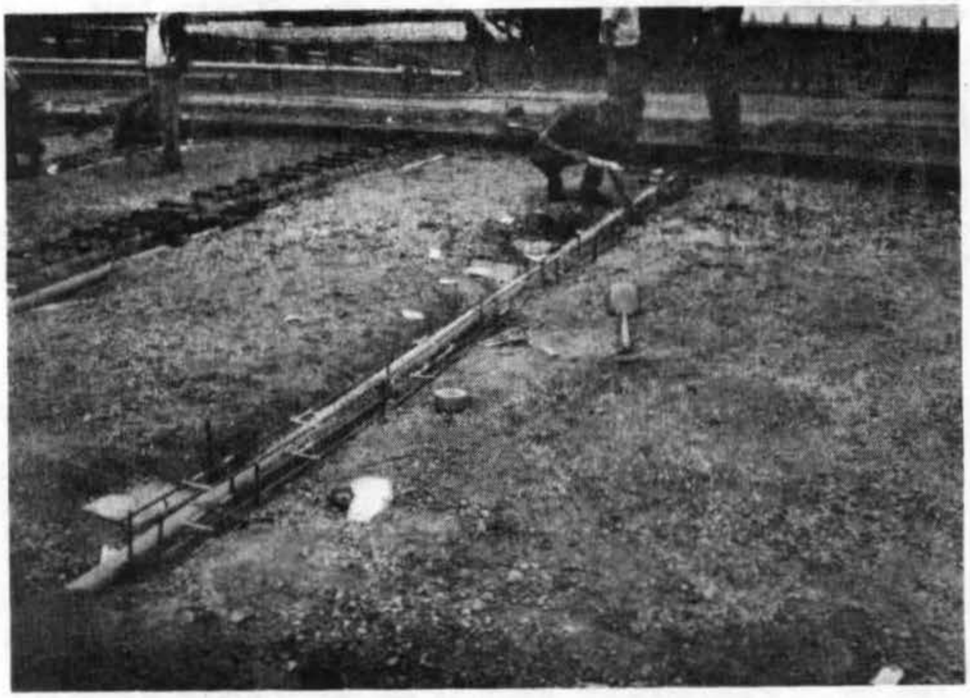


Figure 46 Midslab Support Cage Installation

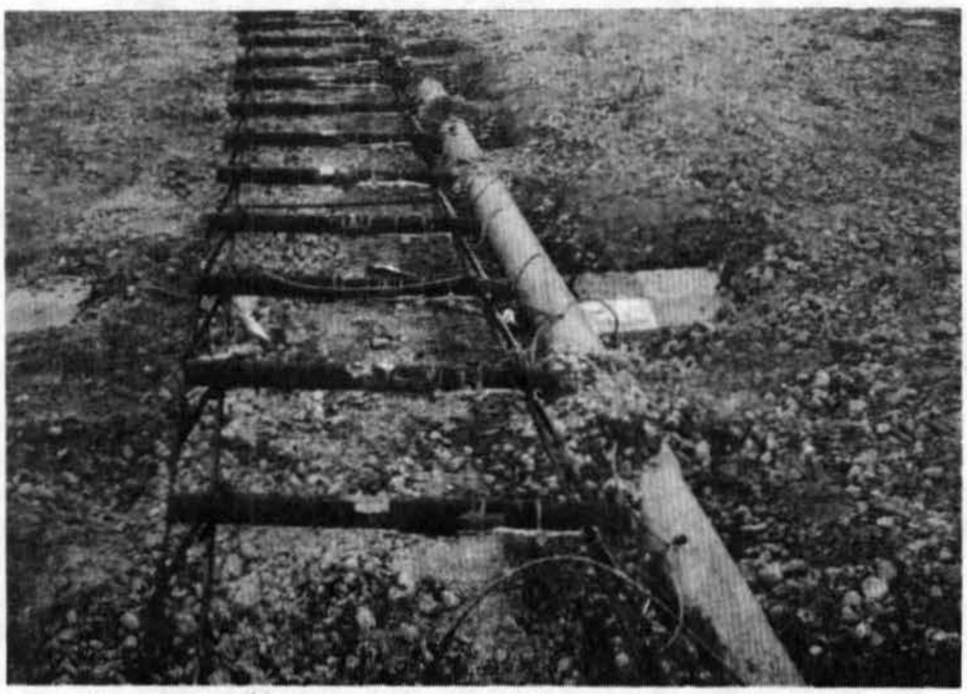


Figure 47 Dowel Bar Assembly In Place

Figure 48 Dowel Bar Assembly Ready for Installation

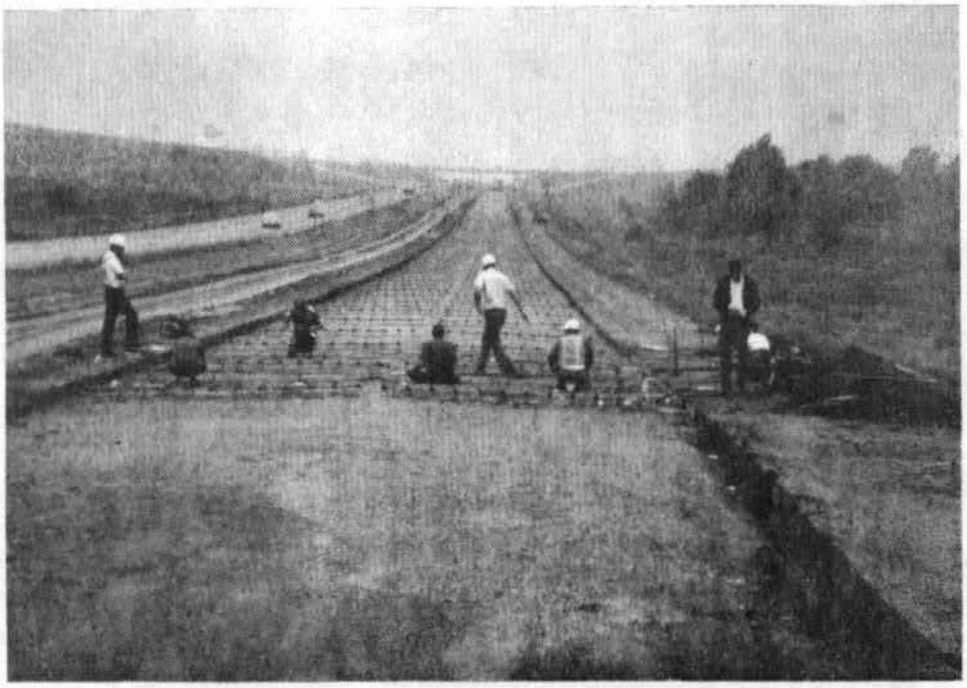


Figure 49 Installation in Progress

Figure 50 Placement of Carrier Conduits

Figure 51 Installation of Concrete Gages (note: wires are only tight enough to hold gage in place)

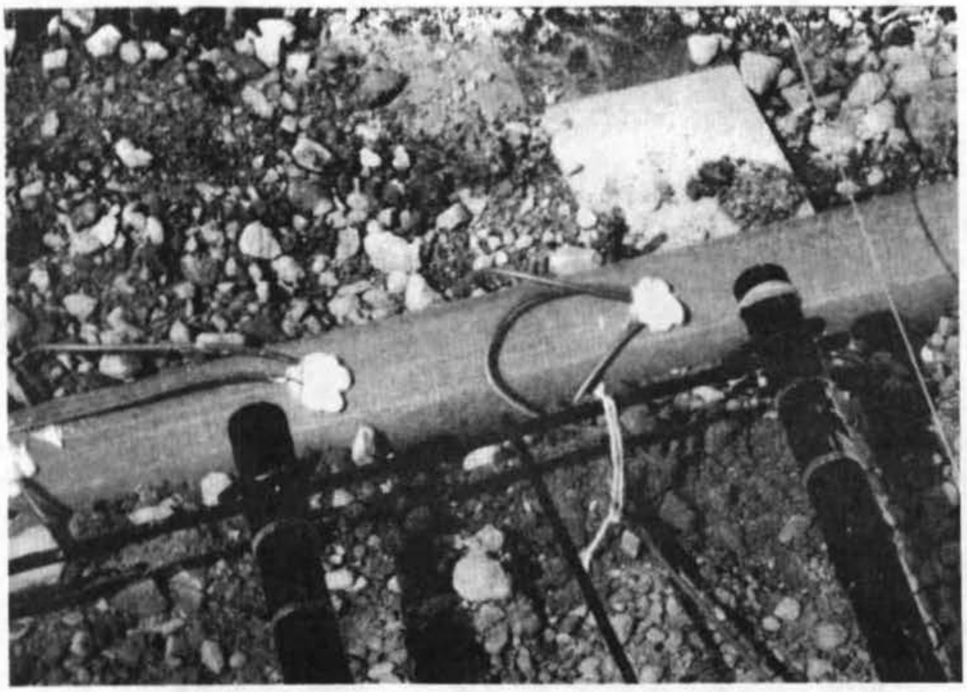


Figure 52 Sealing the Carrier Conduit Connections

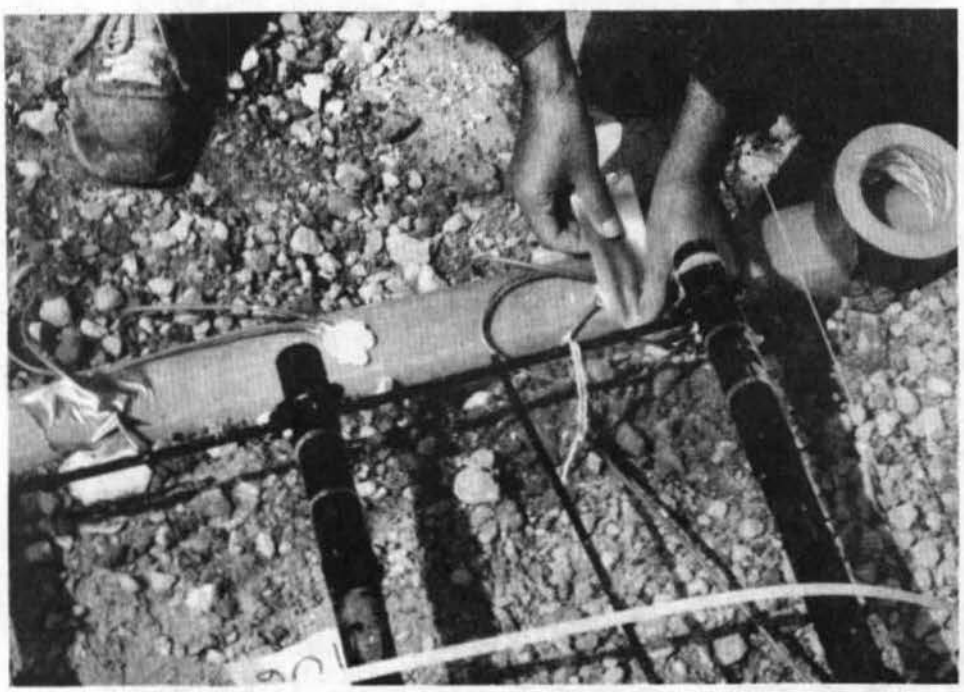


Figure 53 Completed Dowel Bar Gage Installation

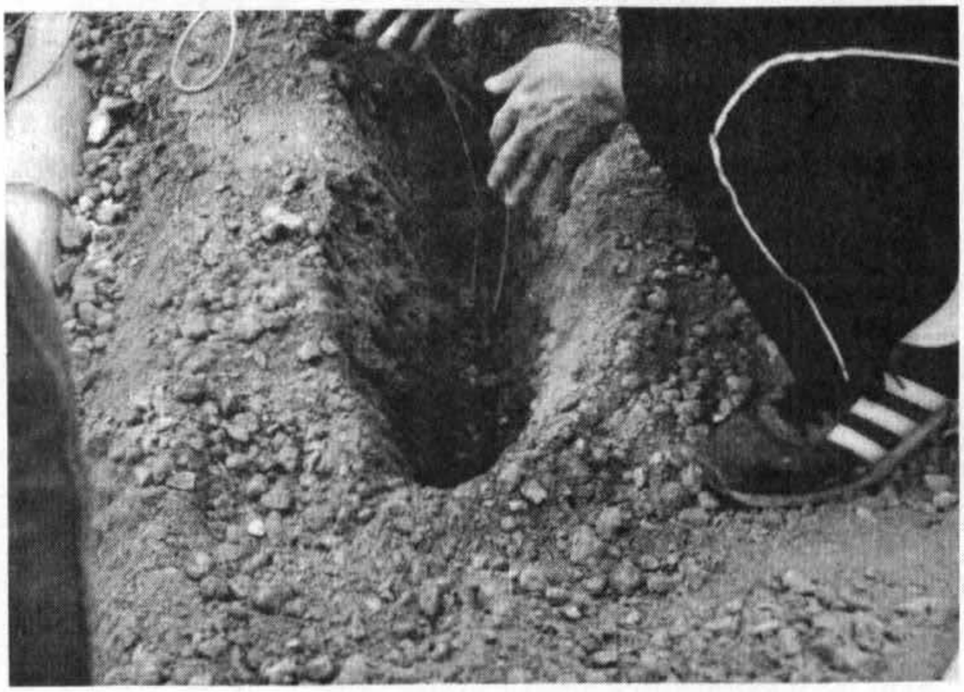


Figure 54 Installation of Temperature Gage in Base Course

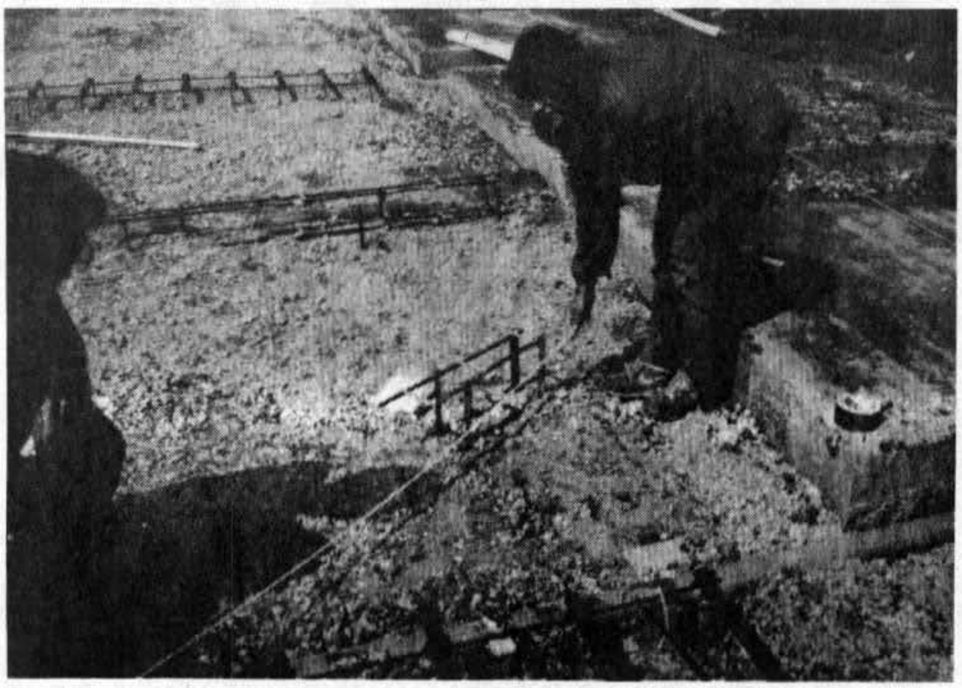


Figure 55 Installation of Corner Concrete Gages

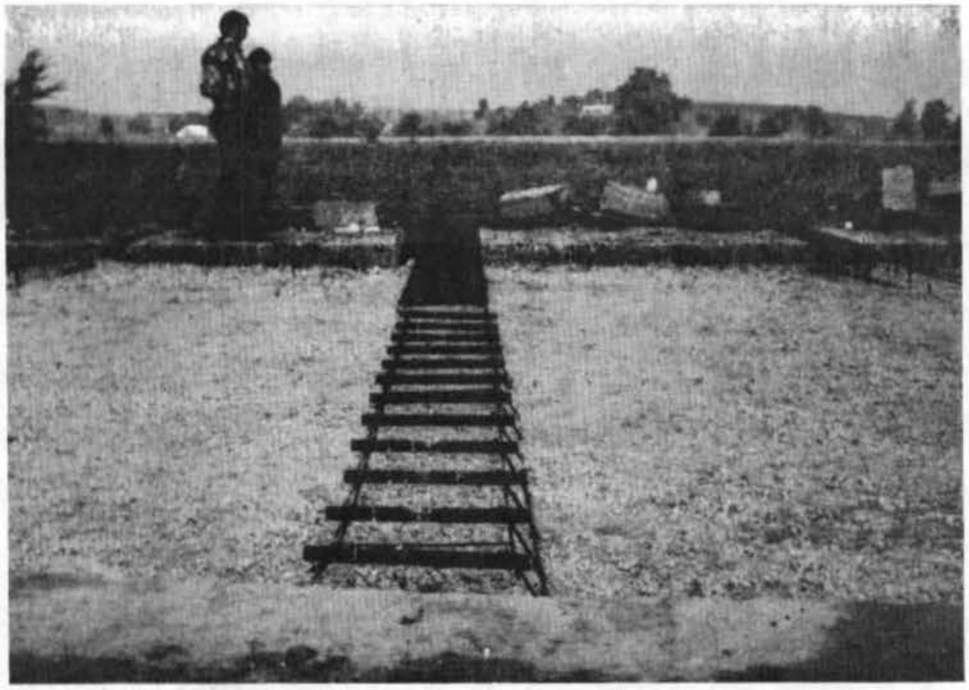


Figure 56 Completed Joint Installation

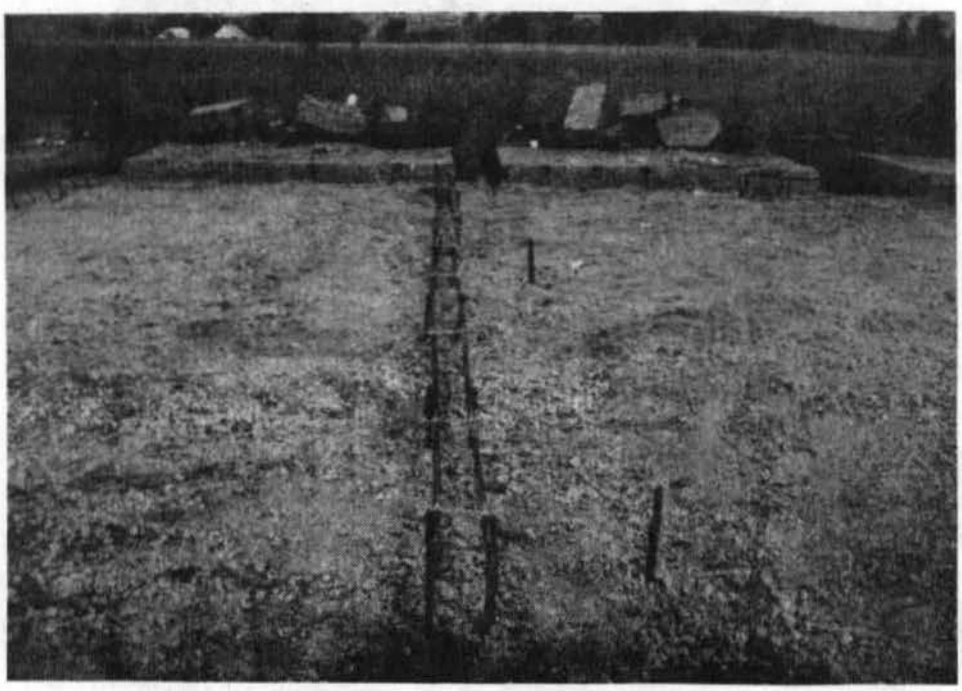


Figure 57 Completed Midslab Installation

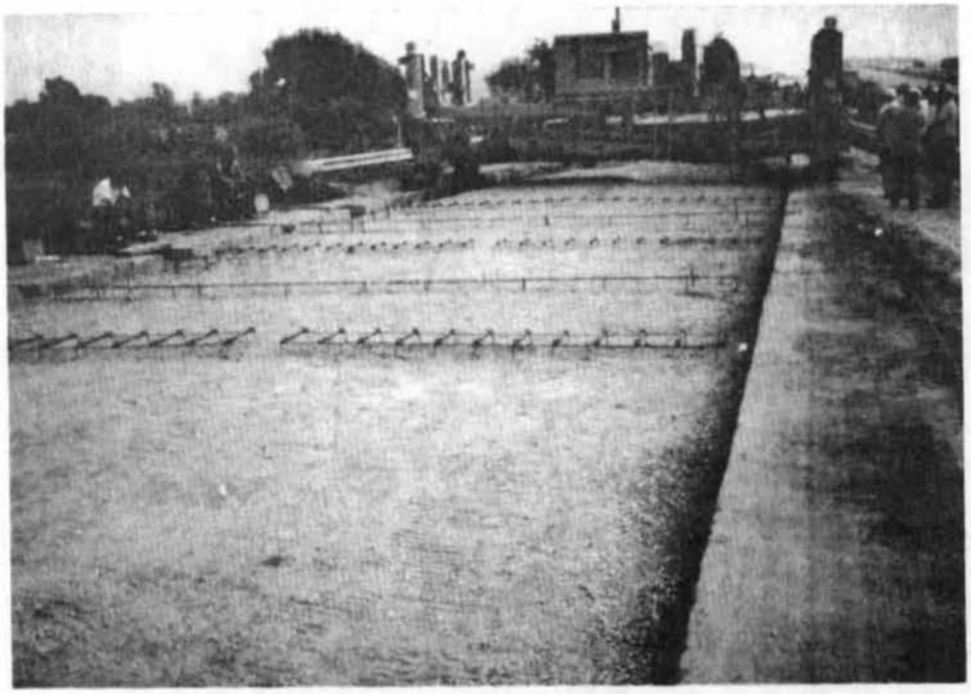


Figure 58 Paving Train at the Instrumentation Site

Figure 59 Concrete Placement over Corner Assemblies

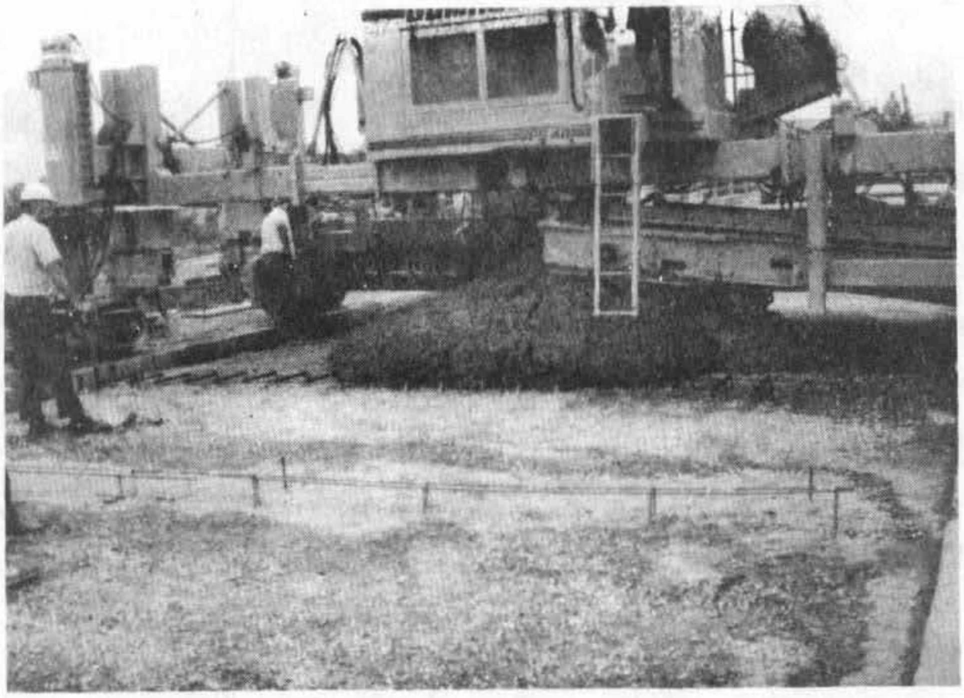


Figure 60 Concrete Placement at the Instrumentation Site

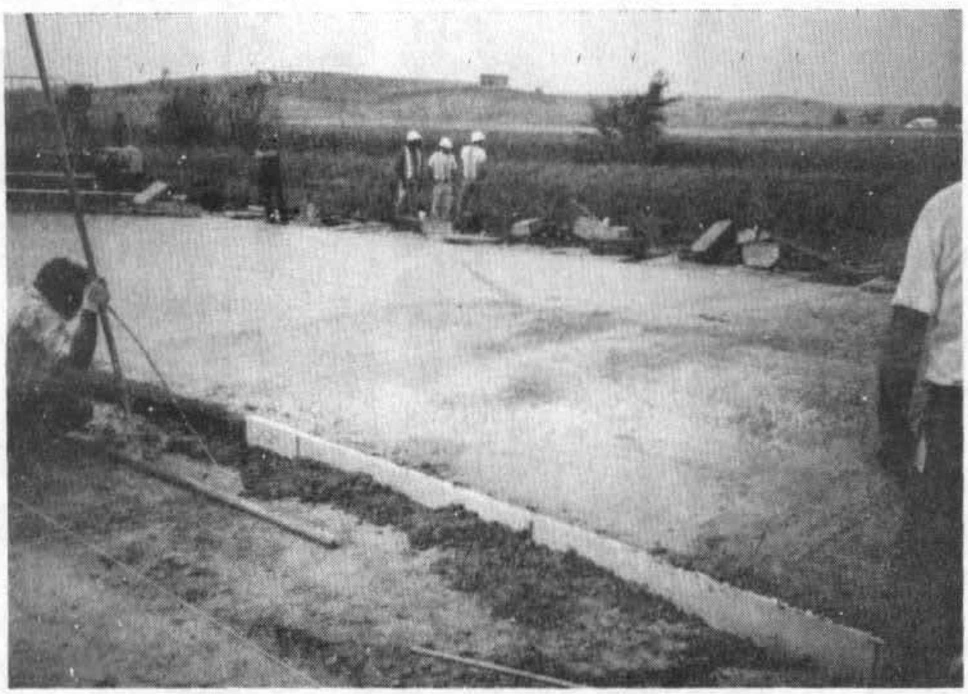


Figure 61 Completed Instrumentation Slab Construction

To prevent the possibility of concrete roll pressures in front of the paver from overturning the bar cage assemblies, some hand placement of concrete was done by the research staff. This was done immediately in front of the paver with shovels using the paving concrete. Material was placed in and around the assemblies. One concrete gage was lost during this operation due to a foot being used to move the concrete into place. The entire concrete operation was completed at the site in less than an hour with no delay to the contractor.

Several follow-up activities were required to make the site ready for data collection. The first of these was the burial of the connecting cables between the site and the control box and the construction of the control site. This activity should not be taken lightly as the 120 separate wires totaling 18,000 feet in length require a great deal of time and fortitude to handle. Using PVC 90 degree elbows and junction boxes, the electrical conduits under the pavement were connected to the conduit sections running longitudinally along the pavement to the control box. A series of three such four inch diameter conduits were used to connect the control box and the junction boxes. Two 90 degree, three inch elbows were required on the outside shoulder end of each electrical conduit to allow for the change in elevation between the pavement section and the longitudinal section. This type of arrangement provides for approximately one foot of cover over the longitudinal pipe for vehicle safety and rodent protection. Previous installation of cable showed that rodents will attack coated cables in shallow earth locations.

The junction boxes were included for possible need to gain access to the cables for repair or for installation of additional cables. They can be opened from the top and are placed approximately one foot under the surface of the shoulder. All conduit joints were sealed to prevent water intrusion over time. The boxes also allowed for the common housing of cables from one to two separate pavement areas in one longitudinal conduit. This reduced the number of required conduits from five to three and reduced the amount of trenching and backfilling. Installation of this part of the project was completed under rainy conditions after the concrete placement. Backfilling and shoulder shaping was accomplished by Department of Transportation staff.

Construction of the control cabinet foundation was accomplished by the research staff with the aid of the contractors staff and equipment. Provisions were made to gain access to the connection cables through the floor of the box area. A prefabricated control box was assembled by the research staff at the site and placed by the Department staff. The metal box includes a special electric heater and air conditioner to provide a constant temperature and humidity for the data collection equipment housed in the control box. The box was also insulated and lighted and equipped with a telephone to provide full field communication and work space. A special transformer and base were supplied by the power company immediately adjacent to the control box, to step down the 7,000 volt line to the 110/220 volt connections needed. Final connections of the power and the telephone were made by the respective companies when the control box was completed.

The final site work carried out prior to opening of the road was the installation of the deflection gages. The Department survey crew and materials testing drill crew were again used to locate and drill the pavement above the buried reference holes. Due to precision in referencing the original holes, only one concrete drill hole did not provide proper alignment with the reference pipe below. Problems were experienced in drilling through the plywood marking devices below the pavement. The standard 4 inch diameter core drills are fed water for cooling of the cutting edge. The same water made the plywood expand and lodge in the drill. Removal of the wood from the bit was difficult. The wiring for the gages had been fed through the reference hole conduit sidewall approximately 4-6 inches below the top for ease of recovery from the pavement surface. The addition of the plywood cover made drill pressures difficult to determine by the operator. When enough pressure was applied to pass through the wood, the drill would sink into the conduit and cut the wiring. This happened in three successive tries on this project. In the remaining holes the drill was stopped above the wood and a hole was punched through the wood with a bar for access.

Redundancy and Gage Testing

The field layout of the site shown in Figures 26-29 illustrate the theory of redundancy used in the project. The literature search and discussions with other using similar instrumentation indicated that many projects are lost due to damage to the instruments during installation. In this case there is redundancy in the way the instruments are located in both lanes at three consecutive joints and two mid slab locations. The researcher can study the effects of the vehicle in a particular lane of operation and its effect on the joints surrounding the test slab and the pavement slabs adjacent to it at the same time. We would anticipate monitoring the gages in two consecutive joints and one midslab location for both lanes simultaneously.

The same theory is used in the location of the deflection devices. They are located in the wheel path areas from previous research done by others. Consideration was given to additional devices placed across the slab, but the results of others and the added cost discouraged further consideration.

On August 10-11, 1987 continuity testing of the instruments was carried out in the field. Completed circuits were found at 48 of 50 weldable gages. One gage provided no circuit and another showed signs of damage and inconsistent results. Of the 38 concrete strain gages installed, three gave no response and one gave intermittent response. All 16 temperature gages responded positively. Three of the 16 deflection gages were not installed due to damage of the wiring. Of the remaining 13 gages, one showed signs of fluctuating voltages during testing. This represents a 92.4% positive response. This is very good compared to other study results where a 50% failure rate is not uncommon.

DATA HANDLING

Equipment Selection and Purchase

Data collection and analysis equipment selection is an item of the project which must be planned at the same time the instruments are being selected. In other reported projects, a portable van, trailer or self-contained unit is moved from site to site by a vehicle for the collection of data. In the case of this project, no such vehicle existed and there was a concern about the accuracy of data collected in this manner. The site is located such that the vehicle would always be visible to the traffic stream and might influence the mix and weight characteristics of that traffic stream. The location of the site being 150 miles from the central analysis location, created additional logistics problems.

A decision was made in the development of the work plan to provide a form of remote sensing in connection with the project. Equipment was to be selected which would provide on site collection and analysis of multiple gage outputs. The results were to be available at the site for calibration and analysis as well as being transmitted over telephone lines to a central Ames location. The original plan called for the field unit to have the ability to scan up to 120 separate gages at the rate of 1,000 times per second. Compatibility with existing hardware at the Department of Transportation was a consideration along with the mobility of the equipment to be moved to another site in the future.

Major suppliers of such equipment were contacted and discussions were held with two such companies. The discussions indicated the the equipment required for the specifications desired would cost as much as the entire project budget. At this point, a compromise was reached to limit the number of sensors to less than two thirds of the total at any one time and accept a scan rate of 300-400 times per second per gage. Purchase of the equipment was accomplished through the Department of Transportation Office of Purchasing. The hardware included two micro processors with keyboards and monitors (field and office unit), a data collection unit with two extenders, printer, plotter, and modems. This contract also included time for assistance in setup and troubleshooting.

Hewlett Packard equipment was selected for the project. The hardware consisted of a model 310 series workstation for the central Ames office site and a model 320 series engineering workstation for the field location. The central location micro computer has a color graphic monitor and associated card, one megabyte of RAM and a 20 megabyte hard disk with the floppy disk. An eight pen plotter and printer are connected to this unit in special cabinet for transport between offices. It uses a 3600 baud modem for communication with the field unit.

The field unit is equipped with a monochrome monitor, three megabytes of RAM, and 40 megabyte hardisk. It is also connected to the central office via the 3600 baud modem. Each of the units comes with the BASIC 4.0 operating system.

The heart of the data collection system is a HP 3852A Data Acquisition and Control Unit with two extender units (3853A). Accessories include two 24 channel multiplexers, two 13-bit high speed voltmeters, a five channel counter totalizer, data acquisition software routines, a DC power supply and enough connection devices to monitor forty 120 ohm strain gages and eighty 350 ohm strain gages simultaneously.

Equipment Installation

The equipment was shipped to the Iowa DOT for assembly. Assembly was accomplished at the office by the research staff rather than at the field location. This proved to be helpful when several small parts were incorrectly picked by the company representative and the plotter was found to be incompatible with the microprocessor. Internal testing allowed for the research team to gain an understanding of the functions of the various parts of the equipment and develop the necessary programs for the operation of the data collection equipment. The units did come with the basic operating software and the subroutines to perform the scanning, analysis and data storage functions.

During the assembly of the hardware units at the Department, another employee was in the field preparing the cable wire ends for attachment to the data acquisition unit, insulating the control cabinet, and installing electrical connections in the cabinet. This type of activity requires a person skilled in electrical wiring and in the basic knowledge of the operation of computerized data collection hardware.

The software development was completed by the use of a private consultant experienced in the use of this particular brand of equipment. It is important in the selection of the hardware and software to consider who will provide this type of service. One can purchase too much or the wrong kinds of software or greatly underestimate the cost of developing such software.

PROBLEMS AND RECOMMENDATIONS

Project Planning

One cannot emphasize enough the need for detailed planning in an effort such as this. It is suggested that the agency in charge of the project assume a team approach. Such a team should include a pavement engineer, programmer, researcher with experience in sensor selection and installation, computer/communications specialist, and department representatives from the areas of construction, maintenance and materials associated with the construction of the project. Each of these persons has a part to play in anticipating the problems and alternative solutions during the planning process rather than after the decisions have been made. In the case of the Iowa project, planning was centered on one pavement engineer, two others experienced in structural concrete instrumentation, a graduate student experienced in instrumentation of railroad road beds, a statistician and an electrical engineer. Two other professional researchers experienced in this type of work in both asphalt and concrete road beds were consulted during this and subsequent phases. This proved to be a very workable arrangement, but due to the changing job roles of the participants, communications was a problem. The researcher should try to select a group that will be available for the duration of the project.

Site Preparation

Coordination was the major problem in this phase of the project. The 150 mile distance between the researcher and the construction project staff necessitated the need for telephone communication. Weekly phone conferences proved helpful in determining when to commence separate parts of the site preparation. The contractors operation schedule also provided problems in the scheduling of site preparation. Even with good phone communication, the weather often changed drastically over the distance between the central Ames location and the field site. Alternative plans for each trip must be made to take advantage of each site visit. The research should anticipate the amount of site visits required to do the preparation and double that figure to account for the coordination problems.

Removal and replacement of the shoulder materials for the utility trenches was accomplished by the contractor on a lump sum basis. Prices for this type of work may appear to be high, but when one considers the problems of obtaining the necessary equipment, materials and manpower, and the unknown existing construction questions, the price is reasonable. In this case, the shoulders were expected to be eight inches thick and turned out to be 15 inches thick. Unanticipated buried concrete lugs on the existing bridge approach turned up in the way of the moisture/density tubes and were removed at no cost.

Coordination with the contractor proved helpful again and again as things such as concrete for the control cabinet foundation and extraction of trenchers that became mired in the mud was experienced.

The coordination with the maintenance forces in the area was essential. They provided a storage and fabrication site at the local garages, radio communication in time of emergencies and actual construction support in the installation of the power cable and the backfilling of the shoulder trenches.

Special coordination was required in the layout and referencing of the deflection gage locations and in the coring both before and after the paving to install the gages and wiring. This was accomplished with personnel and equipment from the Council Bluffs Resident Engineer's office and the District Materials staff.

Each of the above noted coordination problems points out the need for the team approach and the coordination of efforts with outside agencies such as the telephone and power companies.

The costs and details of the power and phone installation were the biggest surprise in the site preparation. The site required a permit from the state for the installation of the lines underground and on the Interstate Right of Way. Aerial service cost estimates were very high and coupled with anticipated maintenance problems forced the underground installation. The type of power cable and size necessary to meet the company requirements and eliminate voltage losses was only available through the power company and one other supplier. In most cases such as this the researcher is dealing with only one power and one phone company and must deal with their requirements and schedules. In our case several local storms placed additional requirements for time on each of the agencies and slowed the progress on this project.

<u>Gage Preparation</u>

Gage preparation on this project operated smoothly with only minor communication problems. The key to the success of the gage installation is the use of the experienced technical staff, selection of the materials to be used and the use of the laboratory for preparation. In this case the technical staff knew what brands and models of gages to purchase, the probable vendor, and how to prepare each gage for installation. The Principal Researcher provided the basic research layout, goal, and the purchasing mechanism for the project. Without the assistance of trained staff, this part of the project would be very time consuming and costly.

The laboratory environment provides the controlled area with the necessary tools to accurately weld connections, layout wire lengths, and test each gage. Doing this type of work in the field would most likely result in many gages connection failures. In this project the dowel bar assemblies were delivered to the laboratory by the Department and returned to the field site by the research staff at the time of installation. The only work required was that of removing the epoxy coating from the bars and developing a flat area on the round bar for the installation of the weldable gages. A special hand grinder shown in Figures 33 and 34 was used to accomplish this task.

Gage Installation

The installation of the gages proceeded smoothly on this project. It was due to two primary factors. The first was the preparation of the gages and all other associated equipment in the laboratory. The numbering of all project parts and the development of a plan layout sheet added to the efficiency of installation at the site.

The use of adequate staff is the second factor. Where installation is to take place immediately in front of the paving operation, steps must be taken to have persons installing equipment on all parts of the layout at the same time. This plan will rely heavily on the preparation of the layout sheets and should include a walk through of the plan in the laboratory. This should assure that the right equipment is available for the job and that each person knows what is expected of them when they reach the site. In our case this pointed to the need for a portable generator to operate power tools which increased the rate of production at the site.

In this project the installation began at the westerly most joint instrumentation and proceeded easterly one joint or one midslab location at a time. The controlling operations were the placement of the concrete sensors on the chair assemblies and the installation of the wiring from each pavement area into the PVC carriers under the slab. The carrier was laid first in a shallow trench in the base material and the sensor was attached to the bars. The sensor cables were laid out longitudinally on the grade as the sensors were attached. Holes were drilled in the carrier conduit and a plumbers tape was used to draw the cable through the conduit to the shoulder of the road. When all cables were drawn through a particular conduit, the pavement end and the cable entry holes were sealed with silicone caulk. This system worked very smoothly with the assistance of some six of the Resident Engineer's staff and four of the research team.

The cables from each run across the pavement were bundled at four to five foot intervals for ease of passage through the longitudinal conduits in the shoulder. In this case elbows, junction boxes, and ten foot straight sections of the conduit were threaded onto the cable at its end and walked back to connect to the existing pavement conduit sections.

<u>Data Handling Preparation</u>

Several items of information must be decided in the planning stages of the project to make this portion of the work proceed smoothly and on time.

This was a learning experience for the project leaders. The project investigators must first establish:

1. What will be measured?
2. How fast will it be measured?
3. What are the limitations of the sensors that the data collection equipment will need to meet?
4. Are there budget limitations on hardware costs?
5. Will the information be gathered and analyzed at the site or a central location?
6. What software will be required to operate the system and do the analysis?
7. Will software development be required or is software readily available from commercial sources?

If data collection hardware or sensors are available prior to the project, they may dictate the answers to the other questions in this list. In this project, the previous work consisted of the railroad and bridge beam instrumentation work. This helped identify the equipment needed to meet the project goals. The literature search also pointed out the strong and weak points of various types of sensors for consideration in obtaining maximum reliability of survival in the concrete situation.

The speed of data collection and the number of sensors to be scanned at any one time will have a direct bearing on the cost and size of the data collection units. The cost of scanning 120 instruments at the rate of 1,000 times per second per instrument was estimated to cost between $175,000 and $200,000. By reducing the rate of scan to 300-400 times per second per instrument and scanning some 50-80 instruments at a time, the price was reduced to $60,000.

The project staff must make allowance for delays in the delivery of data collection equipment due to the nature of the order. In most cases this is a special order of several parts of subsystems and requires close communication between the investigator, the purchasing agent and the vendor representative. The cooperation in this case was good and some equipment had to be returned and replaced due to incompatibility of parts or changes in the method of handling the data.

The project manager chose to use the subroutines provided by the vendor to do most of the analysis of the data at the field site. The services of an individual consultant were required to assist in the development of the programming statements to tie the subroutines together and transmit data to the central office. This work is still underway at the time of this report.

RESEARCH RESULTS

The research results to date include the successful installation of the sensors in the field site and the purchase of the equipment necessary to operate the system. Some 119 sensors have been installed with a 90% survival rate during the pavement construction. A staff has been trained in the installation and use of the sensors for future projects of this type. In many highway agencies instrumentation projects are not considered due to the lack of knowledge in how to structure such an experiment.

The project has proceeded at a pace less than expected for several reasons that should be considered in any future projects of this type. Project staff have changed positions and made it more difficult to continue a sustained effort each day on the project. The delays in the installation of the equipment due to the pavement construction schedule have set each phase of the project back some three to six months. Although some delays were experienced in the selection and ordering of the WIM equipment, the project is proceeding toward the collection of data and the analysis of the data at this time.

One phase of the project is yielding results at this time. The collection of moisture/density information has been going on since May of 1987 with five successive measurements in each of the five conduits at the site. The graphic displays of the data shown in the appendix do show that the longitudinal subdrains at the outside edge of the driving lane are drawing down the water from across the pavement. This data reinforces the conclusions expressed in the current AASHTO Pavement Design Guide relative to the installation of drainable bases and longitudinal drains.

The density information provided by the site is less easily explained. At many of the locations there is a distinct drop in the density at or near the midpoint of the passing lane. Since this is a new application of the equipment in being operated horizontally, the results are still under study by the vendor and the research staff.

There are some contributing factors that may be influencing the results of the tests. Water has been found in a least two of the tubes each time of testing. The tubes were originally sealed at each 10 foot joint and capped at each end. This may be the result of weakened joints or condensation in the pipes. Secondly the site is located in the sag of a vertical curve immediately adjacent to a median dike and cross road pipe location. This creates a saturated soil condition during the times of peak runoff that are experienced in this area. The base material around the carrier conduits was hand tamped during the instrument installation process and may vary enough to be influencing the results. It is very difficult to install the conduits in the base and allow heavy equipment to compact the base without damage to the conduits at the shallow depth of 6-10 inches. We chose to install the conduits after base compaction and retamp the areas disturbed.

DEVELOPMENT COSTS

Hardware Costs

The hardware costs for a project such as this can run into unlimited amounts of money unless specific goals for the project are established in the planning stages. The following costs represent list unit prices paid for the equipment used to prepare, install and operate the system that is described in this report. Discounts to highway agencies will vary and are not included in the unit prices shown. Prices will vary with the suppliers utilized and the detail of the project experimental design, but the list provides the "first time" planner with a way to develop a budget for the project.

Computer equipment and accessories

Midland Ross voltage surge suppressor model #6100V	$18.38
Hewlett Packard	
HP-IB cable 1m	80.00
HP-IB cable 2m	90.00
DC power supply	850.00
Rack kit	61.00
1 MB memory card	1,450.00
1 MB memory card for mainframe	2,000.00
DA&C mainframe unit	3,600.00
Rack hardware	55.00
Extender unit	2,400.00
Extender rack hardware	55.00

87.

24 channel multiplexer	900.00
High speed DVM voltmeter	2,500.00
5 channel counter/totalizer	950.00
GPIO cable 4 m	300.00
Hard disc drive	2,740.00
12 inch monochrome monitor	325.00
DMA board	500.00
40 MB winchester hard disk with floppy disk unit	4,450.00

88.

20 MB hard disc with floppy disk unit	2,740.00
Color pro plotter	1,295.00
Quiet Jet Printer	$567.23
Model 320 computer, 32 bit SPU	8,000.00
Model 310 computer with 12 inch color display and keyboard	7,850.00
Video board	800.00
US english HPHIL keyboard	225.00
8 slot expander	1,900.00
Terminal block	150.00
Terminal, 120 ohm	400.00
Terminal, 350 ohm	400.00

Control cabinet and accessories

Hoffman cabinet and accessories, #A726036FSD	$1,040.00
Air conditioner, #A136AC06T with rain hood	1,190.00
Heater, A-DAH 2100FT	88.00
Fan, A4AXFN (with A-GARD4 guard)	22.75
Panel supports, A-72FSCPS	40.00

Mounting angles, A-72RA24TH	36.00
Shelf, D-KL29SH	27.00
Moisture/density gages	
Troxler model 1352 depth density gage with 100 foot of cable	$3,005.00
Troxler model 3321 moisture gage with 90 foot of cable	3,005.00
Troxler model 2601-B scaler	2,190.00
Preparation equipment	
Belden #8723, 4 conduction wire in 1,000 foot spools	$84.93
Crowsfoot #9RY43629, 1 inch	4.95
Conduit, rigid aluminum, 2 inch diameter x 10 foot	17.73
Conduit couplings, aluminum, 2 inch diameter	2.03
Preparation equipment	
Conduit caps, aluminum, 2 inch diameter	$4.00
Dynafile kit #11021	$500.00
Dynafile belt	5.00
Dynafile stroke sander contact arm #11258	85.25
Drive, 3/8 inch speed wrench	10.82
Krylon #1304 clear spray	2.24
M coat A kit (six plastic containers)	15.00
M coat B kit	
M coat JL-3 kit(six plastic containers)	40.00
Plastic conduit in 10 foot lengths, 3 inch diameter	10.01
Plastic conduit in 10 foot lengths, 4 inch diameter	14.27
Plastic conduit elbows, 3 inch diameter x 90 degrees	9.97
Plastic conduit elbows, 4 inch diameter x 90 degrees	17.27
Plastic conduit couplings, 3 inch diameter	2.75

Plastic conduit couplings, 4 inch diameter	4.25
Plastic conudit end caps, 3 inch diameter	0.65
Plastic conduit glue (pint can)	4.84
Plastic conduit pull boxes, 3 inch x 4 inch	33.33
Plastic conduit pull boxes, 4 inch x 3 inch x 4 inch	33.33
Reinforcing bar, #4 x 20 foot	3.50
Surface irradiated polyolefin #FIT-300-1/8,1/4,1/2 (package)	7.68
Shrinkable wire cable markers #MRK-C-NS (package)	5.54
Threaded rod, 3/4 inch x 8 feet	12.80
Sensors	
PML-60 concrete gage	$15.76
LWK-060W25B-350 weldable strain gage	16.91
Sensors	
#WTG-50C temperature sensors	$10.20
Model no. 243-000 displacement transducers, DC-DC series 240	207.00
Utility installation materials	
#2 solid 15KV rated #24-1046 (price per foot)	$0.63
Blackburn rod, 5/8 inch x 10 feet	12.07
Blackburn clamp, G-5	2.04
Breaker, QD-260	12.05
Load center, QD-2-4L70R3	22.00
Load center, QO08-16L #100S	22.00
Breaker, QD-120	5.30
Galvanized nipple, 1 inch x 3 inch	0.69
T&B locknut, 1 inch #143	0.27
T&B bushings, 1 inch #224	0.25

Square D Hub, B100	5.70
Standard meter socket, 240 volt	16.50
Cold drawn DOM tubing 4 1/2 inch OD x 3 1/4 inch ID (per foot)	25.50

<u>Software Costs</u>

The software purchased with the equipment is designed to do the basic data collection and the cost of that software is shown below. It does not include any communications software (field to office) or the basic spreadsheet materials that can be used to analyze the data.

RTR basic	$430.00
DACQ/300 data acquistion manager software	1,950.00

<u>Installation Costs</u>

Several costs associated with the project should be considered in the planning of future installations of this nature. They include the following:

Contractor services in preparation of the site	$640.00
Telephone company wire and installation charges	980.00
Power company installation charges	3,752.44

These charges do not include the monthly operation charges that will depend on the amount of usage of the installation. Department of Transportation installation charges for installation and operation of the site to date are not included and are ongoing at this time. They include electrician, engineer, statistician, construction, and administrative time.

<u>Total Site Costs</u>

The following represents an estimated cost of the various parts of the installation as stated in the original proposal.

Item	Estimated Cost	Actual/projected Cost
Gages - purchase and installation	$27,000	$58,500
Power and telephone supply to the site	2,000	8,000
Monthly service charges for power and phone - 2 years at $125 per month	0	3,000
Consultation travel expense	0	2,500
Computer hardware	96,000	65,500
Software, testing analysis	26,000	33,700
Weigh in motion materials, equipment and installation	4,500	14,000
Totals	$156,000	$185,200

The total estimated cost does not include some $12,450 in Department of Transportation budgeted services. The anticipated additional costs can be attributed to the delays in the installation, unknown software needs, the inclusion of review by the other principal investigators on the project and additional needs in the development of the weigh in motion devices.

SUMMARY AND CONCLUSIONS

The project to date has proved that instruments can be installed in the pavement during paving operations and obtain excellent survival rates. The project has the potential to measure deflection, concrete and dowel bar strain at successive joints and relate this to the loads and the moisture/density changes at the pavement/base interface. It has shown that arrangements can be made to remotely monitor the information without the knowledge of the vehicle operator. This will assist the research staff in the future with the ability to monitor vehicle location on the slab, weights, strains, and deflections.

It can also be used to calibrate deflection measuring equipment and develop load equivalency factors.

The results to date serve to provide information on the costs, problems and planning steps that should be considered in establishment of instrumentation sites to answer pavement performance questions.

Work was also completed on comparing the results of several slab software programs to indicated how analysis may be carried out on a slab with skewed joint pattern such as the one being used. The analysis compared the results of using ILLISLAB, JSLAB, SLABPACK and FEACONS programs. That report shows that the skewed joints do serve a purpose in reducing the amount of stress on the slabs at each side of the joint. It also provides an indication on what the results of the field monitoring should provide to justify the models currently being used in the design of rigid pavements.

Work will continue on the calibration of the site to known weights of trucks under both static and dynamic conditions and collect data for the next two years. The results of the data will be provided in a second report on the use of the information to aid in improved pavement design.

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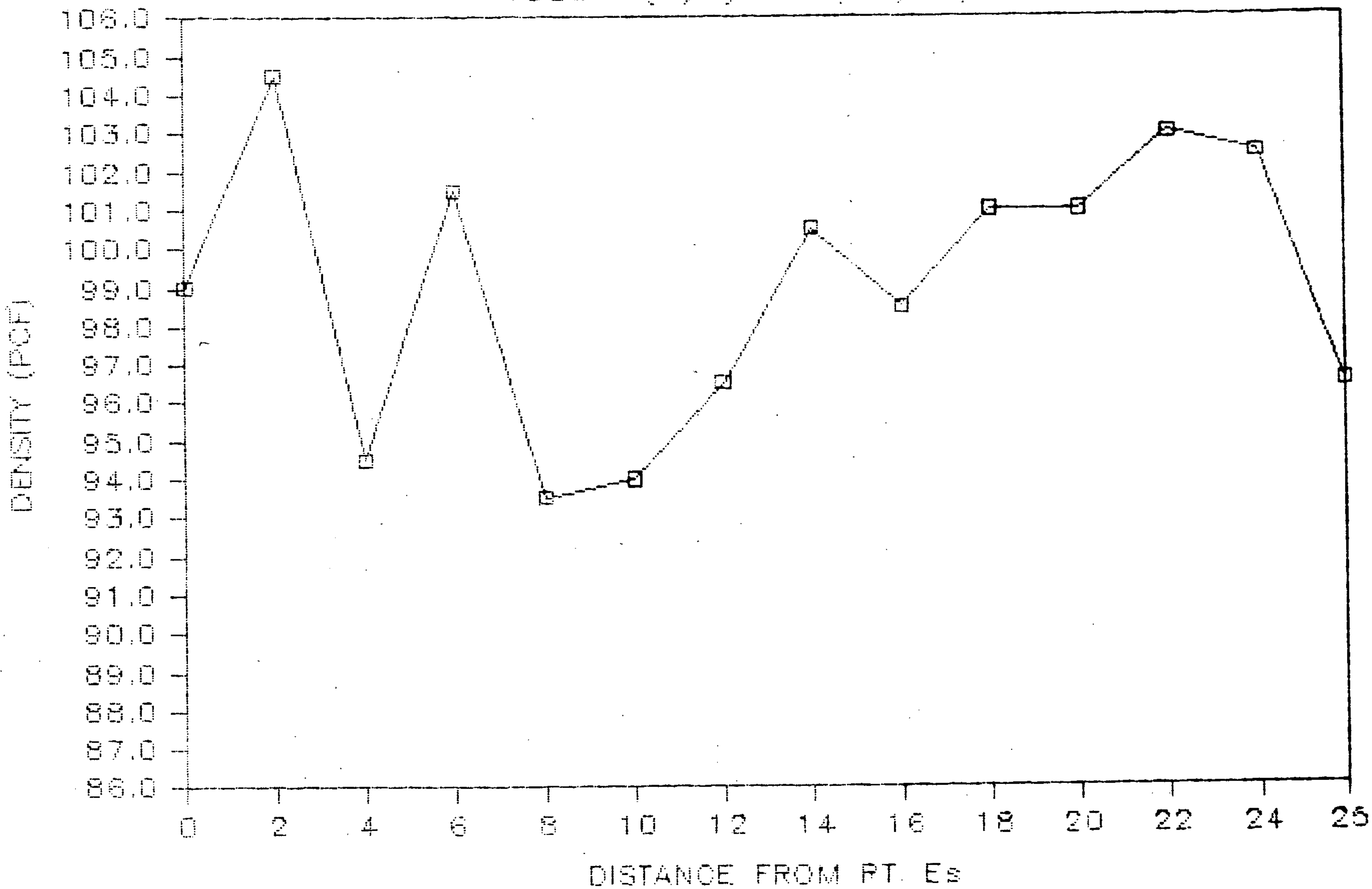
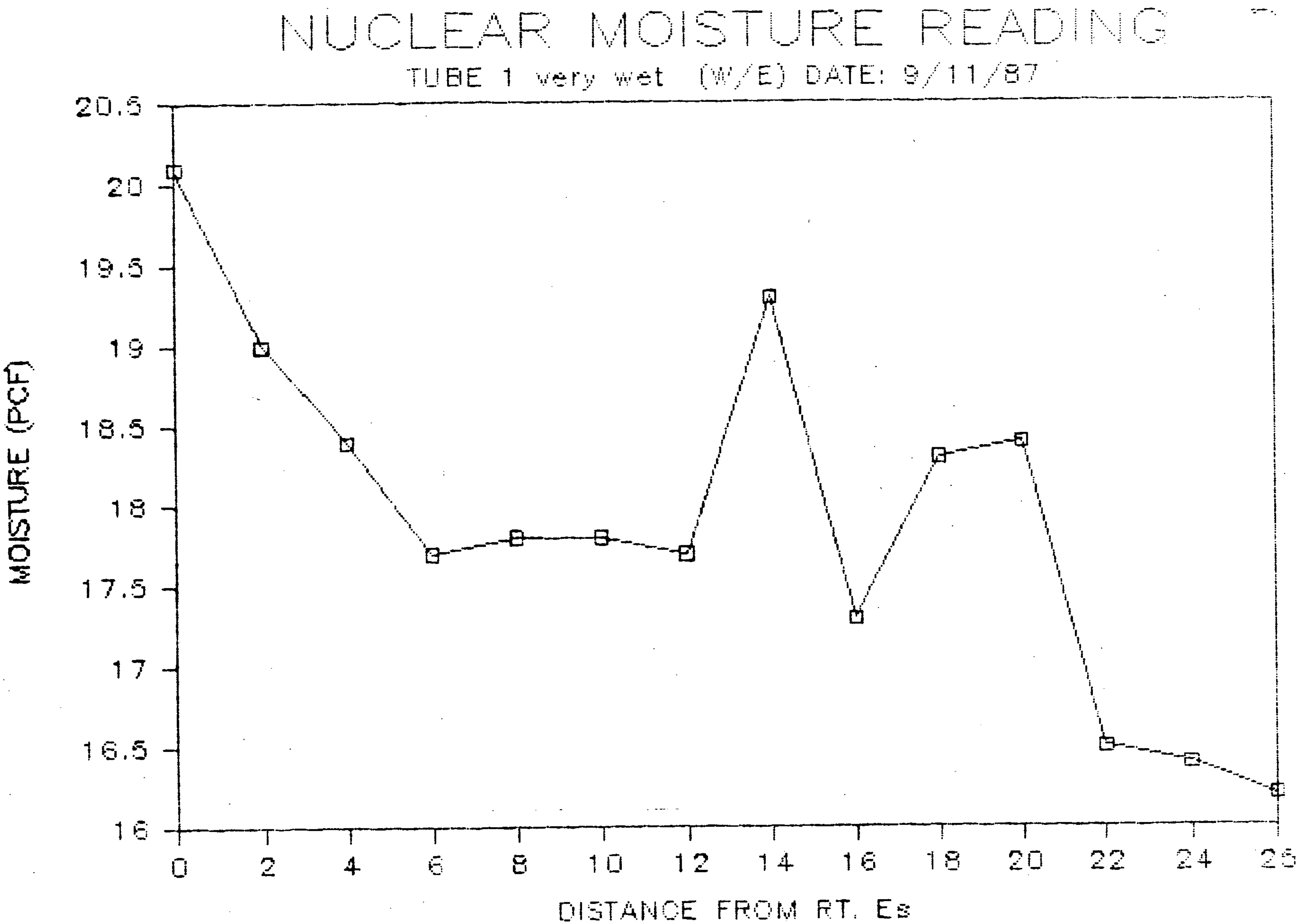
APPENDIX

NUCLEAR DENSITY READING

TUBE 1 (W/E) DATE: 9/11/87

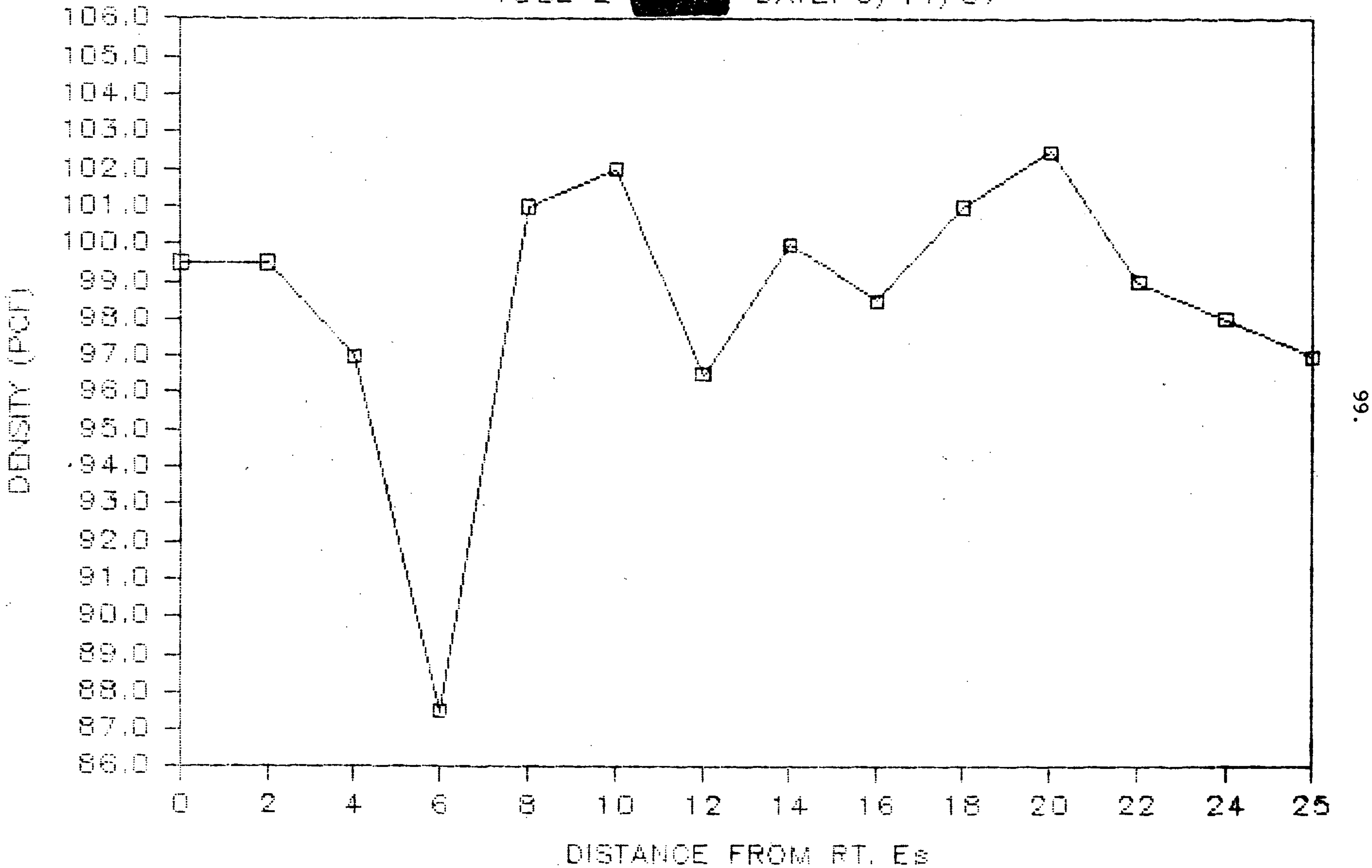




NUCLEAR MOISTURE READING
TUBE 1 very wet (W/E) DATE: 9/11/87
MOISTURE (PCF)
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DISTANCE FROM RT. Es

NUCLEAR DENSITY READING

TUBE 2 [redacted] DATE: 9/11/87



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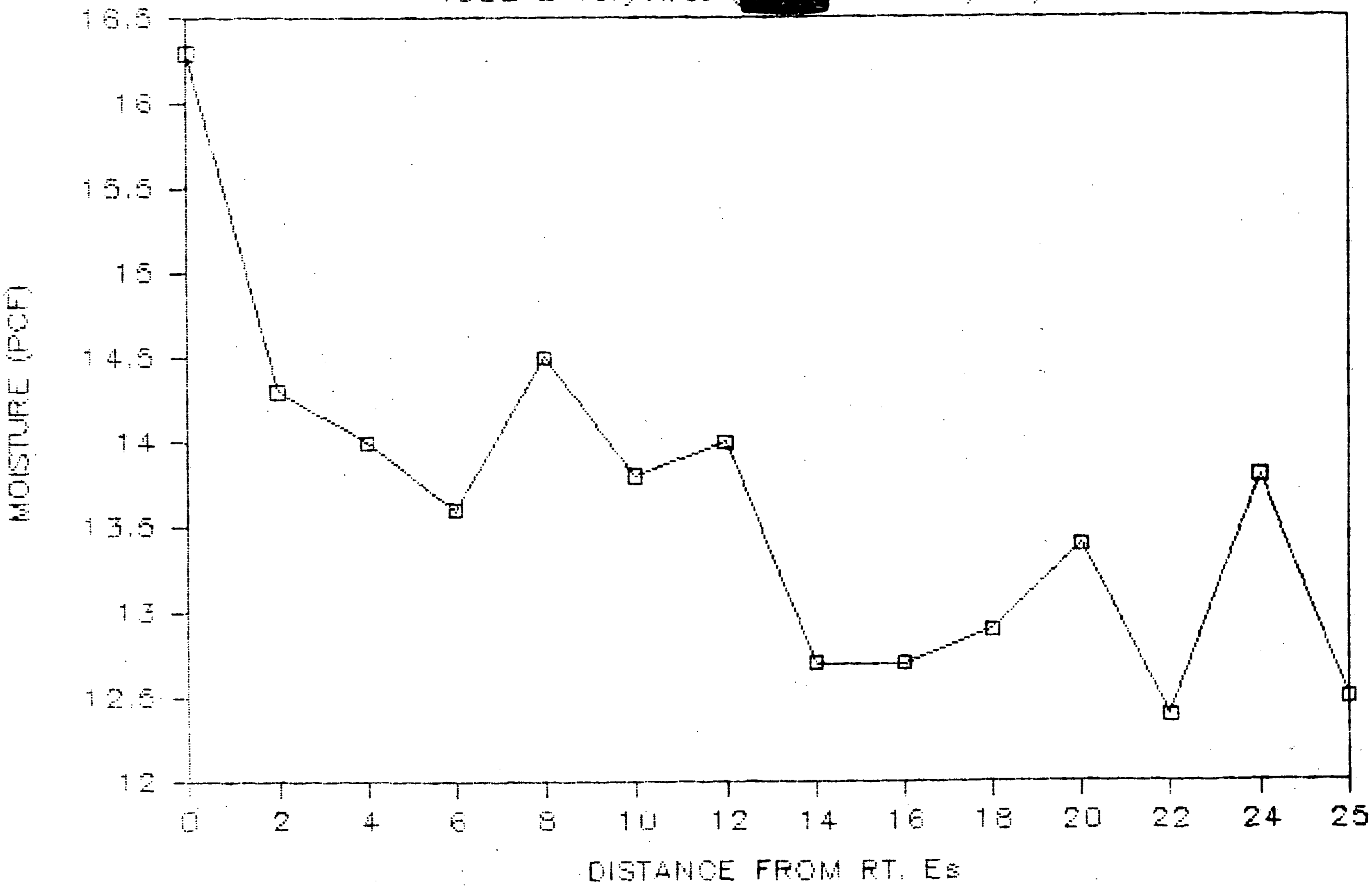

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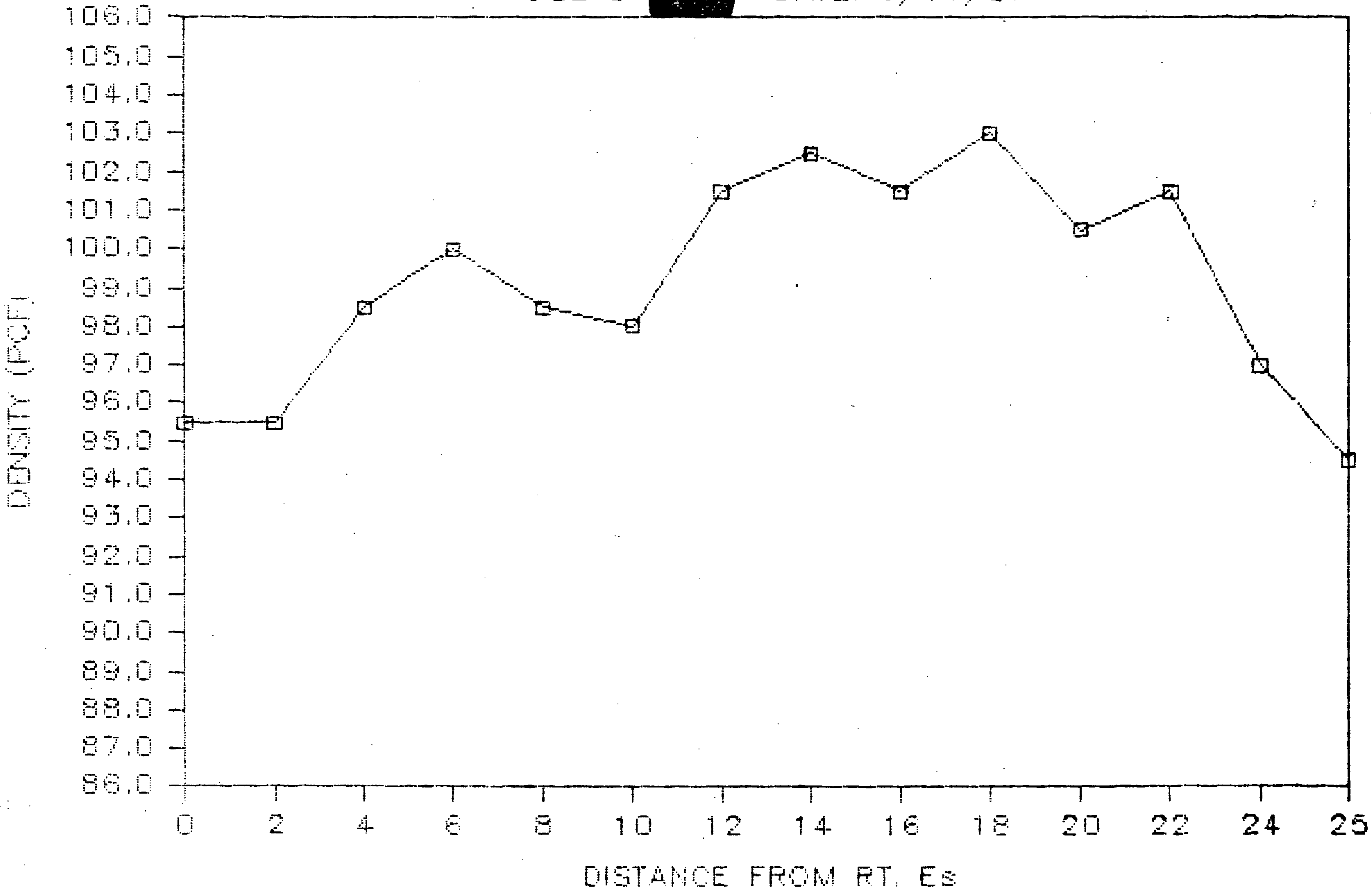

NUCLEAR MOISTURE READING

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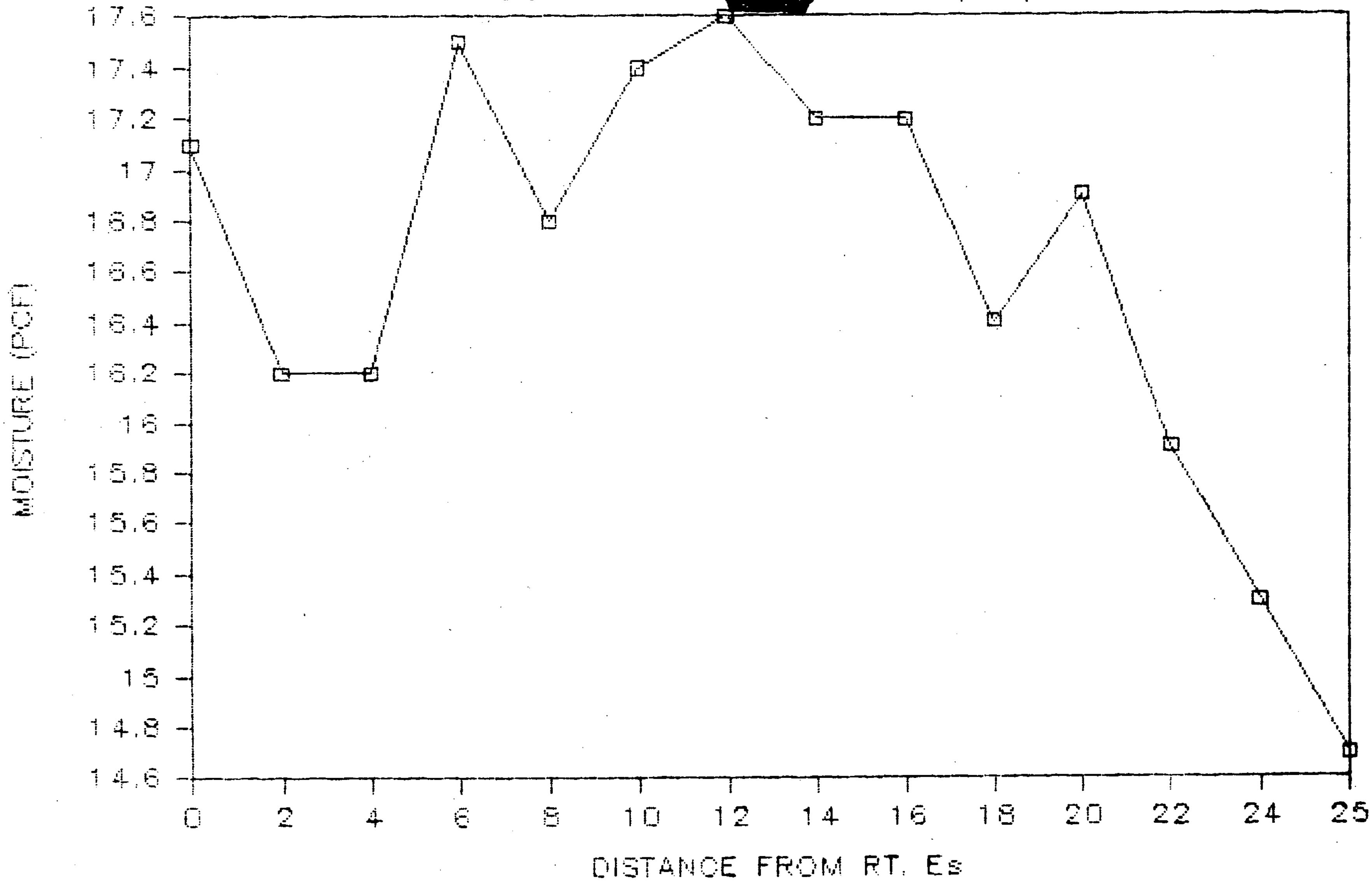

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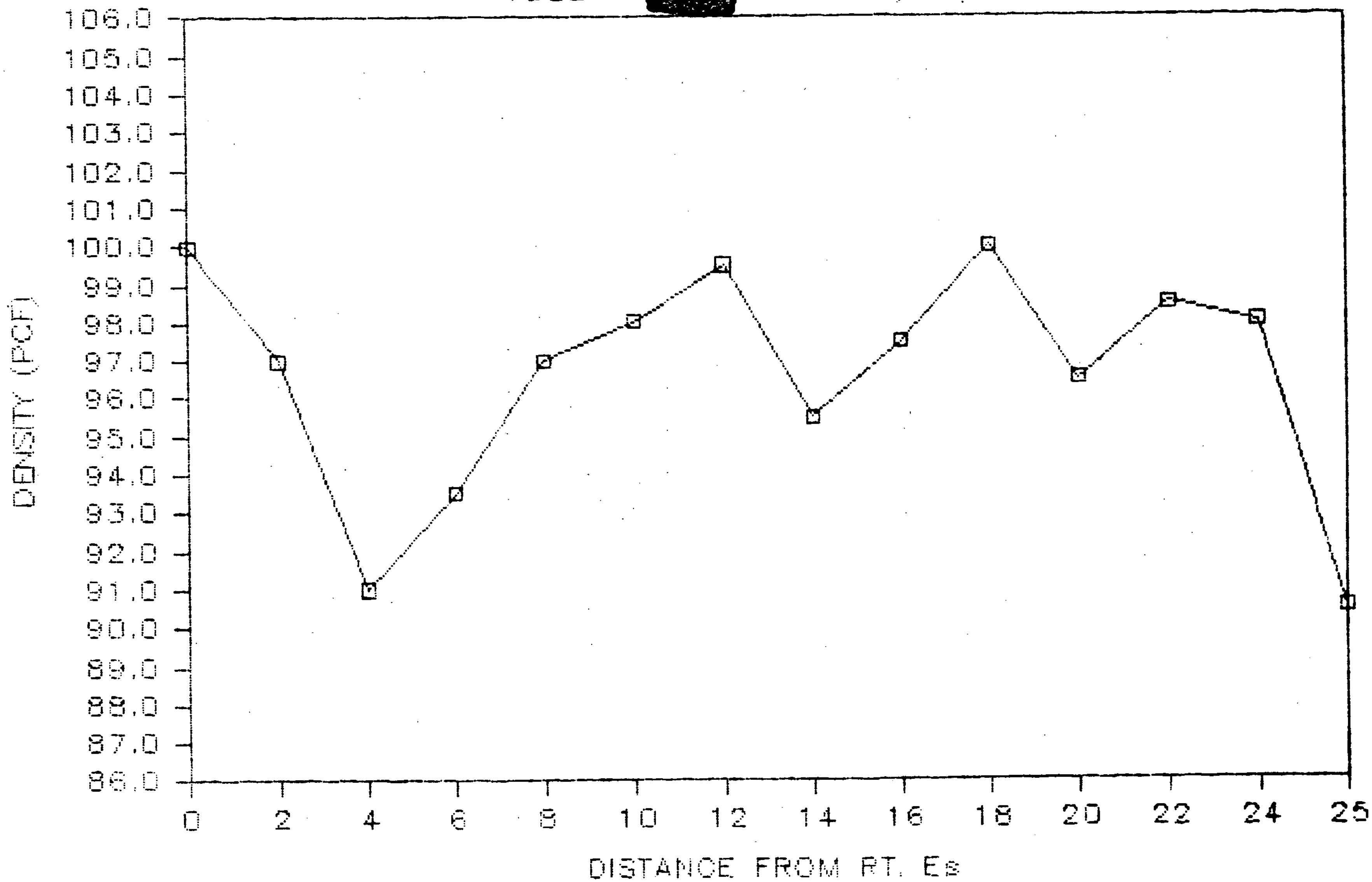

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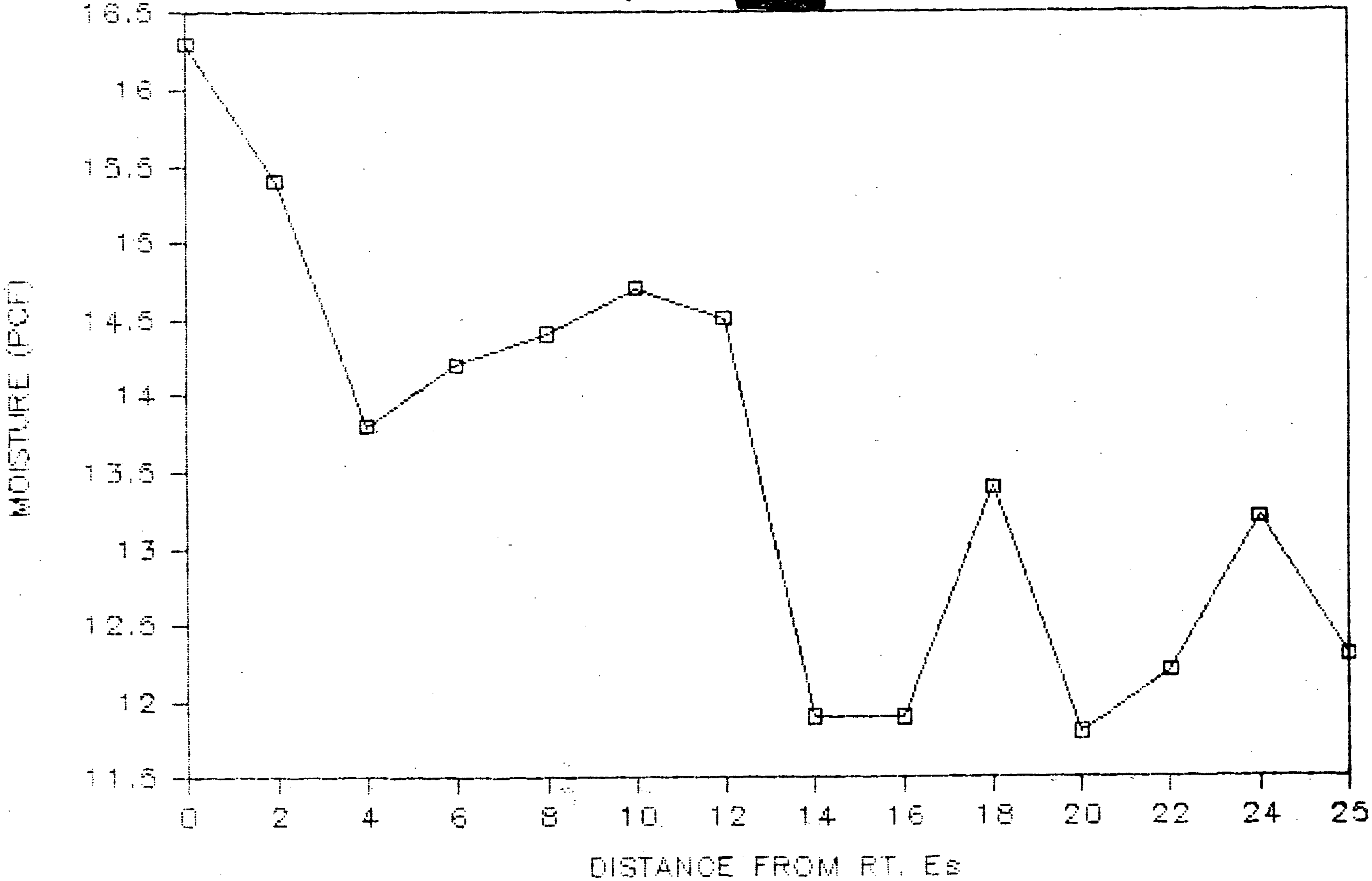

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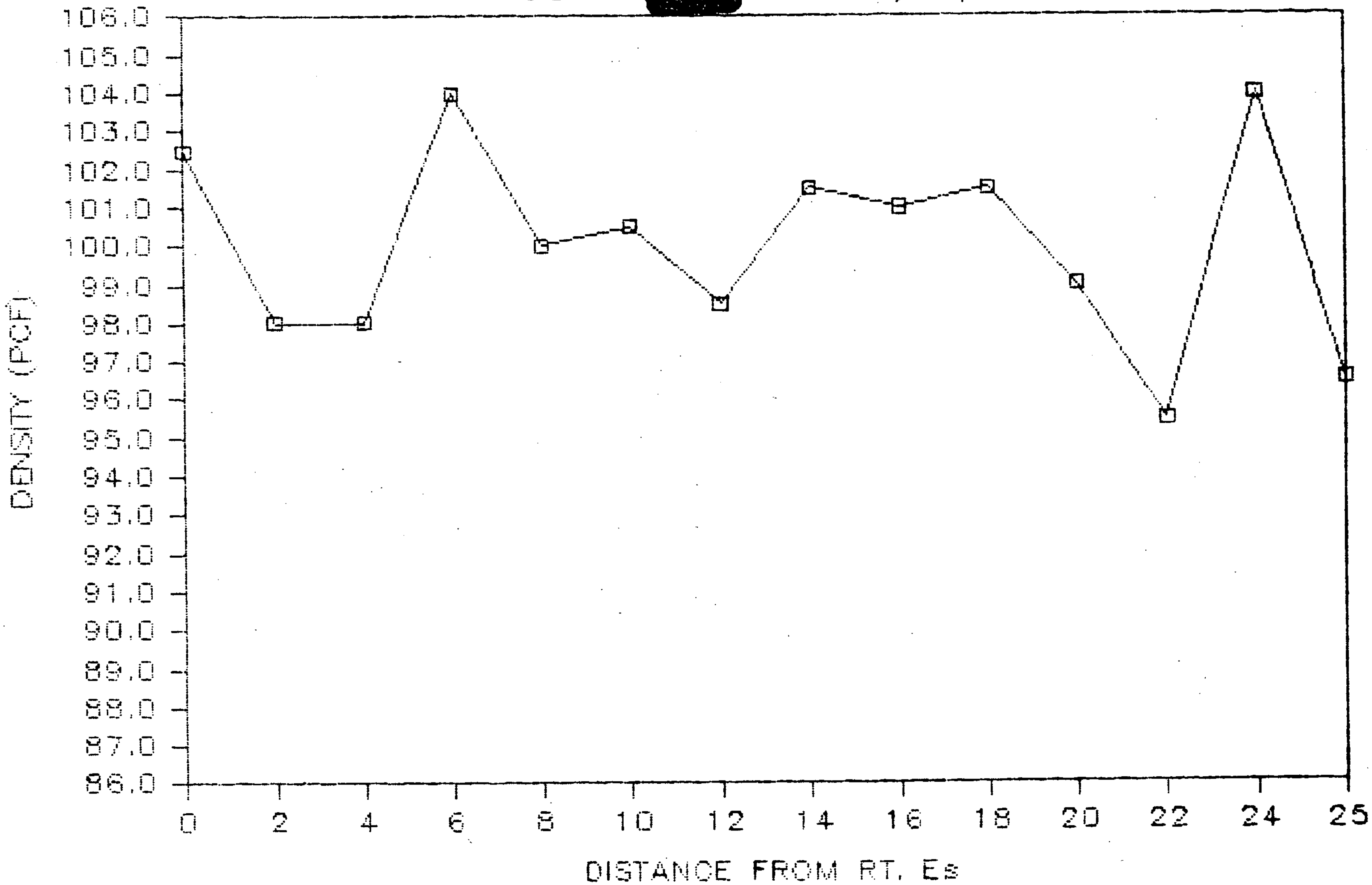

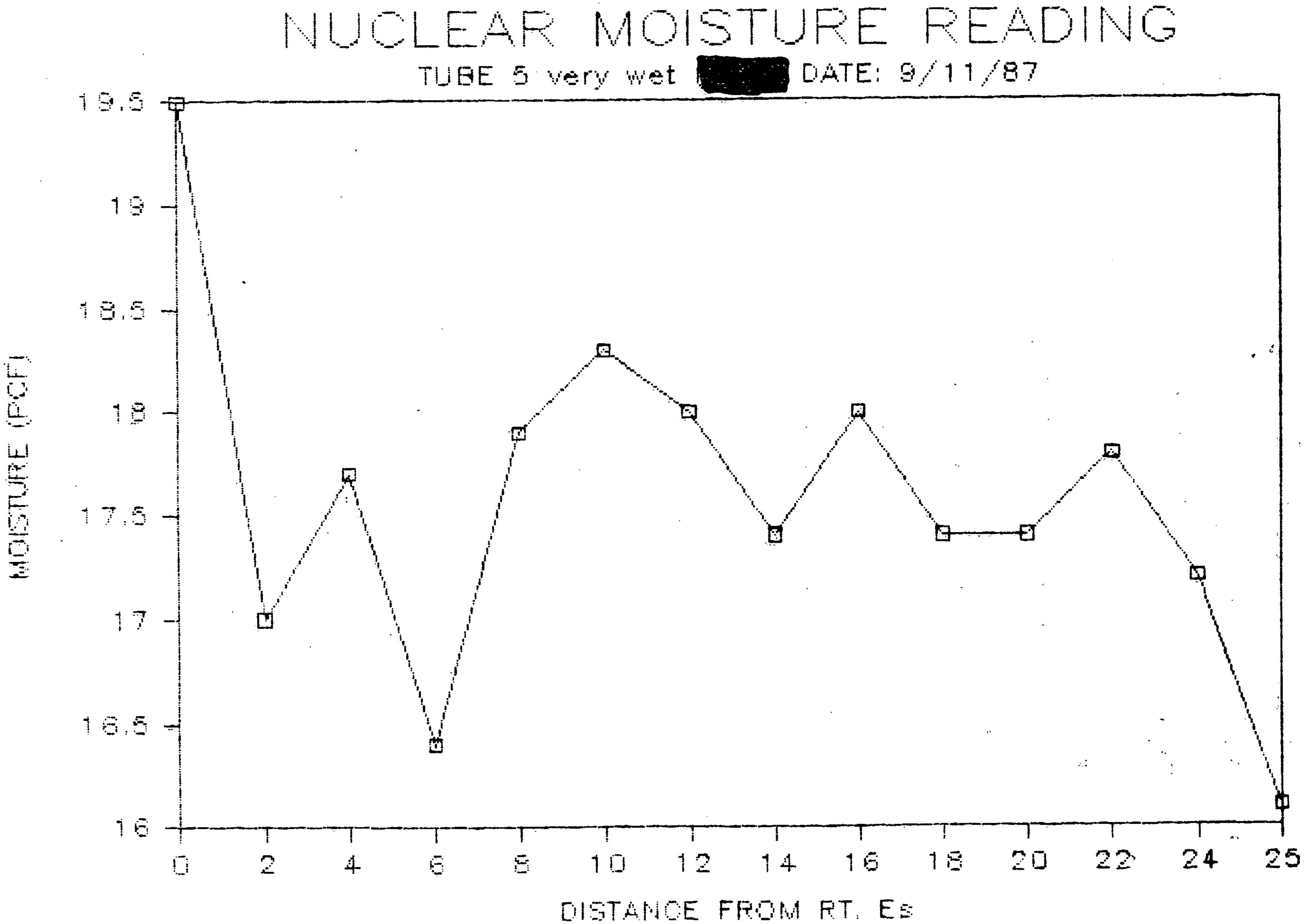
NUCLEAR MOISTURE READING
TUBE 5 very wet [redacted] DATE: 9/11/87
19.5
19
18.5
18
17.5
17
16.5
16
MOISTURE (PCF)
0
2
4
6
8
10
12
14
16
18
20
22
24
25
DISTANCE FROM RT. Es