Improved Pavement Design Through Pavement Instrumentation

James K. Cable

Iowa State University

ABSTRACT

Past methods of pavement design have relied heavily on the use of empirical data and laboratory testing to develop the materials and thickness required for an estimated number of loadings. The technology has advanced to the point where instrumentation can be used to measure the effect of the existing traffic flow on the pavement under various climatic conditions. This project is part of an FHWA Demonstration project and an Iowa Highway Research Board project on pavement instrumentation.

The paper describes the instrumentation that has been developed to monitor the traffic effect on a section of I-80 in Southwestern Iowa. The instrumentation includes the use of piezo electric cables to trigger the data collection and monitor the weight, speed, lateral location and lane placement of the vehicles passing over the data collection site. Data collection equipment includes concrete deflection, concrete and dowel bar strain, and temperature of the pavement and subgrade. A special application of nuclear gages is being used to measure the moisture and density of the material under the pavement at the joints and midslab location. Examples of the results are shown. The site is equipped with telephone lines and computer capability to allow remote sensing of the results at an office location at the University.

Site planning and installation problems and solutions are discussed in this report. The successes and failures of the installation portion of the project are discussed.

This type of location allows the designer and planner to monitor traffic and pavement performance remotely without interference or identification by the traffic to improve the knowledge of pavement/traffic/environment interaction.

INTRODUCTION

Pavement design as we know it today relies heavily on the use of empirical data and laboratory testing to develop the materials and the thickness required for an estimated number of loadings. Field testing of pavement design theory was carried out on some four well known controlled test roads such as the AASHO Road Test in the late 1950's. The technology has advanced to the point where instrumentation can be used to measure the effect of the existing traffic flow on the pavement under various climatic conditions. Iowa State University and the Iowa Department of Transportation are assisting the Federal Highway Administration in demonstrating the use of pavement instrumentation as a way of obtaining this type of data for possible assistance to other states and the Strategic Highway Research Program. Demonstration Project No. 621 "Pavement Instrumentation" is designed to demonstrate the "state of the art" equipment and methods in four states on two types of pavement. The Iowa project is designed to provide a better understanding of the performance of portland cement concrete pavements under actual traffic and environmental conditions.

This paper will describe the methods used and the problems/solutions used to perform the installation portion of the project. The details of the installation are included in the FHWA Report No. FHWA-EP-88-621-001, "Pavement Instrumentation" (Iowa Highway Research Board Project HR 293) dated March 1988.

Project Goals:

The project has both short and long range goals. Those associated with the installation portion of the project include:

Short Range

a. Installation of instruments in a new pavement during paving operations.
b. Development of a data acquisition system including hardware and software appropriate to the instruments installed.
c. Installation of communications link for remote monitoring of the site traffic.
d. Sensor response calibration to the known static and dynamic load situations and ranges.

e. Installation of the moisture/density instrumentation equipment.

The long range goals deal with the monitoring of concrete and steel strains in addition to deflections, moisture and density measurements to reflect the reaction of the instruments and the pavement to traffic and environment.

Project Objectives:

Three study objectives directed much of the project planning, equipment selection, and sensor placement. The objectives included:

a. Demonstration of portland cement concrete pavement instrumentation
   1. Instrument Placement
   2. Instrument reliability
   3. Hardware/software needs
   4. Instrumentation costs
   5. Potential applications
   6. Pavement performance evaluation
   7. Empirical/mechanistic design procedure development

Site Installation and Operation Problems/Solutions:

The following portions of this paper will describe the installation and the problems/solutions that each engineer should consider in the development of such a site. This type of project requires a large amount of dedication and time by those involved. It can be very frustrating at times, but the potential for a payoff in the improved pavement design that can result, is worth the wait.

Site Selection:

The site for the project was chosen on the basis of the truck traffic available, the existing reconstruction plan and site conditions. At the time the project was in the planning stages, only 5-10 portland cement paving projects were available on the state highway system. A further reduction in potential sites resulted when the need for extensive truck traffic over a three year study period was attached. The need for good historical data on the existing roadbed and pavement section made a pavement reconstruction project advisable. The relative location of static weight stations and classification equipment on the same route are helpful in the calibration of the site and monitoring of total traffic during the study. We were anticipating the need for a bridge of specific construction adjacent to the site to act as a weigh-in-motion bridge and trigger the instrumentation.

When all these criteria were added together, one site remained. The site is located in Pottawattamie County in Southwestern Iowa in the westbound lanes of I-80. The location is approximately one mile east of the Minden interchange and two miles east of the junction of I-80 and I-680. It is part of a seven mile reconstruction project and a 1,400 sag curve on a relatively flat grade. Truck traffic is in the range of 50% of the ADT. A static scale and classification unit is located upstream from the site and a bridge is located immediately adjacent to the test pavement. The new pavement consists of a 6.5-9.5 inch crushed concrete base and 11 inches of portland cement concrete pavement. The new pavement is 24 foot 10 inches wide with the extra width in the outer lane and the edge line is painted 10 inches from the lane/shoulder joint. Longitudinal subdrains are installed on the outside edge of the driving lane at a depth of 4 ft below the pavement surface. Figure 1 illustrates the layout of the site with the piezo cable trigger installation at the right of the diagram, the instrumented slabs in the middle and the weight in motion piezo arrangement at the left or west end of the site.

Utility Installation:

The site is not without logistical problems. It is located some 180 miles from the Ames office site. This created coordination problems in the installation period. The site being located in a rural area, some 4,000 feet from an inhabited dwelling and interchange was difficult to secure. We elected to install the strain gages on the dowel bar assemblies at the office and transport them to the site at the time of paving the test area. Each of the gages and the lead wires were developed in this manner to reduce field time and assure quality connections. Lead wires were cut to the exact length (100-200 ft) for each sensor to eliminate any splices between the gage and the control box adjacent to the roadway.

Power and telephone service were required to transmit information between the site and the Ames office. This required installation of a buried system between the interchange and the control box. The costs associated with the materials, installation and the acquisition of permits to place the lines inside the Interstate highway right of way were much higher than anticipated. The cooperation of each of the involved parties was excellent and resulted in substantial savings in time and effort to achieve the installation.

Instrument Installation:

Moisture and density measurements are made from inside two inch diameter aluminum irrigation pipes placed transversely across the pavement and embedded in the base material near the subgrade-base interface. The pipes were placed directly under each of the three transverse pavement joints in the instrumented area and at the two midslab locations between the joints. Due to their proximity to the base surface (6 ± inches), they were installed with the aid of a trencher after the base was compacted. Initial installation extended from the outside edge of the shoulder inward to the medial edge of the driving lanes. The use of the inside shoulder as a construction haul road required that the pipes be located and extended through the shoulder after construction of the pavement. The outside shoulders were trenched at each pavement joint and midslab in the test area to accommodate the irrigation pipes and the plastic conduit for the lead wire encasement. The contractor did the trenching and backfilling which turned out to be a major effort due to unexpected shoulder pavement depth (15 ± inches).

The planning effort for a project such as this must consider the objectives and the need for redundancy in sensor installation to assure measurements. To accomplish this the site consisted of two twenty foot long slabs, twenty four foot ten inches wide. This provides adjacent lanes and slabs to measure traffic variables and provide the redundancy in either transverse or longitudinal direction. Iowa's plan called for measurements made in the following manner:

a. Concrete strain
   - One inch below the top and one inch above the bottom surface
   - Longitudinal placement at midslab and in equal transverse spacings
   - Additional sensors placed diagonally in the exterior corners
b. Dowel bar strain
   - Mounted on the bottom of selected bars under the wheel paths, centerline, midjoint and near slab edges
c. Temperature
   - One inch below the top of pavement, one inch below top of base and one inch below top of subgrade
   - One ambient temperature measured near the control box
   - Mounted vertically on a rebar
d. Pavement deflection
   - Vertical transducers mounted in special metal housings
   - Installed after the pavement had cured.
   - Located in the wheelpaths near the transverse joints
e. Relative moisture/density of base/subgrade
   - Measured at the joints and midslab
   - Located transversely near the base/subgrade interface
   - Utilizes manual measurements with atomic measuring devices
f. Traffic
   - Classify, count, and weigh vehicles at highway speeds accurately
   - Trigger the data collection unit
   - Locate the vehicle laterally on the pavement lane

Some prepaving work was accomplished to place five foot sections of PVC pipe vertically under the pavement at the deflection sites. These sensors were placed through the concrete after construction with the aid of a concrete drill. Caution should be exercised in the placement of the wiring to such holes, temporary covers and drilling control. The use of colored plywood targets (1 foot square) allowed for easy identification of misaligned holes, but seized the drill bit. This difficulty also allowed for over compensation in drill pressure and resulted in wires close to the surface of the pipes being cut during drilling. The use of a survey crew to locate the PVC pipe locations before and after paving operations did reduce the improper hole alignment to only one in sixteen. Figure 2 shows the location and cross sectional view of the deflection gages at the joint and midslab locations.

Installation of the concrete and dowel bar sensors at the site was accomplished in less than eight hours. A forty-eight hour advance notice was supplied to the research team. The dowel bar assemblies were delivered to the site and set late on the first afternoon. The team of four, assisted by five to ten state highway officials completed the installation of the concrete sensors immediately in front of the paving train. Over one hundred sensors and lead wires were placed, secured against construction failure, put through lead PVC conduits to the shoulder edge. Additional sections of pipe, in the foreslope, parallel to the roadway, carried the lead wires to a central control cabinet near the center of the overall site. Only one concrete sensor was lost in the placement of the concrete by laborers and a slipform paver. Figures 3, 4, and 5 identify the location of each of the concrete, dowel bar, and temperature gages in the test slabs.

The installation used premolded concrete gages to minimize installation. They were mounted between simple rebar cages built in the base material. The dowel strain gages were epoxied to the bars and welded to the lead wires as were the concrete gages. The deflection gages and eight foot reference rods were inserted into the preconstructed holes and in the Iowa designed housings. The temperature gages were attached to the rebars in a manner similar to the dowel bar installation. The attachment of the gages to the lead wires in the office prior to field installation is a must in insuring proper operation.

The piezo cable arrangements for vehicle classification (instrument triggering) and the weigh-in-motion were accomplished as shown in Figures 6 and 7. The cables are imbedded in a shallow aluminum channel placed in a multiple saw cut in the surface of the pavement. The classification unit is located upstream from the instruments to classify the vehicles and trigger the instrument data collection unit only when a preset vehicle size arrives in either lane. This unit can gather speeed and axle spacing to classify the vehicle. The weigh-in-motion arrangement gathers information on the speed, axle spacings and weights, and lateral location on the pavement. It will act as a weighing device at the site and assist in the calibration of the instrumented area.

A continuity check was performed on the gages in August of 1987 and over 92% of the gages provided positive responses. This is excellent considering often similar research efforts result in less than 50% surviving the construction.

The remoteness of the site provided one perennial problem for the research team. Rain seemed to plague the project during construction. Even after the concrete was installed and the lead wires were being installed in the conduits between the slab and the control box, rainwater filled the conduit ditch and made work difficult. The same thing was present during the construction of the trench for the power and telephone cable. The rain and construction related delays caused the installation to take place in September vs July and produced extra manpower needs not anticipated in the planning stages.

Data collection and analysis equipment:

Decisions made in the planning, purchasing and installation phases of this area of the project are often underestimated. Some researchers will suggest that the software be identified first and then the hardware to operate the system. Others may suggest the opposite method of selection. In the case of Iowa, a decision was made on the hardware based on the desired speed of data collection. The original plan called for the field unit's ability to scan up to 120 separate gages at a rate of 1,000 times per second. Such a unit was found. Further examination of the experimental design identified the large amount of data that will be generated with such a system and has resulted in programming the system for a much slower rate of data collection from a portion of the sensors. The problem is not without problems in the area of programming, communications packages and lack of a common programming language. To date the system has not been fully operated due to these problems. It is suggested that future actions would center on the abilities and familiarity of the research staff with programming languages, analysis and communications packages and hardware as the selection criteria.

Results:

To date only information from the moisture and density tubes has been gathered and analyzed. An example of that data is shown in Figure 8 for one of the tubes. The density is shown with the zero location being the median edge of the passing lane. The data indicates that the density remains constant across the slab with the exception of a point near the middle of the passing lane.

There are two things that should be noted with these graphs. The site was built in a very dry season and has remained relatively dry to date. The second item is the variation in the graphed points near the center of the passing lane. Moisture appears to increase and density decrease at this point before moving in the opposite directions on each side of this point. One theory to date indicates that the action of the trucks on the driving lane tends to try to raise the passing lane off the base, causing the lower density and increased opportunity for moisture to collect.

Computer hardware reliability problems and programming delays have prevented the collection of data. Field installation of the data collection units and piezo cable arrangements are beginning to yield data at the time of this paper. The system is working and some data is currently under analysis. The site is yielding:

1. Vehicle classification data that can be used to identify the effects of scheduled operations of a permanent weight station east of this site on the volume and traffic mix of vehicles in the traffic stream. This unit also triggers the instrumented site data collection unit to maximize the efficiency of data collection and records a time of data collection.

2. The data collection unit is programmed to look at individual types of sensors or groups of sensors during the passage of the truck. This allows the researcher to consider the effect of the load on adjacent slabs longitudinally or transversely in the test area. The unit collects three files of data on each vehicle that record a zero voltage reading one each gage for calibration, the time of the vehicle passage, and the change in voltage due to the load on the pavement at each sensor, that can be converted to strain.

3. The weigh-in-motion arrangement will monitor weights, axle spacings and tire location to correlate the strains to the location of the load as they cross the instrumentation area.

4. Temperature gages will correlate the temperature gradient between the top of the slab and the subgrade with the recorded strains in the pavement. Similar information on deflection of the slab as correlated to the moisture and density of the base and subgrade can help describe the entire pavement mechanisim response to loads.

Anticipated Analysis:

Pavement design is based on an understanding of the traffic mix and loads, pavement materials, and the interactions of pavement, load and environment. This site provides a field laboratory to study all three parts of the puzzle at the same time. The analysis will look at the magnitude of the loads and anticipated strains as they relate to that anticipated in the pavement design. This should yield a predictive measure of the time to the first sign of pavement distress that can be expected. This will also provide a way of testing the traditional pavement design fatique equations over time. The ability to measure the environment, pavement reaction and the load at the same time under natural traffic conditions is a significant step toward understanding the performance or lack of in portland cement concrete pavements.

Recommendations:

The following recommendations are suggested for those installing instrumentation for the first time.

a. Project Planning - Develop an interdisciplinary team approach including a pavement engineer, programmer, researcher with experience in sensor selection and installation, computer/communications specialist, and department representatives in construction, maintenance and materials involved with the actual site construction. Begin the site construction planning at the same time the purchase of the computer and sensor hardware and software are being purchased. Delay times in shipment are longer than anticipated.

b. Site Preparation - Coordinate and communicate with the project contractor from the day of bidding to the construction. This should include construction scheduling, storage of construction materials and subcontractor/utility activities.

c. Gage Preparation - Prepare the gages and lead wiring in the lab. Pretest each sensor and lead wire prior to field installation.

d. Gage Installation - Prepare installation diagrams and conduct trial runs of the installation at the lab to avert the problems of missing equipment or materials in the field. Use adequate amounts of staff to meet the field time limits in installation.

e. Data Handling Preparation - Decide on and order at the same time the field installation is being planned, don't wait. Base those decisions on the following: What will be measured? How fast and how much data will be measured? What are the limitations of the sensors that the data collection equipment must meet? Where will the data be collected, stored, and analyzed? What are the limitations of the current staff and hardware/software to perform the collection and analysis? What are the budget limitations on the hardware and software?

f. Budgeting - Plan for the unexpected in the areas of computer hardware, software, programming and in the utility company accommodation costs. Computer programming and software needs can easily be double the anticipated costs. Utility installation and operation to a remote site is many times what might be expected.

SUMMARY AND CONCLUSIONS

The project has shown that the instrumentation of pavements can be installed during the paving operations with a minimum of disruption to the road construction. It has also shown that the gages have the ability to continue operation long after the construction. Remote sensing is a feasible way to monitor the traffic operations and reactions to the pavement to obtain an unbiased view of the interactions. The data acquired at sites such as this will assist the pavement designer in determining the proper pavement thickness for a given performance requirement.

The results to date serve to provide information on the costs and installation problems associated with instrumentation. They emphasize the planning required in the establishing of such a site. Details of the installation, costs and problems and conclusions reached to date on the project are included in the Federal Highway Administration Demonstration Projects Division Report, FHWA-EP-88-621-001. Work is continuing on the calibration of the site to known weight of trucks under both static and dynamic conditions and the collection of data for analysis.

REFERENCES

1. Cable, J.K., Rohde, J.R., Lee, D.Y., Klaiber, F.W., "Experimental Project No. 621, Pavement Instrumentation" report prepared for the Demonstration Projects Division, Federal Highway Administration and the Iowa Highway Research Board Project HR 293.
2. Wang, Hung-yu, "Comparisons of Solutions for Responses in Jointed Concrete Pavements," a draft thesis, September 1987.

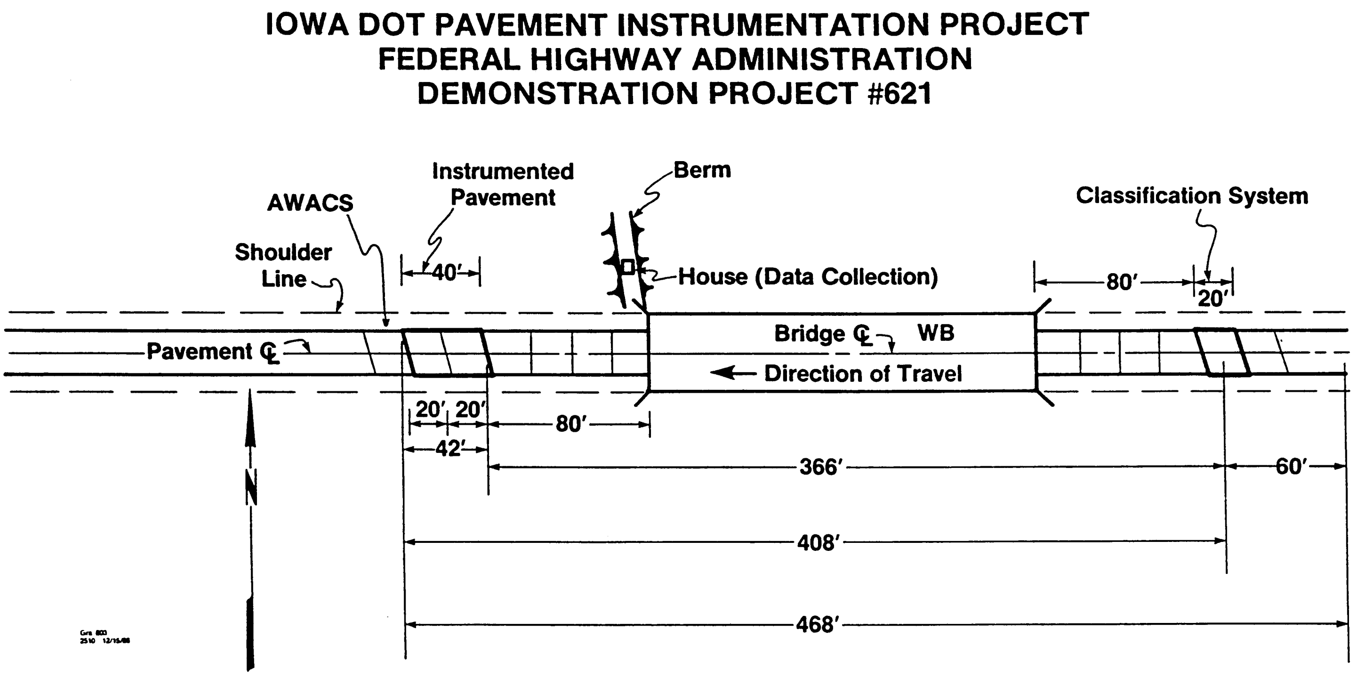


Figure 1. Pavement Instrumentation Site

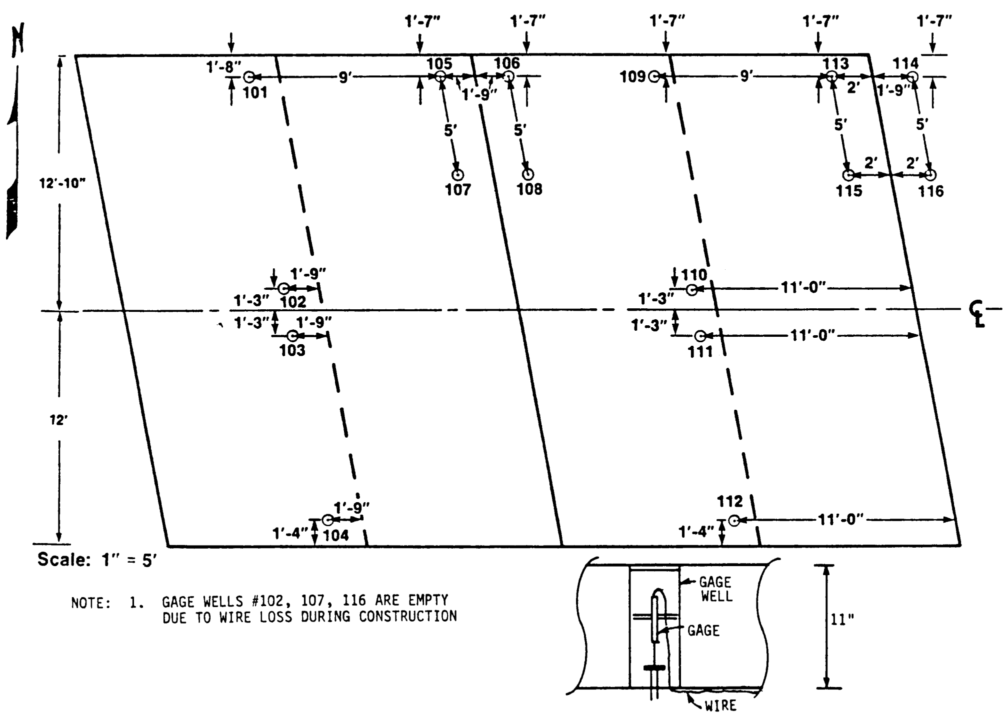
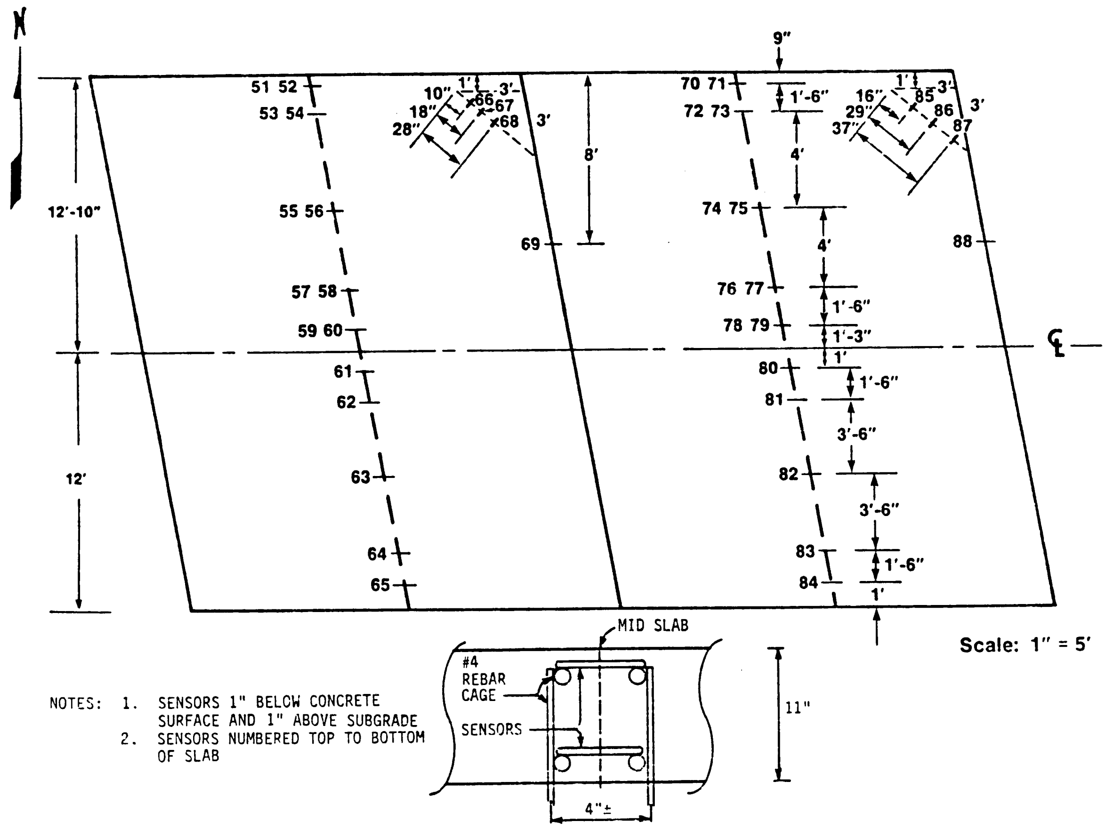


Figure 2. Deflection Sensor Location



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

Figure 3. Concrete Sensor Location

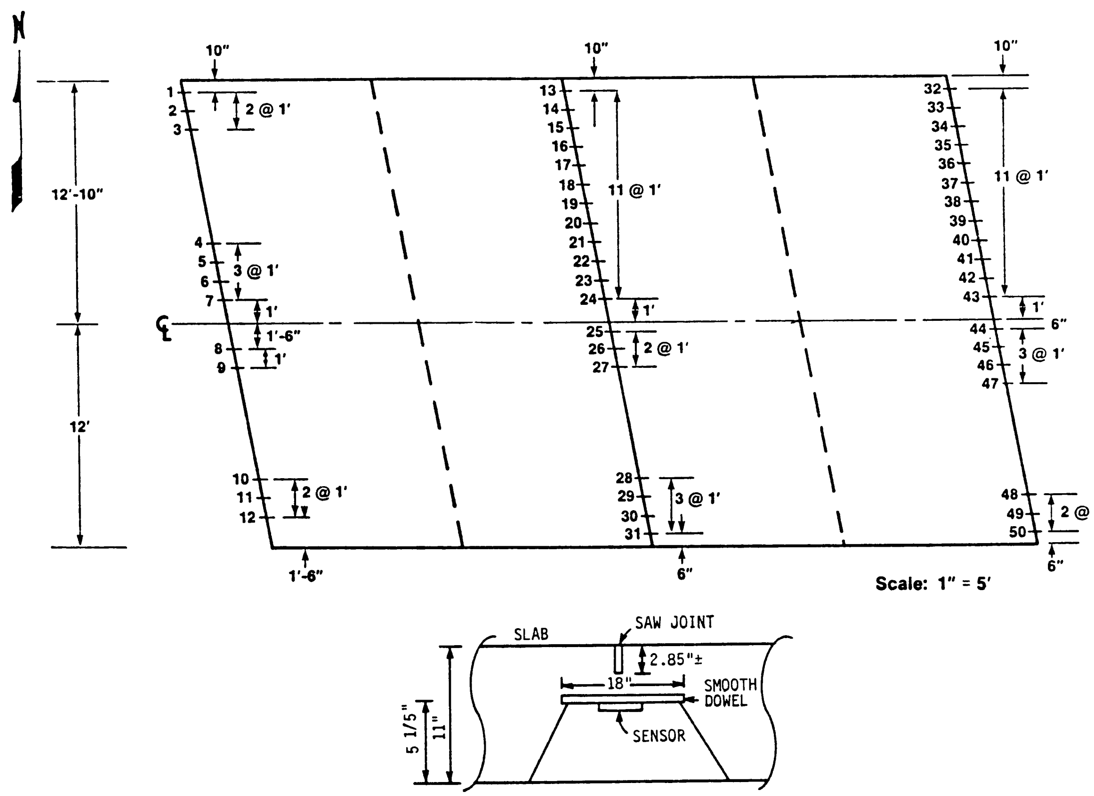
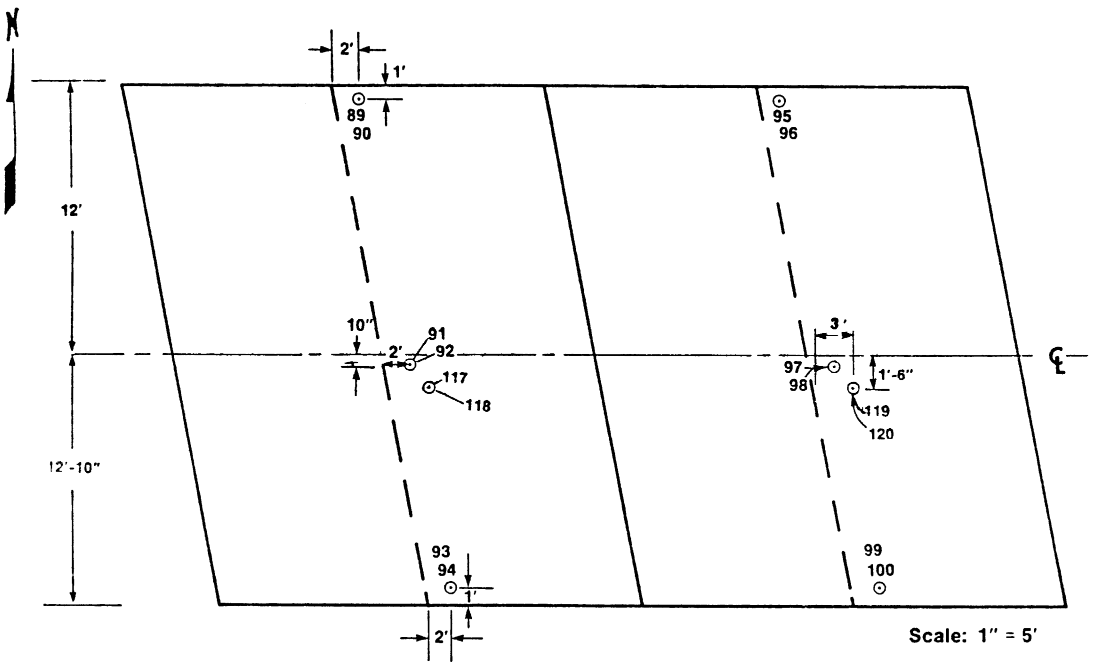


Figure 4. Dowel Bar Sensor Location



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 5. Temperature Sensor Location

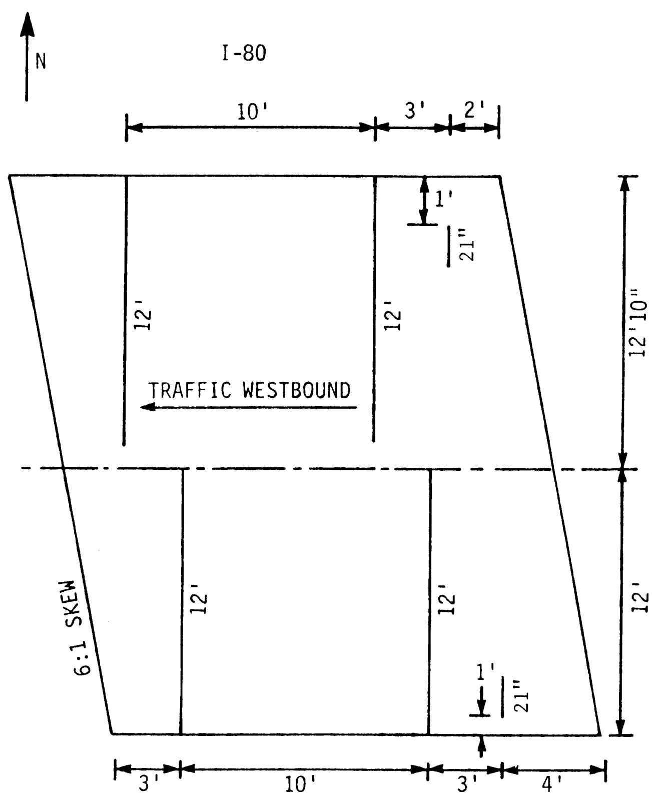


Figure 6. Vehicle Classification Piezo Cable Configuration

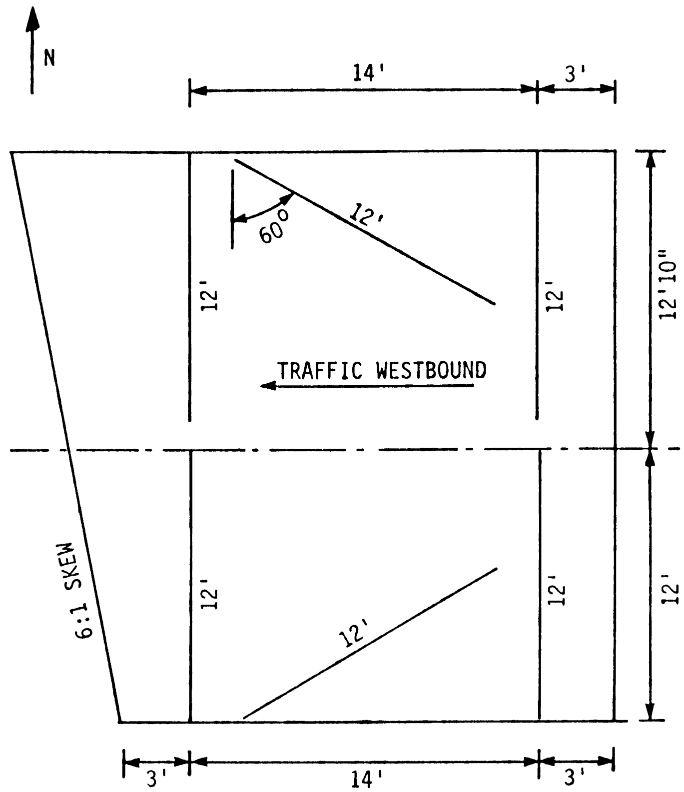


Figure 7. Vehicle Weigh-in-motion Piezo Cable Configuration

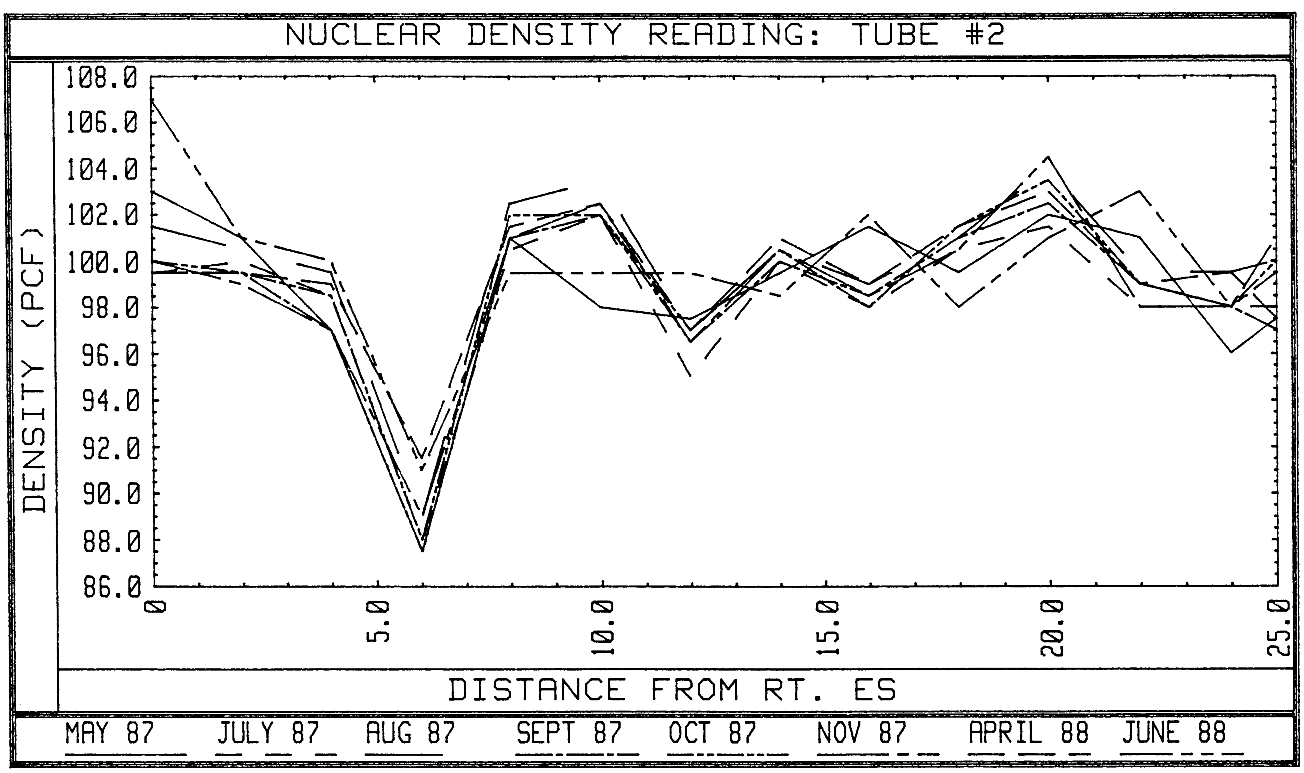


Figure 8. Base Density