Temperature Sensing at MnROAD

General Description

Temperature sensing at MnROAD is accomplished with either thermocouples or thermistors. Predominately, thermocouples are used. The thermistors used at MnROAD are generally integrated into other instruments (e.g. Decagon ECH_2O-TE and 5TE Water Content Sensors, Geokon 4200A Vibrating Wire Strain Gauge, Geokon 4800 Circular Earth Pressure Cell). The two-letter designations for temperature-sensor data are TC for thermocouples, ET, XV and RT for thermistors. These thermistors are integrated components of other instruments.

Pre-manufactured thermocouples are rarely used. The general approach is to build vertical thermocouple arrays using type T (copper-constantan) thermocouple extension cable.

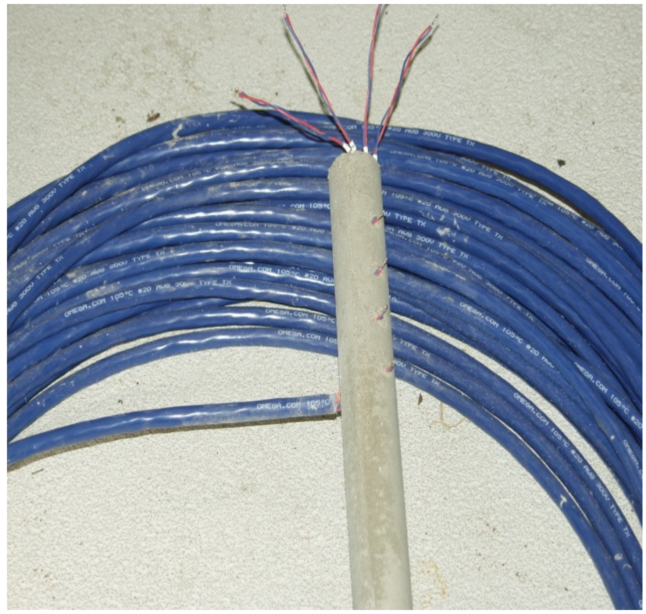

Figure 1: 8-Sensor TC Tree

Thermocouples work for measuring temperature because the joining of two dissimilar metal conductors generates a small voltage, called the Seebeck voltage or thermoelectric effect, which is proportional to the temperature difference between the hot (point of interest) end and a reference junction. Thermocouples are passive sensors. That is, they do not require an excitation voltage to generate a response to environmental change. Type T junctions typically have sensitivity of approximately 43 µV/°C. The measurement instrument is created simply by twisting the bare ends of the copper/constantan pairs together and soldering the junction. The reference junction is located within the data logger at the data acquisition point. A precision of ± 1°C has been achieved.

Thermistors are temperature-sensitive resistors. Unlike thermocouples, thermistors do require an external voltage to determine the resistance of the sensor at the time of measurement. Thermistors are made from semi-conductive materials; principally metal oxides but silicon and germanium are also used. Thermistors register large changes in resistance for small changes in temperature making them useful for measuring small changes in temperature. Thermistors are fragile and subject to self-heating. They are of two types Negative Thermal Coefficient (NTC) and Positive Thermal Coefficient (PTC). NTC thermistors decrease in resistance as temperature increases. PTC sensors increase in resistance as temperature increases.

Thermistors used in the Geokon Vibrating Wire Strain Gauge are NTC resistors. The thermistors used in the Decagon moisture sensor are an integrated part of the sensor circuitry and the raw data are not a resistance but somehow modified.

MnROAD's practice has been to develop thermocouple trees for each research cell measuring temperatures at researcher-defined intervals from the pavement surface to a point up to eight-feet below the surface. In recent times, the length of the "standard" tree has been reduced to six-feet. Temperature trees of varying lengths and numbers of sensors are constructed at the researcher's request.

Thermocouple trees have been constructed in a number of ways to satisfy the needs of the researcher. They have been constructed with single pair extension cable or multi-pair cables. Thermocouple pairs have been tie-wrapped to wooden dowels, molded into PVC pipes with modeling plastic, and molded into concrete using 1.5-inch diameter PVC pipe as the mold. Current practice is to construct temperature trees with 8, 12, or 16 sensor thermocouple extension cable for a simple, robust, and reasonably accurate temperature measurement tool.

Specifications

Multi-pair thermocouple extension cable is widely available. Extension cable for type T thermocouples is designated Type TX by ANSI. Each pair is made up of one constantan wire and one copper wire. Conductors are available in both solid and stranded and in 20 and 24 gauge respectively. Individual conductors are insulated with a polyvinyl jacket 0.015 inch thick. Pairs are individually twisted seven turns per foot. A clear Mylar tape is applied over the combined pairs. A copper drain wire is wound over the Mylar-covered combined pairs and is in contact with an aluminum-backed Mylar tape that serves as an electrostatic shield. The cable is jacketed with 0.045 inches of polyvinyl.

MnROAD uses 20 gauge solid conductors only as the copper/constantan conductor pairs are twisted and soldered together and used as thermocouples.

Pre-installation

Building the Thermocouple Tree is described in a separate document called "Building Temperature Sensor Arrays" and is available on request. This document provides detail on the planning for, designing and building a TC tree.

Pre-installation testing includes continuity of individual conductors on delivery of cable and testing of the completed array prior to installation.

MnROAD has determined that the accuracy of temperature arrays, constructed as mentioned above, are well within the acceptable range required for pavement design and research.

Installation

Installing a TC tree is a fairly simple process. . Thermocouple Trees are installed from the final base grade (just prior to paving). Installing at this time provides a reference elevation to insure proper sensor depths. MnROAD has installed TC trees at a variety of offsets from centerline but typically in the center of the traveled lane with HMA pavements and in the center and the outer edge of the traveled lane in PCC pavements.

The standard MnROAD TC tree is six-feet long. Sensor depths are defined by the researcher to provide a detailed temperature profile in the pavement, base and sub-base materials. Four, eight, twelve, and sixteen sensor trees are common at MnROAD.

To install the array, a hole is drilled in the roadway grade of large enough diameter to accommodate the re-compaction of the material removed. Care should be taken to segregate the various materials as they come out of the hole. Having a supply of the various virgin materials on hand might be helpful as some of the materials will be contaminated (intermixed) as they come out of the hole and virgin materials may be needed to reconstruct and compact the base and sub-base layers below.

After installing the tree but prior to pulling the lead cable to the control cabinet, test the continuity of the thermocouple pairs.

Figure 2: Installing a TC Tree

The tree should be constructed so that the lead cable is protected and buried at least two-inches below the surface of the base. Use appropriately sized PVC or flexible metal conduit to further protect the cable.

Pull the lead cable through a conduit/hand-hole system to the control cabinet and connect the individual, numbered pairs to the data logger/multiplexer. Begin collecting data as soon as possible so that potential problems may be addressed prior to paving.

Data Collection

Thermocouple leads are connected to Campbell Scientific CR1000 data logger via multiplexer(s). Individual sensors are polled every 15 minutes. Temperature is calculated by an internal function of the data logger as the data logger poles each sensor and the data stored in the logger's memory. Thermocouple data is stored in degrees Celsius. The logger is downloaded every night with the data stored on the loading server until morning when it is formatted and moved to the MnROAD database.

Thermistor data from Geokon static devices are recorded and stored in the same way as thermocouples but only raw data is stored since January 2010. Prior to January 2010 Temperature was calculated as the data was collected. The raw data currently (since January 2010) stored in the data base is resistance in Ohms.

To calculate temperature from raw thermistor data use the Steinhardt-Hart equation.

Equation 1: $T = \{1 / (A + B(\ln (R)) + C(\ln (R))^3)\} -273.15$,

Where T is in Degrees Celsius, R is in Ohms, and A, B, and C are constants: 0.00145051, 0.0002369, and 0.0000001019 respectively.

Data Checks

The TC_VALUES from the thermocouple wire data is run though a set of checks once it is entered into the database. Because MnROAD's database now stores millions of data points, an automated database filtration process was created. This system must allow researchers to isolate erroneous and missing data without deleting any data points. Data filtered out will have one of two qualities: 1) the data is missing or 2) the data is out of range. The system must complete this check for all of the data currently in the database and also for any future data added as well.

Procedure:

The following is a series of simplified steps taken to produce the TC data checks. A detailed procedure is fully documented in a separate document - (MnROAD TC_VALUES Check Documentation.DOCX)

Step 1: Set the 'check flag' field to 0 (raw data)
Step 2: Develop a table of monthly statistics for each cell and sequence to check the data against.
Step 3: A series of procs and loops were created using the following flags.

0. Set the new data to zero.
1. Value = Null check – set flag to 1 if false
2. Value = Null check – set flag to 2 if true
3. Value = Too sparse data – set flag to 3 if less than 60% data is being reported
4. Value = Extreme Outlier data – checks against static ranges generated by the monthly statistics – set to 4 if valid
5. Value = Outlier data – checks against dynamic ranges generated by the monthly statistics reading – set to 5 if valid
6. Value = data screened for missing or erroneous values – set to 6 if passes all checks.

Database Tables

MnROAD has an oracle database that each dataset is achieved for future use. Currently temperature data is not made public though our data release due to the large amount sensors installed and the data collection frequency (collect data every 15 minutes), but is available to anyone by contacting us with a data request. Though the data request we will be able to narrow down to the right cell, layers, sensors, data frequency that you require though running custom database queries. We are working on possibly having a set format for future data released and sharing the results of our data validation for these measurements.

MnROAD Data contains the following tables collected every 15 minutes:

- **TC_VALUES**
  - Thermocouple data is being collected from all MnROAD test cells
- **XV_VALUES** and **RT_VALUES**
  - Thermistor parameters associated with Vibrating Wire (VW) Strain Gauges available from all the PCC test cells at MnROAD.
- **ET_VALUES** - Raw thermistor data from the Decagon Moisture Sensors
  - Decagon thermistor data is available in most cells constructed since 2008

Each of these tables contain the following fields

Cell	Unique number assigned to a test section
Seq	Sequence - Unique number assigned to an individual sensor in a cell
Day	Date (DD-MMM-YYYY) the data was collected
Hour	Hour (0-23) the data was collected
Qhr	Quarter Hour (0,1,2,3) related to 0,15,30,45 minutes.
Minute	Minute (0-59) the data was collected
Value	Value of the data collected • TC_VALUES (Thermocouple data) is reported in degrees C • XV_VALUES (Vibrating Wire thermistor data) is reported in degrees C prior to 2010 and as a resistance since January 2010. • RT_VALUES ( ) (Vibrating Wire thermistor data) is reported in degrees C prior to 2010 and as a resistance since January 2010. • ET_VALUES
Check	Value of the database check done on the TC_VALUES data tables only. See the discussion above related to this data field.

For more information

For more information about MnROAD and the Road Research program at MnDOT:

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