NCHRP Web-Only Document 87 (Project 6-15): Contractor's Final Report and Field Manual

Test Methods for Evaluating Field Performance of RWIS Sensors

Prepared for:

National Cooperative Highway Research Program

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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PART I: FINAL REPORT

The final report for NCHRP Project 6-15 is not included herein at this time. However, it will be added later. The URL for this web-only document will remain the same even after the document is updated. Please check back later to see whether the final report has been added to this document:

http://trb.org/news/blurb_detail.asp?id=6163

PART II: FIELD TEST PROCEDURES FOR TESTING ENVIRONMENTAL SENSOR STATIONS

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COMMON TERMS

Central Server: Computer that collects data from many ESS sites

ESS (Environmental Sensor Station): All the components of a roadside weather station including atmospheric and pavement sensors

RPU (Remote Processing Unit): Electronic device that communicates with sensors, located roadside at the ESS site

RWIS (Road Weather Information System): Entire system for monitoring road weather over a usually large geographic region

PARTICIPATING VENDORS

Special thanks to the following vendors for their participation in the field test portion of this project.

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Nu-Metrics, Inc.
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Surface Systems, Inc.
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1. INTRODUCTION

At least 42 state departments of transportation (DOTs) and other public and private sector agencies which use Road Weather Information Systems (RWIS) typically specify requirements for the accuracy of instruments at Environmental Sensor Stations (ESS) at the time of procurement. These instruments include atmospheric and pavement surface and subsurface sensors. Most agencies rely on vendor-developed testing and calibration methods or they accept the sensor data without regular testing of calibration. This creates uncertainty in the accuracy of the data generated by the sensors and compromises the value of the information in decision-making.

As part of the National Cooperative Highway Research Program (NCHRP) it was determined that a need existed to develop guidelines for practical field testing of ESS sensors to evaluate if a sensor is providing an accurate representation of actual conditions at the installed site.

The procedures contained in this document define the equipment and describe the procedures that state, county and city personnel can use to measure sensor parameters and evaluate sensors.

The standardized methodologies for field testing various models of ESS *pavement* sensors were developed as a result of research performed by SRF Consulting Group, Inc., Braun Intertec and International Idea Institute, Inc. under NCHRP Project 6-15, Testing and Calibration Methods for RWIS Sensors. Pavement temperature, surface state, and freezing point temperature are the three pavement sensor parameters that were addressed in the study.

In order to develop these procedures, extensive laboratory and field tests were conducted, analyzed and documented. The basic approach of the process was a comparative test between baseline and pavement sensor data. Various potential field test procedures were developed and evaluated using a laboratory environment where external variables could be controlled and the tests could be repeatedly run. Based on these tests, a draft document of standard field test procedures was prepared. These draft field test procedures were then evaluated during on-site field testing in Minnesota, Nevada and Pennsylvania before being finalized for this document.

2. TEST PREPARATION

2.1 PERSONNEL TRAINING

The first step in preparing for field testing is to adequately train the personnel that will be responsible for field test activities. A trained presenter, using a PowerPoint presentation (available at http://trb.org/news/blurb_detail.asp?id=6163) that was developed to complement these guidelines, usually provides training for these test procedures. During the training presentation, all the testing equipment should be on hand so that the presenter can illustrate the procedures effectively. After the training, both the presenter and trainees should run through the test procedures together. They should read each test procedure and perform each step either at a simulated test area, such as a parking lot, or gathered around a table. This hands-on experience is essential for learning and understanding the tests.

Also, test equipment will need to be procured and prepared. Lists of that equipment can be found in the Field Test Procedures Section.

Figure 1. Classroom Training.

3. SAFETY CONSIDERATIONS

In order to do accurate field testing of pavement sensors, physical contact with the sensors is required. This means that personnel will be working on the roadway in a lane closure. Some necessary safety precautions **must** be taken to ensure the safety of both test operators and drivers on the highway.

3.1. PERSONNEL SAFETY

Safety is always a critical issue when working on highways, but it becomes increasingly important when the test operator is subjected to long hours near very fast-moving traffic. Because of this consideration, safety must be taken as the first priority when running the tests.

- If traffic, weather or any other conditions develop while running the tests that create safety hazards, testing should be halted immediately until the conditions improve or the problem can be resolved.
- Depending on factors, such as how far the operator must travel to the test site, how many tests are required and how the sensor responds, the operator may be required to work long hours or may become fatigued. Although a single person may run the procedures, an additional operator is recommended to aid and/or replace the first operator if necessary.
- Many of the tests will be conducted under poor or extreme weather conditions and most require that the sensor be shielded from solar radiation. Use of a shelter tent or collapsible ice fishing shelter, adequately anchored to the pavement, is therefore recommended to protect the operator and shield the sensor during the tests.

To provide additional operator protection it is strongly recommended that a crash truck be provided in addition to the required lane closure.

3.2. ELECTROSTATIC DISCHARGE PROTECTION

Many of these procedures require protection from electrostatic discharge (ESD). If the RPU and pavement sensor equipment is not handled properly, ESD can be hazardous to the operator and damage the equipment. In order to properly deal with electrical devices, please carefully read the equipment manuals.

3.3. LANE CLOSURES

Lane closures are required for pavement sensor testing so that the pavement sensors can be accessed directly. Because the procedures involve contact with the surface of the pavement and sensor, adequate space to safely run the procedures is necessary. Information about safe lane closures may be found in the Manual on Uniform Traffic Control Devices (MUTCD) available from the Federal Highway Administration. Because different states have different policies, it is best to check with the locally adopted MUTCD and follow any other safety considerations that may apply. Figure 3 illustrates a crash truck being used to protect a work area, in this case, the left lane of a four-lane divided roadway.

Figure 2. Operator Performing Tests in a Closed Lane.

Figure 3. Crash Truck Protecting Operators in a Lane Closure.

4. ESS DATA COLLECTION METHODS

4.1 METHODS FOR OBTAINING RPU DATA

In most pavement sensor installations, the sensor passes data to a Remote Processing Unit (RPU), usually located in a cabinet near the site of the pavement sensor. This RPU may often be accessed by a computer via a serial, modem or Ethernet connection. In order to access this data at any given field site, it will be necessary to either access the RPU's data locally with a portable computer or call a central server or office for the information. Depending on the situation, this could be performed using cell voice or data service.

Based on the findings during the research for developing these guidelines, some RPU manufacturers will not release detailed RPU access information for publication. In addition, each manufacturer has different procedures to access their RPUs. Therefore, it is necessary for the individual agency or the owner of the equipment to directly obtain the necessary RPU access procedures from the RPU manufacturer. Once the agency has access to the RPU, the procedures for testing the pavement sensor will be the same for all pavement sensors, regardless of the sensor manufacturer. The owner of the equipment should be able to obtain the information necessary to access the RPUs from the manufacturer who they have purchased the equipment from. Note that some manufacturers may require their technicians to be at the sensor site to access the RPUs. The usefulness of these test procedures depends on having access to data from the test site.

Another issue that the agency will need to resolve, through the manufacturer, is how their sensor determines surface conditions. Some sites use information inputs other than pavement sensor readings to determine a single parameter. A common issue can appear during the surface state tests. Sometimes, the wrong surface condition is displayed if the RPU requires inputs from atmospheric sensors for precipitation and humidity to determine the surface state. For example, if a sensor is dried and sheltered from precipitation on a rainy day, the sensor may not report dry because its precipitation sensor detects the rain. Knowledge of these sensor intricacies is essential to producing accurate evaluations. Sensor vendors have a good understanding of these phenomena.

Another issue to address before performing the tests is changing the interval between readings. Because all the tests to be conducted require timely information, it is best if the pavement sensor data can be read at two-minute increments. RWIS data is typically not updated or needed this often. Therefore, in order to run these tests effectively, it likely will be necessary to configure the RPU or computer to give more frequent updates.

The following sections present two methods for obtaining data from the RPU. These procedures are general enough to apply to many types of ESS stations.

4.2 ACCESSING AN RPU DIRECTLY

Most RPUs can be configured to send serial data to a computer. A terminal program running on the portable computer can often read this data if the data rates are set appropriately. Usually, this information is given in a delimited format that can be understood without decoding. For example, the data in the third column might be temperature data, while the fourth column might be a surface state in a binary format, such as "0" for "dry" and "1" for "wet." Data format information is available from the vendor.

In order to access the RPU, each state highway agency should contact the RPU manufacturer to determine the best way to access the data. The manufacturer may also have expertise that will make the testing run more efficiently.

Typical RPUs can send data to a computer over a 9-pin serial connection with an RS-232 connector. This can be connected to the computer via the COM port. This scenario is shown in Figure 4. In some cases, it may be necessary for a manufacturer's representative to be on hand to access the RPU data directly. In other cases, this person may be able to configure the sensor to make it more useful for the sensor testing.

In some cases, the RPU is connected to a serial server that may be accessed with a TCP/IP connection through a hub at the ESS site. This type of connection is advantageous because the portable computer may be connected to the ESS system without changing the way the system functions. This scenario is shown in Figure 5.

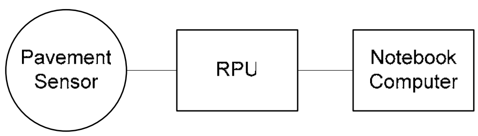


Figure 4. Possible Testing Configuration – Version A

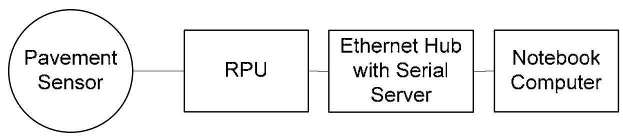


Figure 5. Possible Testing Configuration – Version B

A caveat to these approaches is that the distance from the RPU to the pavement sensor site is often too far or crosses a traffic lane. In certain cases it may be necessary to use special hardware to send serial or Ethernet data over a long distance. Possible solutions are wireless serial data radios or line drivers which send the data over twisted pair. If these solutions are not available, it may be necessary for one operator to stand at the RPU site and tell the other operator the sensor status over a radio. Obviously, this is not an optimal situation, but it removes some of the technical issues.

4.3. CALL UP CENTRAL SERVER

It will not always be possible to access the RPU by connecting a portable computer to it in the field. In those cases, it will be necessary to contact a central office or server to receive the data from the end user. Someone in the central office would then convey the data to field personnel. However, these systems may not update frequently enough to get the data required for the test procedures. If this is the case, it may be possible to configure them to update more frequently, such as every two minutes. This scenario is shown in Figure 6.

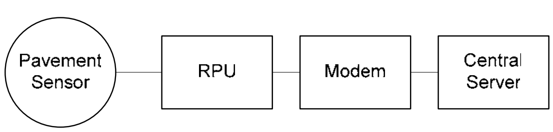


Figure 6. Possible Testing Configuration – Version C

5. FIELD TESTING PROCEDURES FOR PAVEMENT SENSORS

The following detailed procedures can be used for testing the performance of in-situ pavement sensors. This section also contains a listing of equipment and supplies for each test. The procedures described here have been developed and tested to assure they provide accurate and repeatable results.

These are testing procedures that are conducted in-situ, usually on busy highways, close to traffic. It is critical that the all safety procedures outlined in Chapter 3 be addressed and followed first before beginning any field-testing.

During the testing program it was determined that ESS Pavement Sensors were not adaptable to field calibration. Therefore no field calibration procedures are shown for ESS Pavement Sensors.

5.1 PAVEMENT SENSOR TESTING OVERVIEW

The following five different field-tests are provided for the complete testing of ESS Pavement Sensors under various conditions:

- Pavement Sensor Test 1: Pavement Temperature at Ambient Conditions
- Pavement Sensor Test 2: Pavement Surface (Dry/Wet/Ice) Conditions
- Pavement Sensor Test 3: Freezing Point of Passive and Active Pavement Sensors
    - Pavement Sensor Test 3A: Testing Freezing Point Using Passive Sensors
    - Pavement Sensor Test 3B: Testing Freezing Point Using Active Sensors
- Pavement Sensor Test 4: Ice Bath at 32º F (Optional)

It is recommended that the test be run in the order they are presented. The ambient temperature test is presented first so that it can test the undisturbed pavement and sensors. The surface state test is next because it is desirable to run that test before any salt has been introduced to the sensor surface. Salt will lower the freezing point and make it more difficult to form ice. The freezing point test may be run at any time. The optional ice bath test should be run last because it lowers the temperature and could affect the time it takes to run the other tests.

5.2 EQUIPMENT RECOMMENDED FOR TEST SETUP

As explained in Section 4, ESS Data Collection, field tests require some form of data collection. An ideal method is to be connected directly to the RPU. If the live RPU data can be seen at the sensor site, the tests can be run more quickly and effectively. Other methods are available that may not require the use of this equipment.

The following equipment is recommended:

- Portable computer and communication cables for accessing the RPU to get the pavement sensor data
- Extension cords to power the computer at the sensor site

		
Portable computer	Communication cables	Extension cords (200 feet or longer as needed)

5.3 OPTIONAL EQUIPMENT REQUIRED FOR TEST SETUP

If extension cords do not reach the pavement sensor site or AC power is not available, it may be necessary to use a power inverter and power the equipment from the operator's roadside vehicle. Communication with the RPU may be an issue, but wireless serial communications devices are available.

Fortunately, almost all commercially available power inverters are capable of powering a portable computer. However, Field Test 2 requires the use of a heat gun that requires a powerful inverter. Please make sure that the power inverter can power the heat gun before field testing. If not, a portable generator could be substituted. A propane heater is another option.

A digital camera is useful for documenting the condition of the sensor and the weather conditions during testing. It is also useful for documentation of a particular phenomenon that may happen during the testing period.

5.4 VERIFYING DATA CAPTURE

When the computer is properly connected to the RPU, or other arrangements have been made to get live data, the computer should be tested to verify that all necessary data is available and is giving reasonable values. **Record** the initial test conditions on the first page of the Testing and Maintenance Forms for Pavement Sensors found in Appendix C. Also record the observed pavement sensor condition in the Observation section of the form.

The following data is required:

- Pavement sensor temperature
- Ambient temperature
- Dew point temperature
- Surface state
- Freezing point

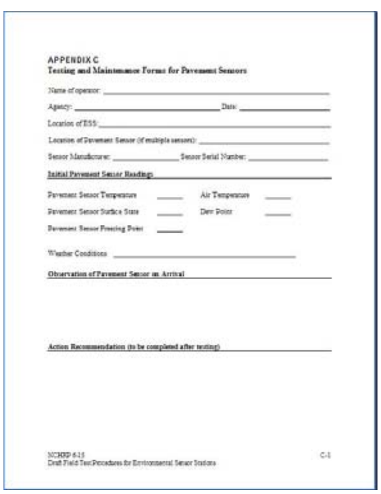
Verify that the data is showing reasonable values and record your observations in the Observation section of the form. The following suggestions may help:

- The thermometer and thermistor in Field Test 1 may be used to get relatively close ambient temperature conditions.
- The thermistor can be changed from Celsius to Fahrenheit by holding the bottom of the rocker switch for ten seconds.
- To quickly estimate a conversion from Celsius to Fahrenheit, double the Celsius temperature and add 32.
- Surface states are often coded as a number in the serial output. Refer to the manufacturer's manuals if the surface state is not evident.
- Freezing point often does not give a reading unless the pavement sensor is wet.

5.5 EQUIPMENT REQUIRED FOR ALL TESTS

The pictured test equipment is required for all tests. This equipment should be readily available during testing.

- All tests require some sort of timekeeping
- A knee pad, such as for gardening, is recommended because many of the tests require the operator to work with the pavement sensor directly.
- Paper towels are generally used for cleaning the pavement sensor. Disposable towels are recommended because the thermal paste in Field Test 1 is difficult to wash out of cloth towels.
- A supply of Testing and Maintenance Forms for Pavement Sensors should be copied from Appendix C before the testing.



APPENDIX C
Testing and Maintenance Forms for Pavement Sensors

Name of operator: ____________

Agency: ____________ Date: ____________

Location of ESS: ____________

Location of Pavement Sensor (if multiple sensors): ____________

Sensor Manufacturer: ____________ Sensor Serial Number: ____________

Initial Pavement Sensor Readings

Pavement Sensor Temperature ____ Air Temperature ____

Pavement Sensor Surface State ____ Dew Point ____

Pavement Sensor Freezing Point ____

Weather Conditions ____________

Observation of Pavement Sensor on Arrival

Action Recommendation (to be completed after testing)

NCHRP 6-15
Draft Field Test Procedures for Environmental Sensor Stations C-1

Copies of the Testing and Maintenance Forms (Appendix C)

Knee pad

Paper Towels

Calculator

Watch for keeping time

5.6 PAVEMENT SENSOR TEST 1: PAVEMENT TEMPERATURE AT AMBIENT CONDITIONS

Field Test 1 measures the pavement sensor's temperature accuracy at ambient conditions.

Test Condition Notes:

- This test may be done at any temperature where reasonable test conditions can be maintained. The test is best done around daybreak to avoid solar radiation. Be sure the sensor and thermistors are shaded from solar radiation for at least 15 minutes prior to the test and also during the test.
- Thermistors and thermometers should be calibrated regularly by a reputable calibration authority and have a current calibration certificate.
- If the test must be done after the sun has warmed the pavement sensor, the sensor must be shielded from solar radiation for an hour or more.
- The sensor surface must remain dry and clean throughout the test.
- The thermal paste becomes stiff if subjected to cold temperatures. It is best to keep the thermal paste warm until it is needed.
- The thermistor will require time to stabilize after being handled.

Equipment and Supplies Required

		
Thermal conducting Paste	Brick with insulation on bottom surface to secure thermistor to pavement sensor	Two handheld thermometers with precision thermistors
		
Supply of tap water to clean pavement	Nylon brush to clean the pins on top of the sensor	Shelter tent, such as a collapsible ice fishing shelter
		
Paint can opener		

Field Testing Procedures – Test 1: Pavement Temperature at Ambient Conditions

To test the pavement sensor for temperature accuracy at ambient conditions, perform the following steps:

Step 1 Read all the manuals and manufacturer's literature on operating the participating sensor. Also read and observe all the safety precautions in Chapter 3.

Step 2 Shield the pavement sensor from solar radiation to block the effects of the environment. Wait at least 15 minutes (or an hour for afternoon testing) for the effects of the solar radiation to dissipate before taking the first reading.

Step 3 Use the procedures recommended by the RPU manufacturer to allow communication from the RPU to the portable computer.

Step 4 Clean and dry the sensor and surrounding one foot area using paper towels.

Step 5 Affix one thermistor to the pavement 2.5" from the sensor and one directly on the sensor using thermally conductive paste.

- Avoid placing the thermistor on the sensor electrodes or in the depression.
- The metallic side of the thermistor should face down.

Step 6 Place the insulated brick on the thermistor. Attach the lead wires from the thermistors to the thermometers.

Step 7 **Record** the following readings at two minute intervals on the Testing and Maintenance Forms until there have been four stable readings for both the thermistor and the pavement sensor:

- Pavement sensor temperature (from RPU)
- Thermistors on pavement sensor and pavement surface

Stability occurs when the both thermistor on pavement surface and RPU reading from pavement sensor vary less than 0.4º F (0.2º C) between four successive readings.

Step 8 Determine the average of the four stable readings for each thermistor and the pavement sensor and **record** the values on the Testing and Maintenance Forms.

Step 9 Clean the thermal paste from the surface of the pavement sensor with the paper towels and brush.

The sensor fails this test if the average values for the pavement sensor and thermistor 2.5" from the sensor disagree by more than 2.0º F (1.1º C).

- The thermistor 2.5" away from the sensor should be used as the main baseline.
- The thermistor on the sensor should be used to better understand the test environment.

If the sensor fails the first test, run the test an additional two times to verify the failure.

Figure 7. Applying Thermal Paste to Sensor.

Figure 8. Completed Pavement Temperature Test Setup (Only One Thermistor Required).

5.7 PAVEMENT SENSOR TEST 2: PAVEMENT SURFACE (DRY/WET/ICE) CONDITIONS

Field Test 2 includes tests for determining dry, wet and ice surface state conditions. Most RPUs determine whether the sensor is dry or not dry by measuring the conductivity of two electrodes on the sensor. Depending on the sensor, the RPU may also use temperature information to detect ice.

Test Condition Notes:

- The weather must be dry or the pavement sensor must be sheltered from precipitation.
- Dry and wet surface state compliance can be evaluated at all temperatures. Before a freezing temperature is reached on the sensor it should give a "wet" reading.
- To form ice, the pavement temperature must be below 32º F. The thermistor and thermometer may be used to check the air temperature.
- If required by the RPU, atmospheric sensors must be connected and working properly.

Equipment and Supplies Required

The following equipment and supplies are needed for testing dry/wet/ice conditions.

		
Heat gun ***Note: Do not hold the heat gun near the sensor surface***	Misting bottle filled with tap water	Nylon brush to clean the pins on top of the sensor
		
0.5 mm feeler gauge to measure film depth	Thermometer and thermistor to check air/pavement temperature	**Optional**: Shelter tent, such as collapsible ice fishing shelter

Field Testing Procedures – Test 2: Pavement Surface (Dry/Wet/Ice) Conditions

To test the pavement sensor for dry, wet and ice surface state performance, perform the following steps:

Step 1 Read all the manuals and manufacturer's literature on operating the participating sensor. Also read and observe all the safety precautions in Chapter 3.

Step 2 Use the procedures recommended by the RPU manufacturer to allow communication from the RPU to the portable computer.

Step 3 Use water and paper towels to clean the pins on the top of the pavement sensor. Dry the subject sensor with the dry towels and heat gun.

Note: Dry the sensor with caution; do not hold the heat gun near the sensor surface.

- Perform this step on all components of the system that the system uses to determine surface state

Step 4 **Record** the following on the Testing and Maintenance Forms every two minutes until a dry pavement surface state reading is recorded:

- Visual determination of state of surface of pavement sensor
- State of pavement surface (from RPU)

Step 5 Shake the misting bottle and uniformly spray a 0.5 mm tap water film on the surface of all applicable sensors. Check the film thickness with the feeler gauge. If the film does not stay on the sensor, place a wet paper towel on the sensor and continue to perform the procedure and record use of the paper towel in the "Notes" area of the Forms.

Record the following on the Testing and Maintenance Form at two-minute intervals until the RPU reports the wet surface state or ten minutes have expired:

- Time of day
- Visual determination of state of surface of pavement sensor (dry/wet/ice)
- State of pavement surface (from RPU)

Step 6 If the pavement temperature is below 32º F, continue to record data until the RPU reports an ice condition. Conclude the test if RPU surface state does not change to ice in a reasonable amount of time (20 minutes).

The sensor fails this test and should be recalibrated or replaced if the pavement sensor does not report the wet or dry conditions. Ice detection should be determined based on a case-by-case basis according to the test conditions. If the sensor fails the first test, run the test an additional two times to verify the failure.

Figure 9. Cleaning Pavement Sensor Depression with a Paper Towel.

Figure 10. Spraying Tap Water on the Sensor Surface.

5.8 PAVEMENT SENSOR TESTS 3A AND 3B: FREEZING POINT OF PASSIVE AND ACTIVE PAVEMENT SENSORS

Depending on whether the ESS station has a pavement sensor that finds freezing point with a passive or an active sensor, the appropriate Field Test 3A or Field Test 3B should be run.

Field Test 3A: Freezing Point of Passive Sensors

For passive sensors to measure the freezing point of a particular brine solution on the sensor surface, the RPU or computer must be configured for that solution. The sensor generally determines the freezing point temperature by measuring the conductivity of the brine between the electrodes on the sensor surface. The relative conductivity values of five brine concentrations are shown in Appendix A. The test is run at 4% and 15% concentrations in order to understand sensor function at low and high salt concentrations.

Field Test 3B: Freezing Point of Active Sensors

An active pavement sensor can be used to determine the freezing point temperature of any brine or mixtures of brine. A Peltier device warms then cools the solution on the sensor. As the device cools the solution on the surface of the sensor, the temperature stabilizes as the liquid changes phase to solid. The RPU detects that the sensor has reached its freezing point and returns that temperature as the freezing point. This process is generally more accurate and is more robust because the freezing point is measured directly, not through conductivity values that are dependent on chemical type. However, the test takes longer to run because of the heating and cooling cycles.

5.9 PAVEMENT SENSOR TEST 3A: TESTING FREEZING POINT USING PASSIVE SENSORS

This test procedure will measure how well a passive sensor can detect a chemical solution's freezing point. The same type of chemical solution used in highway maintenance operations should be used for this test at a 4% concentration. The RPU is should already be configured for the typical chemical type, though this is verified in the test procedure.

The procedures to prepare the 4% chemical solution are listed in Appendix B.

Test Condition Notes:

- Ambient pavement temperature must be within the sensor's range for measuring freezing point. See Appendix B for brine properties and check with the manufacturer's documentation for temperature compliance.
- Passive sensors are very sensitive to concentration changes and film thickness. It is important to thoroughly clean the pavement sensor between runs with distilled water.

Equipment and Supplies Required

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>Device to shelter sensor from evaporation due to wind and sun (ice fishing shelter or 5-gallon bucket)</td><td>One gallon of distilled water</td><td>Heat gun
Note: Do not hold the heat gun near the sensor surface</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>0.5 mm feeler gauge to measure film depth</td><td>Misting bottle filled with 4% chemical solution</td><td></td></tr>
</table>

Field Testing Procedures – Test 3A: Freezing Point Using Passive Sensors

To test passive pavement sensors for freezing point accuracy, perform the following steps:

Step 1 Read all the manuals and manufacturer's literature on operating the participating sensor. Also read and observe all the safety precautions in Chapter 3.

Step 2 Determine which chemical type the sensor is programmed to monitor.

Record the manufactures chemical solution type programming on the Testing and Maintenance Form, in the "Notes" section.

Record the chemical type and concentration of the chemical solution on the Testing and Maintenance Form in the "Chemical Solution Type:" section.

Step 3 Use the procedures recommended by the RPU manufacturer to allow communication from the RPU to the portable computer.

Step 4 Repeatedly (5 times) flush the top of the sensor with distilled water and clean the pins on the top of the pavement sensor with paper towels. Clean and dry the subject sensor and surrounding area using paper towels. If necessary, carefully dry the sensor with the heat gun. Note: Do not hold the heat gun near the pavement sensor.

Note: Dry the sensor with caution; do not hold the heat gun near the sensor surface.

Step 5 Shake the bottle with the 4 percent chemical solution and spray a 0.5 mm film on the entire surface of the sensor. If the sensor has a well or depression, fill it with the solution. If the film does not stay on the sensor, place a paper towel on the sensor and continue to perform the procedure. If a paper towel is used record this in the "Notes" section of the Testing and Maintenance form.

Record the following on the Testing and Maintenance Form at two-minute intervals until the stability criteria is met:

- Time of day
- Freezing point (from RPU)

Stability criteria are met when the pavement sensor freezing point has varied less than 3.6º F (2.0º C) between four successive readings.

Step 6 Determine the average of the four stable readings for the pavement sensor freezing point and **record** the value on the Testing and Maintenance Forms. Repeat steps 4 and 5 for the 15% solution.

The sensor fails this test if the average freezing point value of the pavement sensor and the freezing point of the chemical solution differ by more than 3.6º F (2.0º C). If the sensor fails the first test, run the test an additional two times to verify the failure.

5.10 PAVEMENT SENSOR TEST 3B: TESTING FREEZING POINT USING ACTIVE SENSORS

This test will measure the freezing point performance of active pavement sensors by exposing the sensor to 10% concentrations of chemical solution. The chemical solution type is not relevant to the outcome of this test because active sensors detect freezing point without any user input about chemical solution type.

The procedures to prepare the appropriate 4% and 15% chemical concentrations can be found in Appendix B. The procedures can also be used to prepare other concentrations if desired.

Test Conditions Notes:

- It is important to thoroughly clean the pavement sensor with distilled water.
- Some active sensors require data input from passive sensors. Perform the procedures on all applicable sensors.
- The following table shows the freezing points of various chemicals at 4 and 15% concentration:

Chemical Type	Freezing Point of 4% Concentration in °C (°F)	Freezing Point of 15% Concentration in °C (°F)
Sodium Chloride	27.7 (-2.4)	12.4 (-10.9)
Magnesium Chloride	27.8 (-2.3)	4.0 (-15.6)
Calcium Chloride	28.7 (-1.8)	12.2 (-11.0)

Equipment and Supplies Required

One gallon of distilled water

Device to shelter sensor from evaporation due to wind and sun (ice fishing shelter or 5-gallon bucket)

0.5 mm feeler gauge to measure film depth

Nylon brush to clean the pins on top of the sensor

Two misting bottles filled with 4 and 15% percent chemical solution

Field Testing Procedures – Test 3B: Freezing Point Using Active Sensors

To test an active pavement sensor for measuring freezing point temperatures, perform the following steps:

Step 1 Read all the manuals and manufacturer's literature on operating the participating sensor. Also read and observe all the safety precautions in Chapter 3.

Step 2 Use the procedures recommended by the RPU manufacturer to allow communication from the RPU to the portable computer.

Step 3 Read the <u>temperature</u> (not freezing point) output values from the pavement sensor. If it is within the range for the active sensor to perform freeze/thaw cycles, proceed to Steps 4-6. See manufacturer's documentation for more information about this process.

This step determines whether the temperature conditions are sufficient to test an active sensor. If the temperature is too warm, the active sensor will not be able to freeze the solution. If it is too cold, the heating element will not thaw the chemical solution.

Step 4 Repeatedly flush the top of the applicable sensor(s) with distilled water and clean the pins on the top of the pavement sensor with paper towels. Clean and dry the subject sensor and surrounding area using paper towels.

Step 5 Shake the 4% misting bottle with and spray a 0.5 mm film on the applicable sensor(s). Use the feeler gauge to check the film thickness. If the film does not stay on the sensor, place a paper towel on the sensor and continue to perform the procedure. Use the "Notes" area of the Testing and Maintenance Forms for Pavement Sensors to document the use of the paper towel.

<u>**Record**</u> the type of chemical solution on the Testing and Maintenance Form under "Chemical Solution Type:"

Step 6 <u>**Record**</u> pavement sensor readings for this cycle and an additional two cycles. If the final two sensor readings are within 1 degree, the test is complete. Otherwise, <u>**record**</u> an additional two cycles before stopping the test.

Step 7 Determine the average of the latest two stable readings for the pavement sensor freezing point and <u>**record**</u> the value on the Testing and Maintenance Forms. Repeat steps 3-7 for the 15% solution.

> The sensor fails this test if the average freezing point value of the pavement sensor and the freezing point of the chemical solution differ by more than 3.0º F (1.7º C). If the sensor fails the first test of either solution, run the test an additional two times to verify the failure.

5.11 PAVEMENT SENSOR TEST 4: ICE BATH AT 32º F (OPTIONAL)

This test is recommended if there is doubt about the accuracy of the sensor specifically around water's freezing point (32 degrees). This test is marked "Optional" for a variety of reasons. First, the test takes a substantial amount of time to run. Warm weather conditions could make this test take even more time. A half-hour should be allowed for the ice bath to cool the pavement sensor to 32 degrees. During that time, the bath must be constantly stirred. If this test is to be run regularly, a device could be rigged to automatically stir the bath. Existing devices to mix mortar or ones used to stir cooking pots could be modified for this application.

Test Condition Notes:

- It is necessary to create the required temperature condition at the pavement sensor by using an ice water bath.
- This test may only be run on sensors with temperature sensing elements located near the surface of the sensor. If the temperature sensing element is too far below the surface, the test may take too long to conduct because of the time required to cool the sensor to a sufficient depth.
- The ambient temperature of the pavement should be between 32º F and 50º F. The test may still be performed under warmer temperatures, though it will take more time.
- Ice may be crushed before going out to the ESS site or at the site. To crush the ice on-site, put the ice in a canvas bag such as a bituminous sample bag and carefully crush the ice with the brick used in Field Test 1.

Equipment and Supplies Required

		
Thermal conducting paste	One handheld thermometer with precision thermistors	One gallon of chilled (below 40º F) distilled water
		
Stirring instrument such as a plastic slotted spoon	10-inch section of 12-inch diameter PVC pipe	10 pounds of crushed ice cubes
		
Plastic bag		

Field Testing Procedures – Test 4: Ice Bath at 32º F (Optional)

To test the pavement sensor for temperature compliance, perform the following steps:

Step 1 Read all the manuals and manufacturer's literature on operating the participating sensor. Also read and observe all the safety precautions in Chapter 3.

Step 2 Use the procedures recommended by the RPU manufacturer to allow communication from the RPU to the portable computer.

Step 3 Clean and dry the subject sensor and surrounding area using paper towels.

Step 4 Place the PVC section around the pavement sensor. Slide the thermistor under the edge of the PVC so that the thermistor rests on the pavement sensor

Step 5 Put the large plastic bag in the PVC with the bag overlapping the edges of the PVC as shown in Figure 11. Fill the pipe section with the gallon of distilled water.

Step 6 Add enough crushed ice to produce a thick layer of slushy ice in the bath.

Step 7 Stir the mixture continuously and maintain the thick slushy ice layer.

Record the following on the Testing and Maintenance Form at two-minute intervals until the pavement sensor stabilizes within 1º F (0.6º C) of 32º F (0º C):

- Time of Day
- Pavement Temperature (From RPU)
- Thermistor temperature

If the reported sensor temperature does not decrease substantially or approach 32º F (0º C), after 10 minutes, stop the test.

Note: *Even if the sensor gets down to 32º F (0º C), the pavement sensor temperature readings could still decrease below that temperature. Continue to take readings until the temperature stabilizes within 1º F (0.6º C). Stop the test if the pavement sensor gives readings below 29º F (-1.6º C).*

The sensor fails this test and should be recalibrated or replaced if the temperature reported by the sensor does not stabilize within 3.0º F (-1.6º C) of 32º F (0.0º C).

Figure 11. Bag Placed Over PVC section.

Figure 12. Distilled Water Poured in PVC and Bag.

Figure 13. Ice Poured Into PVC and Plastic Bag.

6. FIELD TEST PROCEDURES AND CALIBRATION METHODS FOR ATMOSPHERIC SENSORS

Atmospheric sensors monitor meteorological information related to the road environment and assist with forecasting, detection and monitoring of weather and road conditions. Atmospheric sensors are located above and near the roadway at the ESS site. Independently, they can identify parameters, such as strong cross winds. In combination with pavement sensors, they can identify conditions, such as icy roads.

Typical sensors for RWIS systems at ESS sites are wind speed and direction, air temperature, dew point and humidity, precipitation and visibility. Other sensors that are sometimes used are solar radiation and atmospheric pressure. In order to maintain accuracy, atmospheric sensors need to be tested and/or calibrated in accordance with manufacturer-provided procedures.

Because atmospheric sensors are tested and calibrated using a variety of vendor-specified means, no standardized testing and calibration guidelines exist at this time. Temperature sensors can be tested statistically. Vendor contacts for some manufacturers and vendors are provided for agencies to obtain the most current calibration and testing procedures.

The following vendors make and/or distribute atmospheric sensors:

Belfort Instrument Company 727 South Wolfe Street Baltimore, MD 21231 Tel. (410) 342-2626	Optical Scientific Inc. 205 Perry Parkway, Suite 14 Gaithersburg, MD 20874 Tel. (301) 963-3630	Surface Systems, Inc. 11612 Lilburn Park Road St. Louis, MO 63146 Tel. (314) 569-1002
Boschung America P.O Box 8427 930 Cass St. New Castle, PA 16101 Tel. (724) 658-3300	ETI Optical Infrared 1317 Webster Avenue Fort Collins, CO 80524 Tel. (970) 484-9393	A. Thies GmbH & Co. KG P.O. Box: 35 36 D-37025 Goettingen, Germany Tel. +49 551 79001-0
The Eppley Laboratory, Inc. 12 Sheffield Avenue Newport, Rhode Island 02840 Tel. (401) 847-1020	R.M. Young Company 2801 Aero Park Drive Traverse City, MI 49686 Tel. 231-946-3980	Vaisala Inc. PO Box 3659 Boulder, CO 80307 Tel. (303) 499-1701
Met One Instruments, Inc. 1600 Washington Blvd. Grants Pass, OR 97526 Tel. (972) 412-4747	Rotronic Instrument Corp. 160 E. Main Street Huntington, NY 11743 Tel. 631-427-3898	Vaisala Inc. Handar Business Unit 10-D Gill Street, Woburn, MA 01801 Tel. (781) 933-4500

Two other resources for agencies to learn more about how sensors are tested and calibrated using alternative means, such as statistical means, are the CLARUS initiative and Meteorological Assimilation Data Ingest System (MADIS).

Clarus Initiative

Website: http://clarusinitiative.org

Contacts: James Pol (james.pol@fhwa.dot.gov)
U.S. DOT ITS Joint Program Office
202-366-4374

Paul Pisano (paul.pisano@fhwa.dot.gov)
Road Weather Management Program, FWHA
202-366-1301

MADIS

Website: http://www-sdd.fsl.noaa.gov/MADIS/

APPENDIX A
Phase Diagrams and Conductivity Curves for Brines

Because different chemicals have different properties, it may be beneficial to know about the properties of salt solutions to configure the RPU.

Solution Phase Diagrams

For the evaluators of pavement sensors to have some idea of the behavior of the various brines in regards to their concentrations and temperatures, Figure A-1 is provided for reference. As can be seen, each brine has its own characteristics.

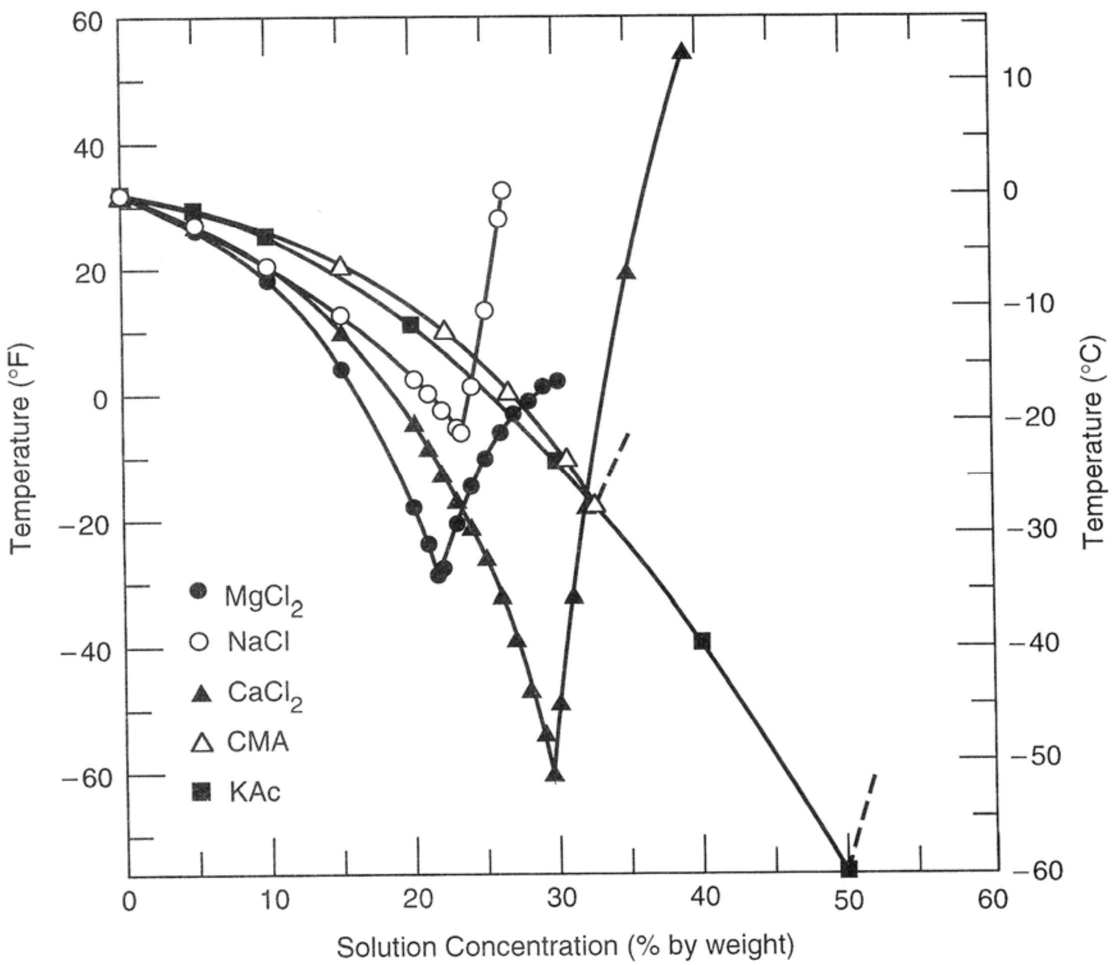


Figure A-1. Phase Diagrams of Five Brines

Conductivity Curves and Values for Solutions

During the research work for the Strategic Highway Research Program's (SHRP) project: "Development of Anti-Icing Technology" [3], laboratory studies were conducted to evaluate the utility of the SOBO-20 salinity tester for the semi-quantitative measurement of chemical solutions applied to pavement surfaces. The studies consisted of evaluating the type of response and range of detection for five different chemicals.

The results of the laboratory studies that included the conductivity measurements for the five chemical brines are presented in Tables G-5, G-6, and G-7. In addition, a composite presentation of the test data is set forth in Figure G-2.

This information is provided so that the evaluator can have a sense of the magnitude of the conductivity values for sodium chloride, magnesium chloride, and calcium solutions.

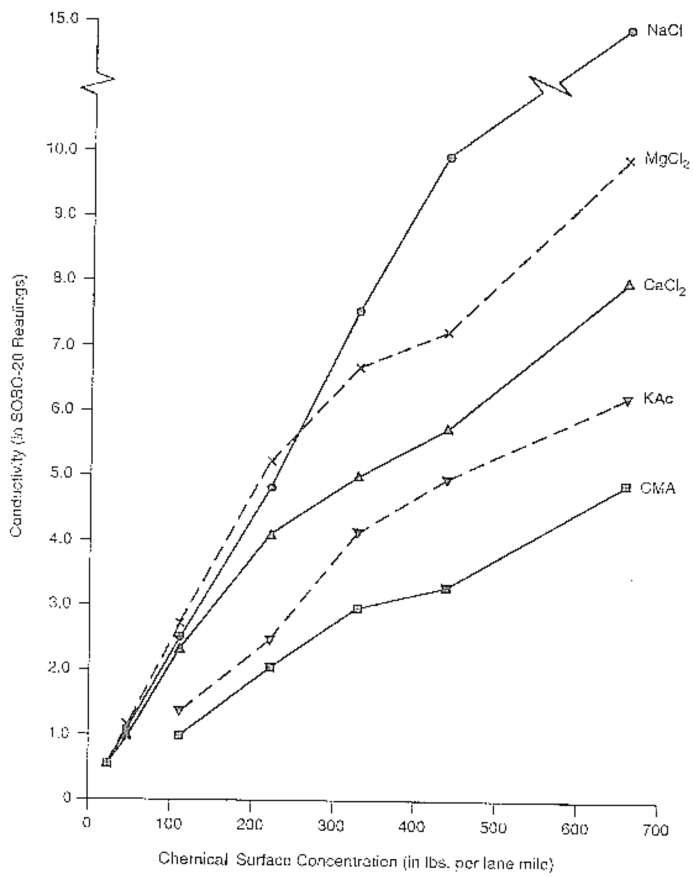


Figure A-2. SOBO-20 Readings versus Chemical Surface Concentration for Five Brines

Source: SHRP-H-385, Development of Anti-Icing Technology, Strategic Highway Research Program, National Research Council, Washington, D.C., 1994.

Table A-1. SOBO-20 Readings and Conductivity Values of Sodium Chloride Solutions

SOBO meter		Actual Reading [a]	Applied chemical surface concentration			Conductivity [a] (µS)
Observed Reading [a]	Scale Factor		(oz/yd^2)	(g/m^2)	(lb/lane mile)	
1	x ½	0.5	0.05	1.7	22	180
1	x 1	1	0.1	3.39	44	308
5	x 1/2	2.5	0.25	8.48	110	767
4.8	x 1	4.8	0.5	17	220	1,517
10	x 1/2	5	0.5	17	220	1,567
15	x 1/2	7.5	0.75	25.4	330	2,500
10	x 1	10	1	33.9	440	3,250
15	x 1	15	1.5	50.9	660	4,767

[a]Average of three determinations

Table A-2. Readings and Conductivity Values of Magnesium Chloride Solutions

SOBO meter		Actual Reading [a]	Applied chemical surface concentration			Conductivity [a] (µS)
Observed Reading [a]	Scale Factor		(oz/yd^2)	(g/m^2)	(lb/lane mile)	
1.00	x ½	0.50	0.05	1.7	22	135
1.00	x 1	1.00	0.10	3.39	44	250
2.75	x 1/2	1.38	0.25	8.48	110	602
5.25	x 1	5.25	0.50	17	220	1,185
10.00	x 1/2	5.00	0.50	17	220	1,222
13.38	x 1/2	6.69	0.75	25.4	330	2,712
7.25	x 1	7.25	1.0	33.9	440	3,500
10.00	x 1	10.00	1.50	50.9	660	5,075

[a]Average of three determinations

Table A-3. Readings and Conductivity Values of Calcium Chloride Solutions

SOBO meter		Actual Reading [a]	Applied chemical surface concentration			Conductivity [a] (µS)
Observed Reading [a]	Scale Factor		(oz/yd^2)	(g/m^2)	(lb/lane mile)	
1.00	x ½	0.50	0.05	1.7	22	135
1.00	x 1	1.00	0.10	3.39	44	250
4.90	x 1/2	2.45	0.25	8.48	110	602
3.90	x 1	3.90	0.50	17	220	1,185
8.80	x 1/2	4.40	0.50	17	220	1,222
10.00	x 1/2	5.00	0.75	25.4	330	2,712
5.75	x 1	5.75	1.0	33.9	440	3,500
8.00	x 1	8.00	1.50	50.9	660	5,075

[a]Average of three determinations

APPENDIX B
Procedures for Preparing Chemical Concentrations

In order to run the freezing point tests in Field Test Plan 4, it is necessary to prepare chemical solutions before going out to an ESS station.

This appendix contains procedures and tables of physical properties of the following chemical concentrations:

Sodium Chloride Brine Preparation

The following equipment and supplies are necessary to prepare the given concentrations of chemical brine to be used for testing the Freezing Point parameter of a pavement sensor.

- Supply of deiodized dry salt, such as table salt. Do not obtain salt from maintenance stockpiles as that salt has approximately 5% impure materials besides the salt.

- Supply of deionized or distilled water

- Scale that will weigh to the nearest gram or 0.03 oz.

- Supply of one-quart jars with lids. Jars must have a graduation for one quart.

- 1 liter graduated cylinder with hydrometer

The following procedures are to be used in preparing the various concentrations of salt brine:

Step 1 Fill a clean one-quart jar approximately 2/3 full of deionized or distilled water.

Step 2 From Table B-1, determine the amount of salt required to make one quart of solution at the desired concentration level.

Step 3 Weigh out the necessary amount of salt and gradually pour it into the jar while stirring the solution. Continue to stir until the salt is dissolved.

Step 4 Add deionized or distilled water to the jar to bring the level to the top of the jar. Screw the cap on the jar. Shake the jar to mix the solution.

Step 5 Remove the lid and pour some solution into a cylinder. Test the specific gravity of the solution with a hydrometer. An additional batch of solution may be necessary to use the Compare the readings with those in Table B-1.

Step 6 Replace the lid and label the jar with the chemical type and concentration.

Table B-1. Proportions for Preparing Sodium Chloride Solutions

% NaCl Concentration	Weight NaCl per quart of solution Oz (Grams)	Freezing Point Temperature ºC (º F)	Specific Gravity at 20.0º C (68.0º F)
1%	0.34 (9.6)	-0.59 (30.93)	1.007
4%	1.37 (38.9)	-2.4 (27.7)	1.0286
10%	3.58 (101.4)	-6.6 (20.2)	1.0726
15%	5.55 (157.4)	-10.9 (12.4)	1.1105
23%	9.00 (255.1)	-20.7 (-5.2)	1.1721

The following table may be used as a reference when preparing the sodium chloride solutions.

Table B-2. Physical Properties of Sodium Chloride

% NaCl by weight	Specific Gravity at 20.0º C (at 68.0º F)	Amount of NaCl per quart of solution (oz (grams))	Freezing Point (ºF)	Freezing Point (ºC)
1	1.0071	0.34 (9.56)	30.933	-0.593
2	1.0143	0.67 (19.12)	29.865	-1.186
3	1.0214	1.02 (28.96)	28.778	-1.790
4	1.0286	1.37 (38.90)	27.664	-2.409
5	1.0358	1.73 (48.93)	26.517	-3.046
6	1.0431	2.09 (59.15)	25.335	-3.703
7	1.0504	2.45 (69.46)	24.120	-4.378
8	1.0578	2.82 (79.97)	22.858	-5.079
9	1.0651	3.19 (90.57)	21.547	-5.807
10	1.0726	3.58 (101.35)	20.185	-6.564
11	1.0801	3.96 (112.24)	18.765	-7.353
12	1.0876	4.35 (123.31)	17.283	-8.176
13	1.0952	4.74 (134.48)	15.732	-9.038
14	1.1028	5.14 (145.83)	14.108	-9.940
15	1.1105	5.55 (157.38)	12.402	-10.888
16	1.1182	5.96 (169.02)	10.607	-11.885
17	1.1260	6.38 (180.85)	8.717	-12.935
18	1.1339	6.80 (192.77)	6.721	-14.044
19	1.1418	7.23 (204.98)	4.611	-15.216
20	1.1498	7.66 (217.28)	2.376	-16.458
21	1.1579	8.10 (229.68)	0.003	-17.776
22	1.1660	8.55 (242.36)	-2.517	-19.176
23	1.1721	9.00 (255.14)	-5.201	-20.667

Source: CRC handbook of Chemistry and Physics, 52nd edition, CRC Press, Boca Raton FL 1972, p. D-213 & D-214.

Magnesium Chloride Brine Preparation

Magnesium Chloride is usually used by highway agencies in liquid form. It is normally marketed in a 30% concentration. However, it can be purchased in solid (flake) form. In preparing solutions of magnesium chloride brine to be used for testing the freezing point parameter of a pavement sensor, it is recommended that liquid material be obtained and a hydrometer reading be taken of the material at 60º F. The material may then be diluted down to the desired concentration.

The following equipment and supplies are necessary to prepare the given concentrations of chemical brine to be used for testing the Freezing Point parameter of a pavement sensor.

- Supply of liquid magnesium chloride brine
- Supply of deionized or distilled water
- Supply of one-quart jars with lids.
- Two-quart glass container
- One liter graduated cylinder
- Hydrometer

The following procedures are to be used in preparing the various concentrations of magnesium chloride brine:

Step 1 Take a temperature reading of the supply of available magnesium chloride brine. If the temperature is not 60º F, either raise or lower the temperature to 60º F.

Step 2 Take a hydrometer reading of the magnesium chloride brine and record the data. If the solution has a concentration of 30%, the specific gravity reading should be 1.283. If not, use the hydrometer reading obtained in the calculations outlined below.

Step 3 From Table B-3, determine the specific gravity of the desired concentration.

Step 4 Perform the calculation as shown in Figure B-1 to determine the amount of dilution required.

Step 5 Pour 50 mL of the strong magnesium chloride brine in the two-quart container.

Step 6 Pour the calculated amount of deionized or distilled water from graduated cylinder into the two-quart container and mix the solution.

Step 7 Pour the diluted solution in a one quart jar and place the lid on the jar. Label the jar with the chemical type and concentration.

Step 8 The concentration of the diluted brine can be checked with a hydrometer reading if it is near 60º F.

Table B-3. Properties for Preparing Magnesium Chloride Brine

% $MgCl_2$ Concentration	Crystallization Temperature ºC (ºF)	Specific Gravity at 15.6º C (60.0º F)
4	-2.3 (27.8)	1.010
10	-7.8 (17.9)	1.086
15	-15.6 (4.0)	1.132
21.6	-33.3 (-28.0)	1.196
30	-16.1 (3.0)	1.283

The following formula may be used to determine the amount of deionized or distilled water needed to dilute a strong solution at 60º F.

- "% Strong" is the original concentration
- "% Weak" is the targeted concentration

$$\left[\frac{\%\text{ Strong} - \%\text{Weak}}{\%\text{ Weak}}\right] \text{X} \quad \text{Specific gravity of Strong Solution}$$

Figure B-1. Dilution Formula for Magnesium Chloride

Example: Assuming the strong brine has a concentration of 30%, its specific gravity is 1.283, and volume of 50 mL. Concentration of 10% is required of the dilution solution.

$$\left(\frac{30 - 10}{10}\right) * 1.283 = 2.566$$

2.566 X 50 mL = 128.3 mL

Add 128 mL of deionized or distilled water to the 50 mL of the 30% concentration of magnesium chloride brine to create a 10% concentration of magnesium chloride brine.

Figure B-2. Example of Magnesium Chloride Dilution

Table B-3 provides the properties of the various concentrations of magnesium chloride brine. If different concentrations are needed than those shown in Table B-3, the appropriate values can be obtained from Table B-5, Properties of Magnesium Chloride Brine. The above formula can be used to determine the amount of dilution required. Table B-6 provides the dilution factors and the amount of deionized or distilled water that must be added to either 30% or 21.6% concentrations of magnesium chloride brine. These two values are generally the concentrations that are marketed by vendors to highway agencies.

Table B-4. Dilution Factors and Amount of Water to be Added to Obtain Desired Solutions

Desired % $MgCl_2$ Concentration	30 % Concentration		21.6 % Concentration	
	Dilution Factors	mL of water to be added*	Dilution Factors	mL of water to be added*
4	8.340	417	5.262	263
10	2.566	128	1.387	69
15	1.283	64	0.526	26
21.6	0.499	25	-	0
30.0	-	0	N/A	N/A

*Amount of deionized or distilled water to be added to 50 mL of concentration of magnesium chloride brine required to create the desired concentration of magnesium chloride brine.

Table B-5. Properties of Magnesium Chloride Brine

% by Weight	Specific Gravity at 15.6º C (60.0º F)	Freezing Point Celsius	Freezing Point Fahrenheit
5	1.013	-2.11	26.4
6	1.051	-3.09	25.0
7	1.060	-4.72	23.5
8	1.069	-5.67	21.8
9	1.070	-6.67	20.0
10	1.086	-7.83	17.9
11	1.096	-9.05	15.7
12	1.105	-10.50	13.1
13	1.114	-12.10	10.3
14	1.123	-13.70	7.3
15	1.132	-15.90	4.0
16	1.142	-17.60	0.4
17	1.151	-19.70	-3.5
18	1.161	-22.10	-7.7
19	1.170	-25.60	-12.2
20	1.180	-27.40	-17.2
21	1.190	-30.50	-23.0
22	1.200	-32.80	-27.0
23	1.210	-28.90	-20.0
24	1.220	-25.60	-14.0
25	1.230	-23.30	-10.0
26	1.241	-21.10	-6.0
27	1.251	-19.40	-3.0
28	1.262	-18.30	-1.0
29	1.273	-17.20	1.0
30	1.283	-16.70	3.0

Source: Chemical Deicer Specifications for the Pacific Northwest States of Idaho, Montana, Oregon, Washington State, p 25.

Calcium Chloride Brine Preparation

Calcium Chloride is usually used by highway agencies in liquid form. It is normally marketed in a 30% concentration. However, it can be purchased in solid (flake) form. In preparing solutions of calcium chloride brine to be used for testing the Freezing Point parameter of a pavement sensor, it is recommended that liquid material be obtained, and a hydrometer reading be taken of the material at 68º F (20° C). The material than be diluted down to the desired concentration.

The following equipment and supplies are necessary to prepare the given concentrations of chemical brine to be used for testing the Freezing Point parameter of a pavement sensor.

- Supply of liquid calcium chloride brine
- Supply of deionized or distilled water
- Supply of one-quart jars with lids.
- A two-quart glass container
- One liter graduated cylinder
- Hydrometer

The following procedures are to be used in preparing the various concentrations of calcium chloride brine:

Step 1 Take a temperature reading of the supply of available calcium chloride brine. If the temperature is not 68º F, either raise or lower the temperature to 68º F.

Step 2 Take a hydrometer reading of the calcium chloride brine and recorded the data. If the solution has a concentration of 30%, the specific gravity reading should be 1.2816. If not, use the hydrometer reading obtained, in the calculations outlined below.

Step 3 From Table B-3, determine the specific gravity of the desired concentration.

Step 4 Perform the calculation as shown in Figure B-1 to determine the amount of dilution required.

Step 5 Pour 50 mL of the strong magnesium chloride brine in the two-quarter container.

Step 6 Pour the calculated amount of deionized or distilled water from graduated cylinder into the two-quart container and mix the solution.

Step 7 Pour the diluted solution in a one quart jar and place the lid on the jar. Label the jar with the chemical type and concentration.

Step 8 The concentration of the diluted brine can be checked with a hydrometer reading if it is near 68º F.

Table B-6. Properties for Preparing Calcium Chloride Brine

% $CaCl_2$ Concentration	Crystallization Temperature in ºC (ºF)	Specific Gravity at 20.0º C (68.0º F)
1	-0.44 (31.21)	1.0065
4	-1.82 (28.73)	1.0316
10	-5.86 (21.45)	1.0835
15	-11.01 (12.18)	1.1292
30	-41.00 (-41.80)	1.2816

Source: CRC Handbook of Chemistry and Physics, 52nd edition, CRC Press, Boca Raton, FL 1972, p. D 224

The following formula may be used to determine the amount of deionized or distilled water needed to dilute a strong solution at 68º F.

- "% Strong" is the original concentration
- "% Weak" is the targeted concentration

$$\left(\frac{\%\text{ Strong - }\%\text{Weak}}{\%\text{ Weak}}\right) \text{X} \quad \text{Specific gravity of Strong Solution}$$

Figure B-3. Dilution Formula for Calcium Chloride

Example: Assuming the strong brine has a concentration of 30%, its specific gravity is 1.283, and volume of 50 mL. Concentration of 10% is required of the dilution solution.

$$\left(\frac{30 - 10}{10}\right) * 1.2816 = 2.5632$$

2.566 X 50 mL = 128.3 mL

Add 128 mL of deionized or distilled water to the 50 mL of the 30% concentration of calcium chloride brine to create a 10% concentration of calcium chloride brine.

Figure B-4. Example of Calcium Chloride Dilution

Table B-6 provides the properties of the various concentrations of calcium chloride brine. If different concentrations are needed than those shown in Table B-6, the appropriate values can be obtained from Table B-8, Properties of Calcium Chloride Brine. The above formula can be used to determine the amount of dilution required. Table B-7 provides the dilution factors and the amount of deionized or distilled water that must be added to either 30% or 21.6% concentrations of calcium chloride brine. These two values are generally the concentrations that are marketed by vendors to highway agencies.

Table B-7. Dilution Factors and Amount of Water to be Added to Obtain Desired Solutions

Desired % $CaCl_2$ Concentration	30 % Concentration		21.6 % Concentration	
	Dilution Factors	mL of water to be added*	Dilution Factors	mL of water to be added*
1	37.166	1858	1	37.166
4	8.3304	417	4	8.3304
10	2.563	128	10	2.563
15	1.2816	64	15	1.2816
30	0	0	30	N/A

*Amount of deionized or distilled water to be added to 50 mL of respective concentration of magnesium chloride brine required to create the desired concentration of magnesium chloride brine.

Table B-8. Properties of Calcium Chloride Brine

Percent by Weight	Specific Gravity at 68° F (20° C)	Freezing Point (Celsius)	Freezing Point (Fahrenheit)
1	1.0065	-0.44	31.21
2	1.0148	-0.88	30.42
3	1.0232	-1.33	29.61
4	1.0316	-1.82	28.73
5	1.0401	-2.35	27.78
6	1.0486	-2.93	26.73
7	1.0572	-3.57	25.57
8	1.0659	-4.28	24.31
9	1.0747	-5.04	22.93
10	1.0835	-5.86	21.45
11	1.0923	-6.74	19.87
12	1.1014	-7.70	18.14
13	1.1105	-8.72	16.30
14	1.1198	-9.83	14.31
15	1.1292	-11.01	12.18
16	1.1386	-12.28	9.90
17	1.1482	-13.65	7.43
18	1.1579	-15.11	4.80
19	1.1677	-16.70	1.94
20	1.1775	-18.30	-0.94
21	1.1876	-20.00	-4.00
22	1.1976	-21.70	-7.06
23	1.2078	-23.50	-10.30
24	1.2180	-25.30	-13.54
25	1.2284	-27.50	-17.50
26	1.2388	-29.70	-21.46
27	1.2494	-32.20	-25.96
28	1.2600	-34.70	-30.46
29	1.2708	-37.85	-36.13
30	1.2816	-41.00	-41.80

Source: Chemical Deicer Specifications for the Pacific Northwest States of Idaho, Montana, Oregon, Washington State, p 25.

APPENDIX C
Testing and Maintenance Forms for Pavement Sensors

Name of operator: ____

Agency: ____ Date: _________________________

Location of ESS:____

Location of Pavement Sensor (if multiple sensors): ____________________________________

Sensor Manufacturer: __________________ Sensor Serial Number: ______________________

Initial Pavement Sensor Readings

Pavement Sensor Temperature _______ Air Temperature _______

Pavement Sensor Surface State _______ Dew Point _______

Pavement Sensor Freezing Point _______

Weather Conditions ____

Observation of Pavement Sensor on Arrival

Action Recommendation (to be completed after testing)

Pavement Sensor Test 1: Pavement Temperature at Ambient Conditions

Notes:

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____

____

Reading Number	Time of Day	Pavement Sensor Reading (2.5” from Sensor)	Thermistor Reading (2.5” from Sensor)	Pavement Sensor Reading (On Pavement Sensor)	Thermistor Reading (On Pavement Sensor)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Average				

Pavement Sensor Test 2: Pavement Surface (Dry/Wet/Ice) Conditions

Reading	Time of Day	Visual Surface State Observation (Circle one)	Pavement Surface State (From RPU)
1		dry / wet / ice	
2		dry / wet / ice	
3		dry / wet / ice	
4		dry / wet / ice	
5		dry / wet / ice	
6		dry / wet / ice	
7		dry / wet / ice	
8		dry / wet / ice	
9		dry / wet / ice	
10		dry / wet / ice	
11		dry / wet / ice	
12		dry / wet / ice	
13		dry / wet / ice	
14		dry / wet / ice	
15		dry / wet / ice	

Notes:

Pavement Sensor Test 3A: Freezing Point of Passive Sensors

Chemical Solution RPU is Programmed For: ________________________

Chemical Solution Used in Test: _______________________________

Run 1			***Run 2 (If Necessary)***			***Run 3 (If Necessary)***		
Reading Number	**Time of Day**	**Freezing Point (Pavement Sensor Reading)**	**Reading Number**	**Time of Day**	**Freezing Point (Pavement Sensor Reading)**	**Reading Number**	**Time of Day**	**Freezing Point (Pavement Sensor Reading)**
1			1			1		
2			2			2		
3			3			3		
4			4			4		
5			5			5		
6			6			6		
7			7			7		
8			8			8		
9			9			9		
10			10			10		
11			11			11		
12			12			12		
13			13			13		
14			14			14		
15			15			15		
16			16			16		
17			17			17		
18			18			18		
19			19			19		
20			20			20		
Avg			Avg			Avg		

Notes:

____

____

Pavement Sensor Test 3B: Freezing Point of Active Sensors

Chemical Solution RPU is Programmed For: __________________________

Chemical Solution Used in Test: __________________________________

Run 1

Reading Number	Time of Day	Freezing Point (Pavement Sensor Reading)
1		
2		
3		
4		
5		
Avg		

Run 2 (If Necessary)

Reading Number	Time of Day	Freezing Point (Pavement Sensor Reading)
1		
2		
3		
4		
5		
Avg		

Run 3 (If Necessary)

Reading Number	Time of Day	Freezing Point (Pavement Sensor Reading)
1		
2		
3		
4		
5		
Avg		

Notes:

Pavement Sensor Test 4: Ice Bath at 32º F

Reading Number	Time of Day	Pavement Sensor Reading	Thermistor Reading
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Notes: