TEMPERATURE INSTRUMENTATION FOR INDIANA'S THERMALLY INSULATED TEST ROAD

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Three thermally insulated test sections were built into an Indiana highway as part of an improvement project. The data collection system included 105 temperature transducers of the thermistor type buried within the test sections. Information is provided principally on the selection, fabrication, installation, and operation of the transducers, which were found to be reliable and economical.

•THE INDIANA thermal test road consisted of 3 instrumented test sections built into an active highway. Each test section was 200 ft long and differed from one another in the amount of foam plastic insulation installed at the top of the subgrade and in total depth of the pavement. The test road and data obtained from it are described in other reports (1, 2, 3, 4, 5, 6).

This paper presents information on the temperature instrumentation system used. The problem is described, and details are given on the instrument fabrication and field installation and on the data acquisition method. Information is also provided on the calibration procedure and on the precision and durability of the instruments.

NATURE OF THE PROBLEM

The innovations in the temperature-measuring system used on this project were the result of the need to meet a limited time schedule within existing budgetary and administrative restrictions. Frost effects are not so severe and widespread a problem in Indiana as in some other areas and are more easily handled because of Indiana's climate and soil conditions. However, the corrective action is often expensive and depletes the available aggregates. Therefore, the proposal by Purdue University to initiate studies of the use of foam-plastic insulation to reduce those costs was encouraged. A time schedule was adopted that was viewed likely to create some difficulties but to maintain the interest of the faculty and graduate students at Purdue and meet their academic schedules and requirements. Meeting the time schedule was a problem for the Research and Training Center, a new organization within the State Highway Commission. The center had little experience in this specific area of work or equipment applicable to it and had an overriding need to devote its limited budget for equipment purchases to items that could be of general utility for a variety of projects.

Instruments available on the market were of the thermocouple type. They are self-generating transducers that produce an electromotive force proportional to a temperature change. A sensitive and precise galvanometer or potentiometer is used to convert that force into temperature. Those instruments would be hard to adapt for use on other projects where the measurements would involve transducers operating on different principles. Furthermore, it is necessary each time readings are taken to have reference points in the circuit at a selected temperature. Inasmuch as readings were to be taken only once each day over a period of some months, an installation in which the reference points could be held at the selected temperature and continuous recorders protected was not justifiable.

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It was eventually decided that some form of thermistor would be used. Thermistors had been used in temperature measurement in a number of cases, although none had been buried in earth materials. The thermistor is a semiconductor, crystal, electronic element that undergoes a change in resistance when its temperature changes. It is commonly used in television sets as a means of limiting current to a safe level until the unit warms up to operating temperatures. It has also been used in temperature-measuring instruments. Selecting the thermistor simplified the data acquisition apparatus enormously because only a resistance-measuring device, such as an ohmmeter, would be needed. Such instruments were available in portable battery-operated form suitable for field use and required no reference temperature source. Thermistors were also capable of the required precision in temperature measurement because their resistance is calculated from an expression in which temperature is in the exponent, and many change resistance by a factor of 10 for a small temperature change. Thus, the problem of burying them in soil was the only remaining one.

SITE CONDITIONS

A part of the urgency to provide instrumentation resulted from the fact that a highway improvement project was scheduled in an area having frost-susceptible soils, and the test road was to be installed as part of that project. The location of the test installation was at the west edge of the city of Rossville where electric power was available for operating the electronic recording systems. A long cut was to be made with adequate length for the three 200-ft test sections, all of which would have a uniform grade and drainage condition, including deep side ditches and wide shoulders cut in the undisturbed soil. The soils at the site were principally silty sands, with sand fractions ranging from fine to coarse but predominately fine and in excess of 35 percent of nonplastic fines.

The contract provided for the placement of the foam-plastic insulation board by the contractor, for the various changes in subbase depth and in elevation of the finished subgrade at the test sections (including deletion of undercutting, which is normal in frost-susceptible soils), and for a limited amount of trenching by the contractor at the middle station of each of the test sections for installation of gauges. The length of time that the trenches were to be left open was limited, and state employees were to install the instruments in them and to do so with minimum interference with the contractor's overall operation. A total of 105 temperature measuring transducers were installed (an equal number in each test section) at locations ranging from the centerline of the roadway to the ditch on the north side and at depths as great as 14 ft below the surface of the finished pavement.

TRANSDUCER FABRICATION

The transducers selected were small glass-encapsulated thermistors in the shape of a bead (Fenwall Electronics, Inc., model EA33JM8). Figure 1 shows one of those beads in an early stage of transducer fabrication. When received from the manufacturer, each bead is approximately $^1/_{10}$ in. in diameter, and has 2 bare-wire leads approximately $^1/_{100}$ in. in diameter. The thermistor shown in Figure 1 already has a short length of hookup wire attached to each of the leads. The hookup wire permits the first soldering operation to occur without the heat damaging the thermistor itself, even with the little heat sink provision possible at that state. Also it increased the durability of the assembly during work in the next stages and made it easier to heat sink during the later soldering to the full length of lead cable.

The complete assembly is shown in Figure 2. In the second step, a length of heat-shrink insulation tubing was slipped over each of the lead assemblies developed (Fig. 1) and shrunk in place over the solder connection between the hookup wire and the thermistor lead. Then the ends of the hookup wires were stripped, connected, and soldered to the stripped ends of a 2-conductor polyvinyl-chloride (PVC) sheathed cable. A single length of vinyl electrical tape was then wrapped lengthwise about each lead from the shrunk tubing to the insulation on the conductor of the cable. That with the shrunk tubing provided a positive separation and prevented shorts between the leads. Two turns

of tape were placed around the end of the sheath of the 2-conductor cable to protect it from being cut, and a wrapping of wire was installed and tightly twisted over the taped sheath to prevent water infiltration and to provide a mechanical connection between the sheathed cable and the epoxy encapsulation.

Finally, the entire transducer assembly was encapsulated in a commercial epoxy that contained no volatile material (Fig. 3). Thus, 100 percent of the weight of material used in the mixture reacted and remained as part of the completed epoxy casting, and no water holes or porosity developed by evaporation of the solvents. A block of paraffin served as a mold for the casting. Grooves having a minimum width and depth slightly greater than ½ in. and a pointed tip at each end were cut in it with a hot iron. The transducer assembly was suspended in the middle of the space so provided and held in place by melting and clamping wax around the 2-conductor lead cable. The groove was long enough to contain the entire transducer assembly and the twisted sealing wire tires. This casting process was possible because the wax did not mix with the liquid epoxy, interfere with its reaction, or adhere to it strongly.

The epoxy was mixed and poured slowly into each of the grooves to fill it completely to the top and was then allowed to set for a minimum of 4 days. The completed transducer, after being removed from the mold, could be visually inspected for defects in casting or location of transducer elements within the epoxy mass because the material remained reasonably transparent. The transducers were cured in an oven at approximately 125 F for 24 hours (according to manufacturer's recommendations, the thermistors were not to be exposed to temperatures higher than 150 F because of a possibility of altering their electrical characteristic). Finally, the transducers were left in a bath of saltwater for a few days and then checked for resistance and for shorts between conductors or from the conductors to the solution. Of the 115 transducers constructed, only 3 had defects, and the 105 selected for actual field use were those that were the most similar in resistance at a series of known temperatures compared to the calibration curve provided by the thermistor manufacturer.

ASSEMBLY FOR FIELD INSTALLATION

So that their field installation would cause no delay to the contractor, the temperature transducers were assembled in the laboratory into a final wiring harness that was ready for burial without further connection work. That also permitted laboratory waterproofing and testing of any splices to be buried and made it possible to reduce the number of long cables to be handled in the field because the wires to a group of transducers that would be buried close to each other could be joined into single multiconductor cables. Eight-conductor cables with PVC sheathing were used as the multiple-circuit cables. The connection to the 8-conductor cable was planned to be located at a point convenient to each of the transducers to be connected to it, and the length of the 2-conductor cable attached to each transducer during its fabrication had been chosen to provide that length plus at least 2 ft of slack. Each of the 8-conductor cables was cut to a length slightly longer than needed to stretch from that connection point to a point on the shoulder slope of the completed highway where eventually a junction box would be located, in which temperature readings for that test section would be obtained.

Each of the 2-conductor cables was tagged according to its position when the transducer was finally installed in the grade, and then all in that group were connected to the 8-conductor cable at a single point. In that connection, 2 of the conductors in the 8-conductor cable were connected in common to one of the leads from each of the transducers involved in that part of the test section. As many as 6 transducers, each having a single color-coded conductor within the 8-conductor cable, were connected to the 8-conductor cable to a junction box to be used in the final field installation.

A junction box with the 8-conductor cable connected to it is shown in Figure 4. Each of the 8-conductor cables was led in, tied down, and connected to an 8-connector terminal strip, labeled and marked in such a manner that the resistance of each transducer could be read between a common terminal and one of the other connecting points, at which the transducer could be identified. The boxes used were metal military ration boxes, which have a waterproof metal lid and inside dimensions of approximately 12 x 12 x 15 in.

FINAL CALIBRATION

The thermistors were all of a single lot and were checked by the manufacturer to ensure that each had a certain calibration value within a very narrow tolerance range. This tolerance range, of course, was much closer than would be required for the eventual field use, but it might have been altered somewhat by the heating and handling in fabrication as well as by the characteristics of the lead wires. Therefore, the final calibration was checked. When the individual transducers had been tested and found free from shorts, those fitting the calibration curve most closely were selected for use in the field installation. Each of those fit a single calibration curve well enough that no reading at any temperature within the expected range would vary from the expected value within more than $^1/_{10}$ of 1 F.

Figure 5 shows the entire set of assembled transducers, complete with junction boxes, during the final calibration process in the laboratory. All of the transducers were immersed in a standard laboratory-temperature bath containing saltwater and then wrapped in fiber-glass insulation. Adding ice or setting the temperature control brought the water bath to a chosen temperature at 10 deg intervals between 0 and 150 deg where it was allowed to stabilize before readings were taken. The resistance of each gauge was read, and a check was made for shorts between leads and the water in the bath. All but 2 transducers as finally assembled met the manufacturer's calibration curve with an accuracy of less than $^1/_{10}$ of 1 F at each temperature. The other 2 transducers were fully operational except for slight shifts in their calibrated values, probably from a resistance difference in some point within the cabling, and special calibration curves were made for use in interpreting their results. No transducers were found to be defective or to have failed during that process, and the assembly was then ready for field use.

Figure 5 also shows the means of connecting the 8-conductor cable and the 2-conductor cables used for each of the transducers. That connection was fully encapsulated in cast epoxy in the same general manner as each of the transducers had been. Before the calibration procedure was begun, those encapsulated connections had also been soaked in a saltwater bath and checked for shorts or other evidence of water penetration.

FIELD INSTALLATION

At each of the test sections, installation of transducers began after the grading operation had cut the subgrade to its finished elevation. At that point, the contractor dug a trench 6 ft deep from the centerline of the roadway to the break of the shoulder. The transducer assemblies were then brought to each of the test sections. Only those transducers and cables could be installed that would be below the foam-plastic insulation or the top of the finished subgrade and in the width that would be beneath the pavement itself or the shoulder. The location of each transducer was established by taping from the centerline and shooting with a level to find its final position. The transducers installed below the bottom of the trench were suspended into holes drilled below the bottom of the trench with an auger. Figure 6 shows transducers during the process of installation when backfilling of the trench itself was nearly complete, and Figure 7 shows the tangle of conductors that might be expected to develop during the process of laying and sorting that many cables. Although the process appears to be confusing, the tagging method and record-keeping process were such that this was actually as organized as many construction operations. As a final check, each transducer was electrically identified at the time of installation by an electronic meter across its terminals in the junction box while being warmed by hand to produce a resistance change.

A sand used as backfill material was from the project and contained little material passing the No. 200 sieve. It was dried by the contractor in his bituminous plant and was poured by hand into the trench in a thin stream from a few feet above, a method that developed a density well above the minimum. The backfill of the auger holes was done by the same method. In addition, the backfill material in the trench was compacted in layers by standard vibratory equipment as the transducer placement progressed. Those transducers placed above the bottom of the trench were actually installed in a

Figure 1. Thermistor after first step in transducer fabrication.

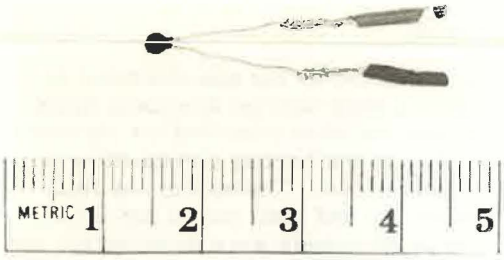

Figure 2. Completed transducer assembly.

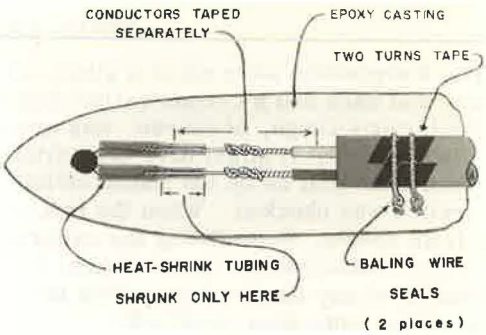

Figure 3. Casting of epoxy envelope.

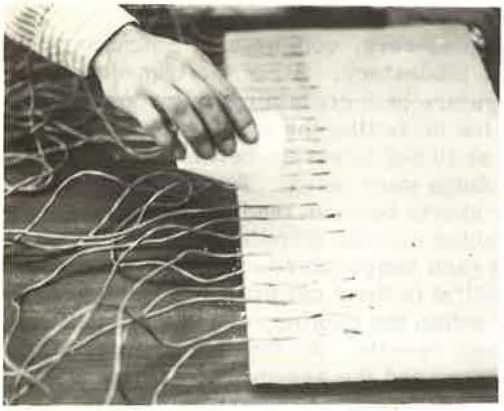

Figure 4. Terminals in junction box.

Figure 5. Calibration of wired system for field installation.

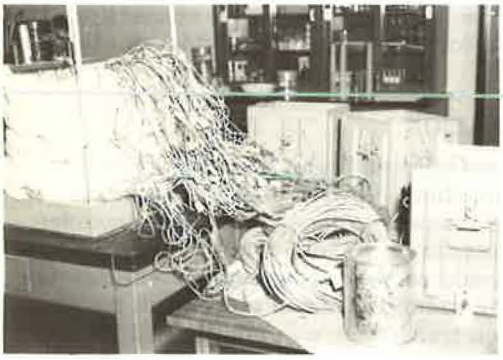

Figure 6. Transducers being buried in shoulder area beneath subbase.

Figure 7. Wired system during placing in shoulder area.

small hole driven into the wall with a sharpened rod. The transducer lead was allowed to hang slack from such a point to the bottom of the trench as backfilling proceeded; enough slack was held at the transducer's location to prevent it from being pulled out by the placement of the backfill.

Field installation of all of the transducers below the finished subgrade surface was completed in fewer than 3 days. At night and after the completion of this stage, the junction boxes and the remaining cables and transducers were loosely buried in the end of the trench. No further placement was done until the foam-plastic material and the subbase layers were all in place. At that time, a trench approximately 4 in. deep was dug by hand in the subbase across from each box to the centerline, and the transducers that were to be within that material were installed. The transducers that were to be installed in the bituminous layers above the subbase were shallowly buried directly beneath their installation points with enough slack wire to permit installation. Those trenches were eventually backfilled by hand with dried and vibrated material. Transducer placement then stopped until the flexible pavement surface was completely in place.

During that interval, the contractor completed ditch grading and sodding. When his work on the pavement surface and ditch was complete, holes were dug in the pavement at the points where the transducers to be in the bituminous pavement had been left. The transducers and their slack wire were recovered from the subbase and put in place, and the holes in the pavement and subbase were backfilled with bituminous mixture, which was obtained hot from the contractor's plant in small quantities and tamped by hand to normal density. Thereafter, the boxes themselves were excavated, the excavation from which they had been removed was enlarged, and a pit was constructed of concrete block and mortar and a steel-plate cover fitted with padlocks to protect the junction box. A small trench was dug by hand out through the ditch slope, and the gauges in that area were installed. As the ditch was filled, a drain was installed from the bottom of the concrete pit to remove any surface water that might enter under its steel cover. The cables, of course, were let in through the bottom of the pit during its construction. The junction box was then placed in the pit, and the cover was installed. When that installation was completed, only 3 transducers had become nonoperational, probably because of breaks in their lead cable during handling or as a result of earth movements during compaction or similar construction operations.

DATA COLLECTION

The portable, battery-operated meter for taking the resistance readings from the transducers (model 300 digital passive scaler manufactured by Western Reserve Electronics) could read all functions to 3 significant digits that were visible on the knobs that were used to adjust to a null balance (Fig. 4). To obtain the readings in a car required the installation of extension cables that could be coiled and left within the junction box such that a board similar to the board in the junction box could be lifted out and taken to a car parked at the location of the concrete pit. That simplified reading and provided more comfort for the technician obtaining the data. A reading was obtained by attaching one lead of the digital scaler to the common point for the transducers connected to a single 8-conductor terminal strip and by touching the other lead to the other terminals of that strip in turn. The readings of resistance were manually recorded by the operator, reduced to temperature by center personnel using calibration curves, and reported to Purdue personnel for their use.

An operator could normally complete the process within 2 hours, including the time to drive the 13 miles or more from the center to the site and back. During that period, he would also obtain the necessary readings from the standard weather station installed in connection with the project and would make other routine observations as required, for example, the depth of water in stand pipes that had been installed along the shoulder line to indicate the water table and of any patterns of ice or snow and their depth on the pavement surface and in the ditch lengths through the test sections. Reduction of the data obtained in a single day into a tabulated form for delivery to the personnel at Purdue usually required less than an hour of time at the center.

RESULTS

The temperature instrumentation system operated well during a 3-year period when data were read daily for the first and last winters and at other times on a less continual schedule. More than 95 percent of the transducers were still yielding data at the end of the first winter, and 85 percent of them were still operating properly and giving accurate data at the end of the third winter. Most of those that were not yielding reasonable data had either open or shorted circuits.

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