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Maura Healey
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Field Study to Determine Salt Usage Efficiency and Transport to the Surrounding Environment on Two Pavement Types

Principal Investigator (s)
Walaa S. Mogawer

Alexander J. Austerman

Kirk Smith

University of Massachusetts Amherst

U.S. Department of Transportation
Federal Highway Administration

Research and Technology Transfer Section
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16. Abstract
The purpose of this study was to collect and analyze field data to determine whether winter salt applications on Open Graded Friction Course (OGFC) and Dense Graded (DG) pavement types are appropriate, deficient, or excessive. The study aimed to provide the Massachusetts Department of Transportation (MassDOT) with evidence-based guidance for optimizing winter maintenance practices for these pavement types.

MassDOT had a unique opportunity to investigate salt usage efficiency on both pavement surfaces at an existing field site located consecutively along I-95 (Rt. 128) southbound in Needham, Massachusetts. The methodology for evaluation of both pavement types, with respect to winter maintenance, included: field site instrumentation, documenting winter maintenance activities at the field location, direct friction measurements, analysis of crash data, photograph comparison, and data analysis.

The overall combined data analysis could not be completed as there were gaps in a crash data and photographs. The winters of 2023-2024 and 2024-2025 were less harsh than historically anticipated for the region, thus yielding limited data to analyze. In fall 2024 the research team proposed a no-cost time extension so that another winter of data could be collected, but there was no formal response to that extension request.

The internet based survey showed that only 12.5% of respondents currently place OGFC in their state. The reasons noted for opting not to use OGFC included snow and ice concerns, durability issues, project failures, cost, and poor performance issues.

Limited field instrumentation data combined with winter maintenance treatment application data indicated that the OGFC and DG pavement surfaces responded similarly to the winter maintenance in terms of pavement temperature and friction (base d on data from both invasive and non-contact sensors). The safety implications related to winter maintenance activities for both OGFC and DG pavement types could not be investigated due to incomplete crash data and limited direct friction measurements. No changes could be recommended to winter maintenance treatment application rate for either pavement type based on this study. Generally the data collected in this study indicated OGFC and DG pavement types perform similarly when the same winter maintenance was applied.

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Field Study to Determine Salt Usage Efficiency and Transport to the Surrounding Environment on Two Pavement Types

Final Report

Prepared By:

Commonwealth Professor Walaa S. Mogawer, P.E., F.ASCE
Principal Investigator

And

Alexander J. Austerman, P.E.
Senior Research Engineer

University of Massachusetts Dartmouth
Highway Sustainability Research Center
151 Martine Street – Room 131
Fall River, MA 02723

And

Kirk Smith
Supervisory Physical Scientist
USGS New England Water Science Center
10 Bearfoot Road, Suite 6
Northborough, MA 01532

Prepared For:

Massachusetts Department of Transportation
Office of Transportation Planning
Ten Park Plaza, Suite 4150
Boston, MA 02116

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Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Massachusetts Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Executive Summary

Winter maintenance is a critical priority for the Massachusetts Department of Transportation (MassDOT) to ensure roadway safety during snow and ice events. At the same time, MassDOT has taken proactive steps to reduce the amount and frequency of salt applications in order to minimize environmental impacts, particularly the contamination of nearby water bodies. However, a key concern has emerged that certain pavement surface types may be receiving unnecessary treatments. This is especially true for Open-Graded Friction Course (OGFC) pavements, which retain a visually "white" appearance after treatment. Maintenance crews often interpret this whiteness as evidence of insufficient salt application, leading to repeated plowing and salting even when conditions do not require it. Because OGFC sections are frequently placed adjacent to Dense-Graded (DG) pavements, these treatments often extend indiscriminately to DG sections as well, resulting in potential over-application.

The purpose of this study was to collect and analyze field data that will determine whether winter salt applications on OGFC and DG pavements are appropriate, deficient, or excessive. Applying too little salt creates safety hazards, while over-application increases costs and contributes to environmental harm. By comparing the performance of OGFC and DG under actual winter conditions, the study aimed to provide MassDOT with evidence-based guidance for optimizing winter maintenance practices.

The project objectives were to: 1) Compare OGFC and DG pavement response to identical winter maintenance (salt) applications in terms of reflected physical parameters, 2) Investigate the safety implications related to winter maintenance activities for both OGFC and DG pavement types, and 3) Evaluate whether either pavement type requires a greater or lower application rate to achieve desired results.

MassDOT had a unique opportunity to investigate salt usage efficiency on both OGFC and DG pavement surfaces at an existing field site. These pavement types were already located consecutively along I-95 (Rt. 128) Southbound in Needham, Massachusetts, between Exits 33 and 35. Each section was already had an instrumentation station being used by the U.S. Geological Survey (USGS). Because the pavement types were laid out back-to-back, winter maintenance activities such as treatment frequency, material type, and dosage would be applied in essentially the same manner to both surfaces.

The methodology for evaluation of both pavement types, with respect to winter maintenance activities, included: survey of personnel from cold regions, field site instrumentation, documenting winter maintenance activities at the field location, direct friction measurements, analysis of crash data, photograph comparison, and data analysis.

To better understand winter maintenance practices across different states with respect to OGFC and DG pavement surfaces, survey questions were developed in collaboration with the MassDOT project champions (PCs). The internet based survey showed that only 12.5% of respondents currently place OGFC in their state. The reasons noted for opting not to use OGFC included snow and ice concerns, durability issues, project failures, cost, and poor performance issues. Survey respondents indicated that they have noticed increased damage to OGFC surfaces as compared to DG surfaces due to normal plowing operation, although frequency of plowing was not increased for OGFC as compared to DG surfaces.

For the duration of this project, data was collected through both existing and newly installed instrumentation at the field site location. Invasive (imbedded) pavement sensors were acquired and installed at the field project location for this study. During the overnights on October 10th & 11th, 2023 the Hoosier Company, Inc. installed the invasive sensors. The sensors were installed in the first travel lane, between the wheel paths. The USGS also acquired and installed a non-contact sensor. The data from these sensors, along with existing USGS instrumentation, was used to compare different properties of each pavement type, with respect to winter maintenance treatment applications, like: air temperature, pavement temperature, freezing point, water film thickness, friction (grip), humidity, and surface condition.

The sensor data was combined with documentation of winter maintenance activities (salt application) at the field location, direct friction measurements, analysis of crash data, and photograph comparison in an attempt to create a comprehensive framework for comparing salt usage efficiency on OGFC and DG pavement types.

The combined analysis of all the data could not be completed as there were gaps in crash data and photographs. Also, the field instrumentation data and direct friction measurements were limited due to warmer winters. The winters of 2023-2024 and 2024-2025 were less harsh than historically anticipated for the region, thus yielding limited data to analyze. The original research scope proposed collecting data over three winters, but only two winters of data could be collected. In fall 2024, the research team and MassDOT PCs proposed a no-cost time extension so that another winter of data could be collected. A formal extension request was submitted in early 2025, but there was no formal response to that extension request.

Overall, the available field instrumentation data combined with winter maintenance treatment (salt) application data indicated that the OGFC and DG pavement types responded similarly to the winter maintenance in terms of pavement temperature and friction (based on both invasive and non-contact sensors). The safety implications related to winter maintenance activities for both OGFC and DG pavement types could not be investigated due to incomplete crash data and limited direct friction measurements. The invasive and non-contact sensors did not indicate a friction reduction for either pavement type, they performed similarly based on the data collected. No evidence was found that OGFC pavement type froze faster than the DG which challenges assumptions about OGFC’s vulnerability during winter events. Finally, the research team was unable to recommended changes to winter maintenance treatment application rate for either pavement type based on this study. Generally the data indicated they perform similarly when the same winter maintenance treatment is applied.

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List of Acronyms

Acronym	Expansion
AASHTO	American Association of State Highway and Transportation Officials
AVL	Automatic Vehicle Location
CSV	Comma Separated Value
DG	Dense Graded
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
MassDOT	Massachusetts Department of Transportation
OGFC	Open Graded Friction Course
PCs	Project Champions
RWIS	Road Weather Information System
SPR	State Planning and Research
USGS	U.S. Geological Survey

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1.0 Introduction and Objectives

This study entitled "Field Study to Determine Salt Usage Efficiency and Transport to the Surrounding Environment on Two Pavement Types" was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

1.1 Introduction

Winter maintenance is a critical priority for the Massachusetts Department of Transportation (MassDOT) to ensure roadway safety during snow and ice events. At the same time, MassDOT has taken proactive steps to reduce the amount and frequency of salt applications in order to minimize environmental impacts, particularly the contamination of nearby water bodies. However, a key concern has emerged that certain pavement surface types may be receiving unnecessary treatments. This is especially true for Open-Graded Friction Course (OGFC) pavements, which retain a visually "white" appearance after treatment. Maintenance crews often interpret this whiteness as evidence of insufficient salt application, leading to repeated plowing and salting even when conditions do not require it. Because OGFC sections are frequently placed adjacent to Dense-Graded (DG) pavements, these treatments often extend indiscriminately to DG sections as well, resulting in potential over-application.

OGFC mixtures differ from DG mixtures in terms of design. While DG mixtures typically contain about 4% air voids, OGFC mixtures are intentionally more permeable, with air void contents of around 15–16% (*1*). Figure 1.1 illustrates the internal void structures of both pavement types. MassDOT has used OGFC since 1984 because of its many documented benefits, including "reduced water splash and spray, reduced potential for hydroplaning, increased friction, and it helps reduce noise" (*2*).

Despite its advantages, OGFC presents unique challenges for winter maintenance. Its open void structure makes it more prone to rapid freezing, chemical transport away from the surface, clogging by sand or debris, and longer retention of snow and ice. These difficulties are particularly pronounced at near-freezing temperatures (28°F–35°F) (*3*). OGFC surfaces are also more vulnerable to gouging from plows and rutting from studded tires. Laboratory studies reinforce these challenges. A 2021 study found that compacted snow bonds more strongly to OGFC than to DG (*3*). Although OGFC mixtures exhibited higher friction after snow removal even without salt their open structure produced a consistently "white" appearance. This misleading appearance may encourage maintenance crews to apply salt more frequently or at higher dosages than necessary (*3*).

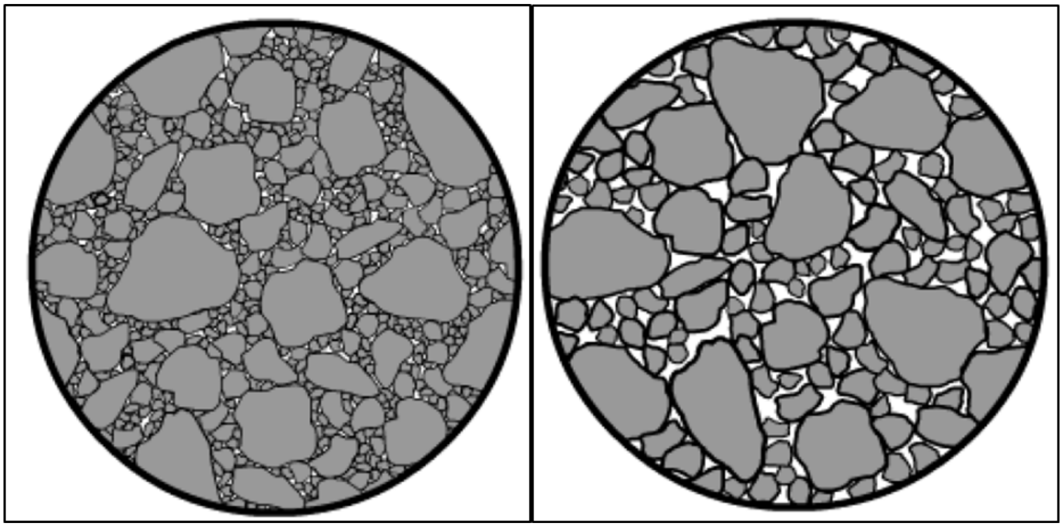


Figure 1.1: Internal void structure of dense graded and open graded friction course mixtures (*1*)

MassDOT's winter maintenance decisions draw on multiple sources, including 45 fixed Road Weather Information System (RWIS) stations, 25 mobile RWIS units, and on-the-ground observations by crews. These inputs feed into Vaisala's Road Weather Navigator software, which incorporates grip levels, theoretical freezing points, and frost warnings to guide treatment actions. Standard treatments include rock salt, liquid magnesium chloride, and liquid brine, with sand and salt-calcium chloride pre-mix used less frequently (*2*). The typical salt application rate in Massachusetts is 240 lb/lane-mile (*2*).

The purpose of this study was to collect and analyze field data that will determine whether winter salt applications on OGFC and DG pavements are appropriate, deficient, or excessive. Applying too little salt creates safety hazards, while over-application increases costs and contributes to environmental harm. By comparing the performance of OGFC and DG under actual winter conditions, the study aimed to provide MassDOT with evidence-based guidance for optimizing winter maintenance practices.

1.2 Project Objectives

The project objectives were:

- Compare OGFC and DG pavement response to identical winter maintenance (salt) applications in terms of reflected physical parameters (ex. measured friction and theoretical freezing point of the resultant deicing solution).

- Investigate the safety implications related to winter maintenance activities for both OGFC and DG pavement types.

- Evaluate whether either pavement type requires a greater or lower application rate to achieve desired results.

2.0 Methodology

2.1 Overview

This research project presented MassDOT a unique opportunity to investigate salt usage efficiency on both OGFC and DG pavement surfaces at an existing field site. As illustrated in Figure 2.1, these pavement sections are located consecutively along I-95 (Rt. 128) Southbound in Needham, Massachusetts, between Exits 33 and 35. Each section is equipped with a U.S. Geological Survey (USGS) highway instrumentation station (Figure 2.2). Because the pavement types are laid out back-to-back, winter maintenance activities such as treatment frequency, material type, and dosage are applied in essentially the same manner to both surfaces. This arrangement, combined with existing instrumentation, made the location ideally suited for evaluating differences in winter salt efficiency between OGFC and DG pavements.

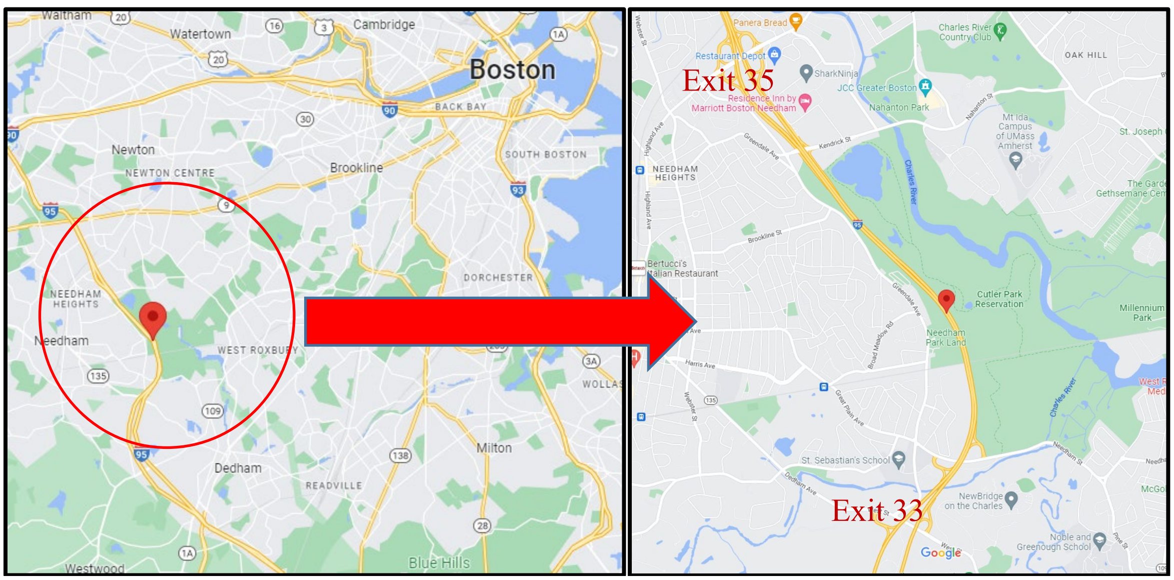


Figure 2.1: I-95 (Rt 128) southbound in Needham, MA field study location (Coordinates 42.2816342,-71.2019692)

Figure 2.2: Southbound Google street view of USGS existing highway instrumentation stations (Google.com)

2.2 Interviews of Personnel from Cold Regions

To better understand winter maintenance practices across different states with respect to OGFC and DG pavement surfaces, interview questions were developed in collaboration with the MassDOT project champions (PCs). Originally these questions were to be asked in virtual interviews of personnel from DOT agencies in cold climates that have experience with both OGFC and DG pavements. Due to the volume of questions of interest to ask each interviewee, the MassDOT PCs elected to utilize the interview questions to formulate an internet based survey. Based on the survey response, the research team could then conduct a virtual interview to gain further depth on the survey responses if necessary. Candidate agencies for survey distribution were identified using Clear Roads and American Association of State Highway and Transportation Officials (AASHTO) contacts. The final survey questions were approved by the MassDOT PCs prior to distribution. These questions provided insight into best practices as well as difficulties encountered with OGFC under winter conditions.

2.3 Field Site Instrumentation

For the duration of this project, data was to be collected through both existing and newly installed instrumentation at the field location. Prior to this project, the USGS stations already had in place an instrumentation stations (Figure 2.3) outfitted with a non-contact IceSight-2020E sensor (Figure 2.4). The Ice-Sight measures air temperature, relative humidity, pavement temperature, and surface condition, and provides an estimate of friction (grip). Other USGS instruments collected key weather and environmental parameters, including: air temperature, snow depth, precipitation (ice, water, or snow), wind speed and direction, runoff flow, water temperature, and specific conductance (salinity). This data supplemented the ongoing USGS research program and provided critical context for this project.

Photo Courtesy of United States Geological Survey(USGS)

WEATHER DATA COLLECTED
1. Air Temperature
2. Snow Depth
3. Precipitation (Ice, Water, Snow)
4. Wind Speed & Direction

ENVIRONMENTAL DATA COLLECTED
1. Runoff Flow
2. Water Temperature
3. Specific Conductance (Salinity)

Figure 2.3: Close up view of existing highway instrumentation station

Photo: https://icesight.com/docs/brochure-icesight2020e-021015.pdf

DATA COLLECTED
1. Air Temperature
2. Relative Humidity
3. Pavement Surface Temperature
4. Surface Conditions
5. Estimate of Friction (Grip)

Figure 2.4: Existing non-contact road surface condition sensor at existing highway instrumentation stations - IceSight-2020E

For this project, the USGS acquired and installed an additional non-contact sensor (shown in Figure 2.5) called the Surfacevue10. The Surfacevue10 provides measurements of air temperature, relative humidity, pavement temperature, surface condition, estimate of friction (grip), and water/ice layer thickness. According to the USGS, this non-contact sensor provides more reliable data than the existing IceSight-2020E non-contact sensor.

DATA COLLECTED
1. Air Temperature
2. Relative Humidity
3. Pavement Surface Temperature
4. Surface Conditions
5. Estimate of Friction (Grip)
6. Water & Ice Layer Thickness

https://www.campbellsci.com/surfacevue10

Figure 2.5: New non-contact road surface condition sensor installed at existing highway instrumentation stations – Surfacevue10

Because non-contact measurements only provide estimates of surface behavior, invasive pavement sensors were installed to directly measure conditions at and below the surface. Based on discussions with the MassDOT PCs and USGS, it was decided to install eight sensors: four passive Lufft IRS31Pro-UMB sensors (Figure 2.6) and four active Lufft ARS31Pro-UMB sensors (Figure 2.7). The IRS31Pro-UMB passive sensor measures road surface temperature, temperature at depth (5 cm and 30 cm), water film height, freezing temperature of de-icing materials, surface condition, friction, ice percentage, and salt concentration (See Table 1). The active ARS31Pro-UMB sensor compliments the passive sensor by actively heating and cooling the sensor surface to measure freezing point independently of de-icing materials. This capability addresses limitations of the passive IRS31Pro-UMB sensors, particularly when blended brines, magnesium chloride, or other treatments are used.

Photo: https://www.lufft.com/products/road-runway-sensors-292/intelligent-passive-road-sensor-irs31pro-umb-2306/

DATA COLLECTED
1. Road Surface Temperature
2. Temperature at Depth (5cm/30cm)
3. Water Film Height
4. Freezing Temperature of De-icing Materials
5. Road Condition
6. Friction
7. Ice Percentage
8. Salt Concentration

Figure 2.6: First invasive sensor installed – Passive Lufft IRS31PRO-UMB

Photo: https://www.lufft.com/products/road-runway-sensors-292/intelligent-active-road-sensor-ars31pro-umb-2305/

DATA COLLECTED
1. Freezing point temperatures: Measured independently from de-icing materials

Figure 2.7: Second invasive sensor installed – Active Lufft ARS31Pro-UMB

Table 2.1: Details About Data Collected from Lufft IRS31PRO-UMB Invasive Sensor

Invasive Sensor Data	Details
1. Road Surface Temperature	Directly measured on sensor surface
2. Temperature at Depth	Depth placement is typically 5cm & 30cm (2 inches & 12 inches)
3.Water Film Height (WFH)	Directly measured on sensor surface
4. Freezing Temperature of De-icing Materials	Directly measured on sensor surface
5. Road Condition	Function of surface temperature, WFH & freezing temperature
6. Friction	Scale of 0.2 to 0.9 (worst to best). Function of ice percentage, surface temperature and WFH.
7. Ice Percentage	Scale of 0 to 100%. Function of surface temperature and salt concentration.
8. Salt Concentration (Conductivity)	Only correct if temperature is ≤ 4°C (40°F) and WFH ≥ 30µm

Each pavement type, OGFC and DG, had two sensor sets (consisting of 1- IRS31Pro-UMB and 1- ARS31Pro-UMB) installed to provide redundancy in case of sensor failure or damage during the project. During the nights on October 10th & 11th 2023, the Hoosier Company, Inc. installed the sensors. The sensors were installed in the first travel lane, between the wheel paths, with final placement approved by MassDOT (Figure 2.8). The IRS31Pro-UMB has two temperature at depth sensors. One was installed at approximately the bottom of the respective dense grade or OGFC layer and the other was installed approximately 18 inches down.

Figures 2.9 and 2.10 show the orientation and layout of the sensors during the installation process for DG and OGFC pavement surfaces respectively. They also show the level of coring, cutting and preparation required to imbedded the sensors into the road. Figures 2.11 and 2.12 show the weather station view of the final sensor installation (Note that only one set is within the camera view for each station) for DG and OGFC pavement surfaces respectively. In these figures, the arrow indicates both the direction of traffic and the location of the other set of sensors that is not visible in the camera view.

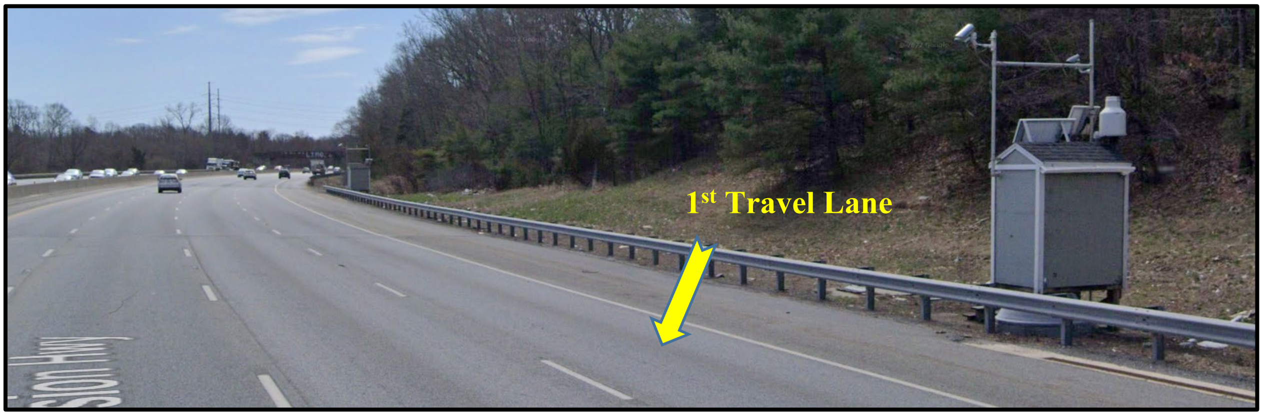


Figure 2.8: Lane for installation of invasive sensors

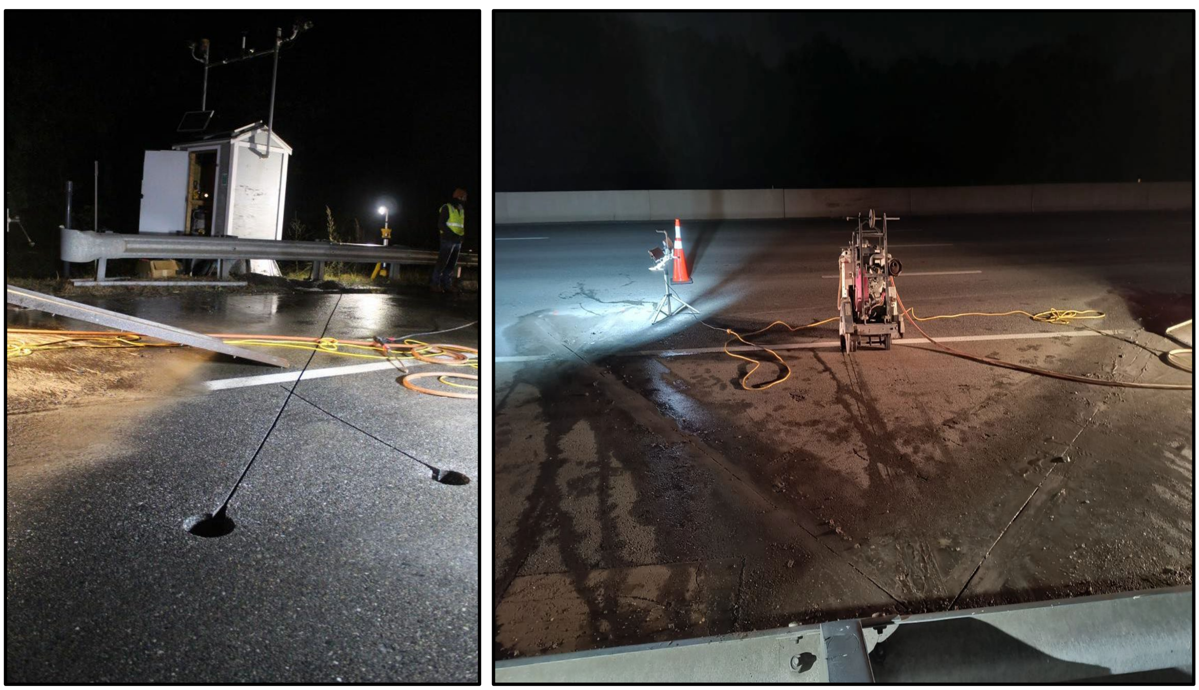


Figure 2.9: Installation of invasive sensors – Dense graded surface

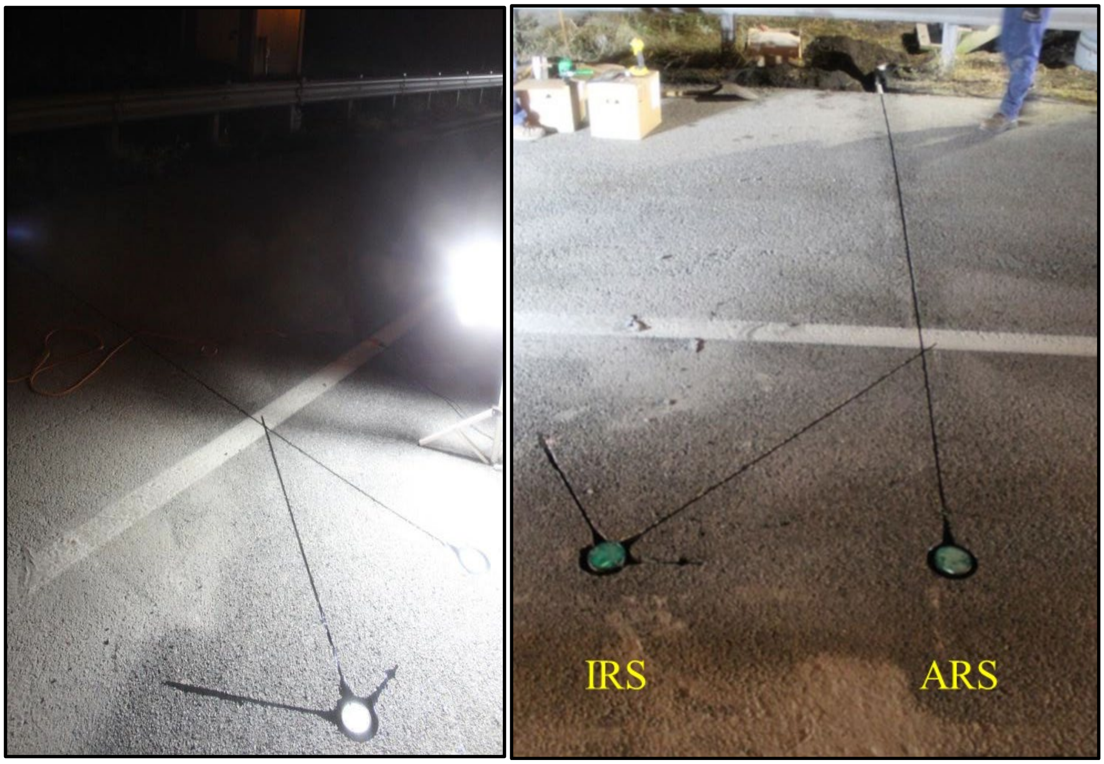


Figure 2.10: Installation of invasive sensors – OGFC

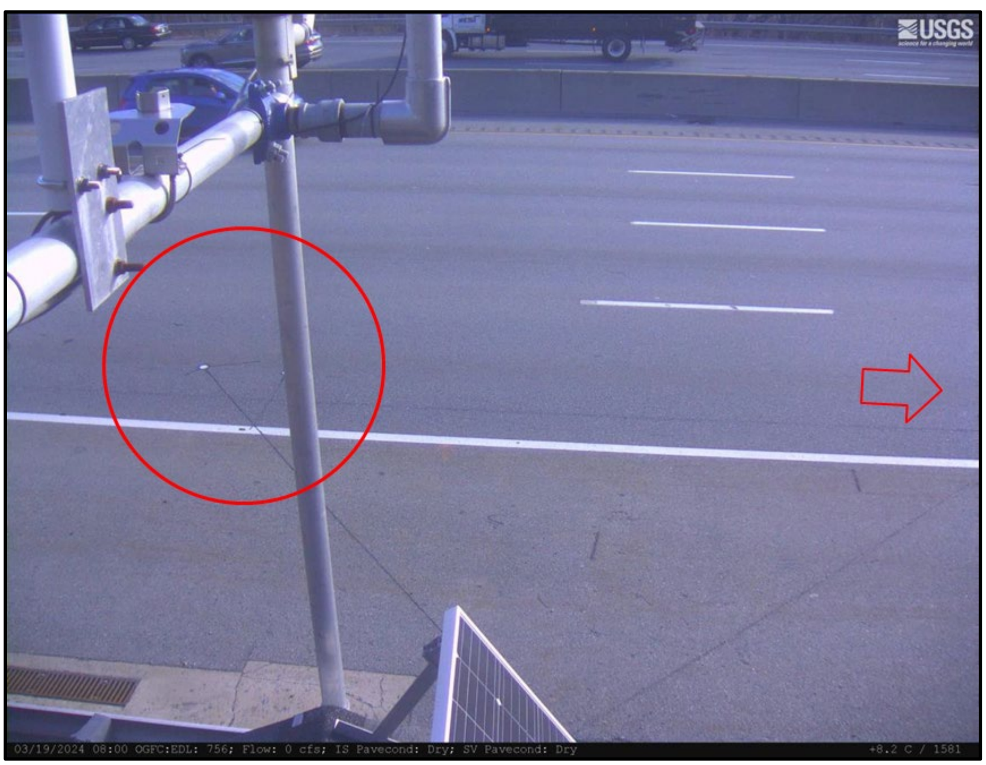


Figure 2.11: View of sensors from weather station – Dense graded

Figure 2.12: View of sensors from weather station – OGFC

The USGS oversaw the integration of the sensors into their existing data acquisition system. They also oversaw calibration and quality control of these invasive sensors over the project duration in addition to maintaining meteorological and runoff monitoring during each winter event. Routine inspections were conducted to ensure accuracy, with data reviewed, validated, and made available through the USGS NWIS system.

2.4 Document Winter Maintenance Activities at Field Location

In addition to sensor data, winter maintenance activities at the study site were to be documented using MassDOT's Automatic Vehicle Location (AVL) and Global Positioning System (GPS) systems. These records quantify the material applied (e.g., rock salt, magnesium chloride, brine), the application rate (solid or liquid), the timing and frequency of application, and the accumulated totals for each storm (*3*).

At the onset of the project, the MassDOT PCs noted that none of the plows that performed winter maintenance activities at the field location were equipped with the AVL and GPS systems. Thus, a spreadsheet was created by the MassDOT PC and given to MassDOT District 6 personnel in a plow chase vehicle to fill out after each winter maintenance application at the project location. This log was referred to as a "Salting Log" (Figure 2.13) as District 6 utilizes dry salt as the standard treatment. One form was supplied for each winter storm.

Dedham Depot Salting Log 2023-2024 Season

Run 1

Date:1/7/24
Time:1:30 AM

Weather and Traffic Comments: Weather: (Clear /Cloudy/ Rain/ Snow/ Ice/ Freezing Rain) Road Temperature (°F): 26
Road Condition: (Dry /Wet /Snowy /Icy / Variable) Traffic Volume: (Low/ Med/ Heavy)

Lane Assigned				
High Speed	Left Middle Travel	Right Middle Travel	Right Travel	Breakdown
E# 91086	E# 00268	E# 06886	E# 03795	E# 01361
Pounds/Lane-Mile NaCl:360	Pounds/Lane-Mile NaCl:240	Pounds/Lane-Mile NaCl:240	Pounds/Lane-Mile NaCl:240	Pounds/Lane-Mile NaCl:240

Run 3

Date: 1/7/24
Time: 4:00 AM

Weather and Traffic Comments: Weather: (Clear /Cloudy/ Rain/ Snow/ Ice/ Freezing Rain) Road Temperature (°F): 28
Road Condition: (Dry /Wet /Snowy /Icy / Variable) Traffic Volume: (Low/ Med/ Heavy)

Lane Assigned				
High Speed	Left Middle Travel	Right Middle Travel	Right Travel	Breakdown
E# 06886	E# 03795	E# 00268	E# 06536	E# 01361
Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240

Run 5

Date: 1/7/24
Time: 5:30 AM

Weather and Traffic Comments: Weather: (Clear /Cloudy/ Rain/ Snow/ Ice/ Freezing Rain) Road Temperature (°F): 30
Road Condition: (Dry /Wet /Snowy /Icy / Variable) Traffic Volume: (Low/ Med/ Heavy)

Lane Assigned				
High Speed	Left Middle Travel	Right Middle Travel	Right Travel	Breakdown
E# 06886	E# 03795	E# 00268	E# 06536	E# 01361
Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240	Pounds/Lane-Mile NaCl: 240

Figure 2.13: Example of salting log for the field project location

2.5 Direct Friction Measurements

Direct measurements of surface friction were also to be collected to supplement the friction (grip) values estimated by non-contact sensors. It was anticipated for selected winter weather events, MassDOT would use its locked-wheel friction tester during off-peak hours. Alternative devices such as the British Pendulum or other slip-wheel sensors could also be used if available. These direct measurements would allow for more accurate assessment of pavement friction and provide validation of RWIS grip values.

2.6 Crash Data

Crash data was to be incorporated into the project through coordination with MassDOT's Safety Section. The research team would obtain information on crashes occurring during winter events at or near the study site, as well as relevant historical data. Information collected would include time of occurrence, roadway conditions, environmental conditions, and vehicle mechanical condition. These data would be used to assess whether winter maintenance practices and pavement type are related to crash incidence. Statistical analysis would be conducted to evaluate correlations between friction measurements and crash rates, helping to validate the reliability of different friction indicators.

2.7 Photographs

Finally, photographs were proposed to be collected to document the visual appearance of both pavement types before, during, and after winter maintenance activities. Automated cameras located at each station capture images throughout winter events, with frequency increased during active storms. These photographs would provide valuable context for understanding the "white" appearance of OGFC and could be correlated with temperature and friction data to determine whether visual cues correspond to actual pavement conditions or contribute to unnecessary treatments.

2.8 Data Analysis

The combined approach of interviews (survey), field instrumentation, winter maintenance records, direct friction testing, crash data analysis, and photographic documentation would create a comprehensive framework for comparing salt usage efficiency on OGFC and DG pavement types. The integrated dataset would enable MassDOT to determine whether current practices are appropriate, deficient, or excessive, and to develop recommendations for optimizing winter maintenance strategies.

3.0 Project Progress

The project progressed steadily through multiple phases aligned with the methodology outlined in Section 2.0. First, a strategic decision was made to broaden the scope by converting the interview questions into an online survey format using Google Forms, thereby reaching a wider range of participants. This survey was circulated to members of Clear Roads and AASHTO partner agencies, resulting in limited but valuable responses that helped inform the direction of the research methodology.

As previously outlined, the invasive sensors were procured and retained for installation by the Hoosier Company, Inc. The pivotal milestone of the project occurred with the successful installation of eight invasive road sensors overnight on both October 10th & 11th, 2023. Four passive IRS31Pro-UMB and four active ARS31Pro-UMB sensors were installed across OGFC and DG pavement sections. Depth sensors were embedded at the bottom of each pavement layer and approximately eighteen inches below the surface, ensuring a complete dataset capturing both near-surface and subsurface conditions. USGS supplemented this installation by integrating the sensors into existing monitoring platforms, installing large solar panels for reliable power, and adding the non-contact SurfaceVue10 sensors. All sensors were confirmed operational by the end of 2023, marking the transition into active data collection.

MassDOT complemented these instrumentation efforts by developing a salting template for District 6 to log every treatment run, including truck identification, lane assignment, and pounds of salt applied per lane-mile. Early logs, such as those from the January 7th, 2024 storm, demonstrated multiple sequential applications and offered a concrete record of winter maintenance practices. In addition, MassDOT began collecting friction data using the locked-wheel friction tester during off-peak hours. Although site-specific crash data was unavailable, MassDOT began exploring statewide crash data for comparative analysis between OGFC and DG pavements.

Throughout 2024, the project matured into full-scale data collection and early analysis. Storm summaries were compiled, and selected events were chosen for in-depth study, including the significant storms of January 7th, 16th, 20th, 23rd, 28th, 2024. These storms provided sufficient salt application activity to evaluate freezing behavior and treatment efficiency. Analysis of temperature data indicated that air temperatures were consistently colder than pavement surface temperatures, with surface temperature trends being comparable between DG and OGFC sections. No evidence was found that OGFC froze faster than DG, a finding that challenges assumptions about OGFC's vulnerability during winter events.

By late 2024, additional field work such as permeability testing was conducted by USGS, and survey responses were further reviewed. Salting logs continued to be compiled alongside USGS storm data, enriching the dataset. Progress metrics showed Task 1 – "Virtual Interviews" (survey) approaching completion, Task 2 – "Data Collection" well advanced with multiple subtasks nearing 80%, and Task 3 – "Data Analysis" moving forward with more than half of the analysis completed. These accomplishments demonstrated steady movement toward delivering final results.

The 2024–2025 winter brought additional storms with high application rates, including events with over a dozen treatments. Logs from this period, coupled with continued friction testing and photographic documentation, expanded the scope of usable data. Meetings with MassDOT confirmed that while localized crash data remained unavailable, statewide crash data could provide meaningful insights. Stakeholders agreed in fall 2024 on the importance of securing a no-cost extension to ensure a complete third winter season of data. A formal extension request was submitted in March 2025, seeking to extend the project into mid-2026. No formal response was received to that request.

4.0 Results and Data Analysis

4.1 Internet Based Survey Results

The approved interview questions were converted into an online survey using Google Forms as shown in Figure 4.1. The survey was located at https://forms.gle/8GnVP2waii6G99Wi7. The survey was distributed in the fall of 2023 and remained open for response until the summer of 2024. Forty one different Clear Roads, AASHTO, and state DOT contacts were sent invitations to participate in the survey.

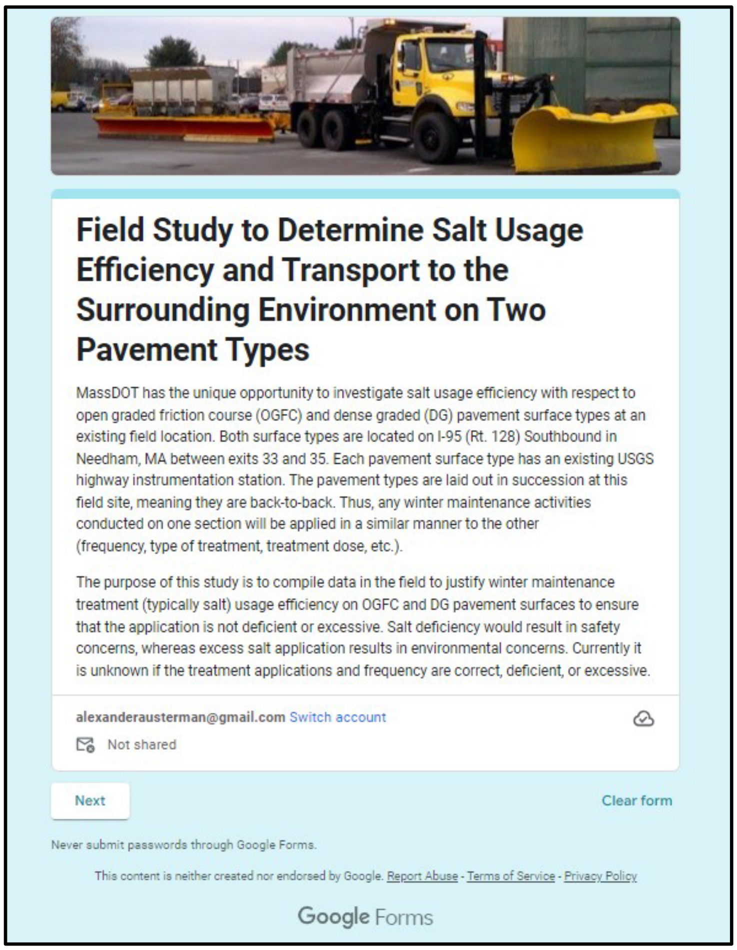


Figure 4.1: Internet based survey

A total of nine (9) total responses were received to the survey from participants representing the following agencies: North Dakota DOT, Texas DOT, Vermont Agency of Transportation (2 responses), Minnesota DOT, Idaho Transportation Department, Nebraska DOT, and Kansas DOT.

Some notable highlights of the survey results include:

- Only 12.5% of respondents indicated that they currently place OGFC in their state.
- The reasons noted for opting not to use OGFC included snow and ice concerns, durability issues, project failures, cost, and poor performance issues.
- The measures utilized for winter maintenance of OGFC surfaces were noted to be the same as other pavements, along with discontinued use of sand.
- Survey respondents indicated that they have noticed increased damage to OGFC surfaces as compared to DG surfaces due to normal plowing operation, although frequency of plowing was not increased for OGFC as compared to DG surfaces.

The complete complied results of the entire survey are located in Appendix A. Based on the survey results, the MassDOT PCs elected not to have the research team interview any of the survey participants.

4.2 Field Instrumentation & Winter Maintenance Activities Data

Data from the field instrumentation needed to first be integrated with the winter maintenance logs supplied by MassDOT District 6. There was no way to automate this integration as the salting logs were compiled completely separate from the field instrumentation data.

First, the number of winter maintenance treatment applications for each storm were compiled from the winter maintenance application logs supplied by District 6 as shown in Table 4.1 for the 2023-2024 winter season and Table 4.2 for the 2024-2025 season. The storms with the highest number of treatment applications for each winter season were selected for full data integration with the field instrumentation data and subsequent analysis.

The field instrumentation data was obtained directly from the following USGS websites where the data and photographs were automatically uploaded from the instrumentation stations:

Dense Graded Sites:
https://waterdata.usgs.gov/monitoring-location/421650071120401/ (Data)

https://apps.usgs.gov/hivis/camera/MA_MA_HWY_I95S_HMA_STATION_00567_NEEDHAM (Photographs)

OGFC Sites:
https://waterdata.usgs.gov/monitoring-location/421652071120601/ (Data)

https://apps.usgs.gov/hivis/camera/MA_MA_HWY_I95S_OGFC_STATION_00568_NEEDHAM (Photographs)

Table 4.1: Winter Maintenance Storm Data (2023-2024)

Storm Date	Number of Treatment Applications	Selected for Data Analysis
12/23/23	None	-
1/7/24	17	✓
1/14/24	2	-
1/16/24	12	✓
1/19/24	None	-
1/20/24	7	✓
1/23/24	5	✓
1/28/24	9	✓
1/30/24	1	-
2/2/24	2	-
2/13/24	4	-
2/15/24	1	-
2/29/24	1	-
3/22/24	None	-

Table 4.2: Winter Maintenance Storm Data (2024-2025)

Storm Date	Number of Treatment Applications	Selected for Data Analysis
12/04/24	5	-
12/07/24	4	-
12/16/25	NONE	-
12/20/25	11	✓
12/23/24	3	-
12/28/24	1	-
1/09/25	NONE	-
1/11/25	7	-
1/12/25	NONE	-
1/19/25	13	✓
1/28/25	4	-
1/31/25	4	-
2/02/25	9	-
2/06/25	5	-
2/08/25	9	-

Data files were downloaded from the appropriate USGS website in a Comma Separated Value (.csv) file. These files were then loaded into Microsoft Excel so that all the field instrumentation data could be combined in one master file. Then, additional columns were added to that master file so that the time of winter maintenance treatment (salting) application could be denoted on the same analysis graphs with the field instrumentation data. All data was plotted with respect to time, giving a clear snapshot of each selected winter storm.

Figures 4.1 and 4.2 show a comparison of air temperature measured by the SurfaceVue10 (non-contact) and the imbedded pavement invasive sensors (IRS) for both DG and OGFC pavement types with respect to salt application. As it can be seen, the air temperature measured by the SurfaceVue10 generally trended colder than pavement temperature measured by the invasive sensors regardless of pavement type.

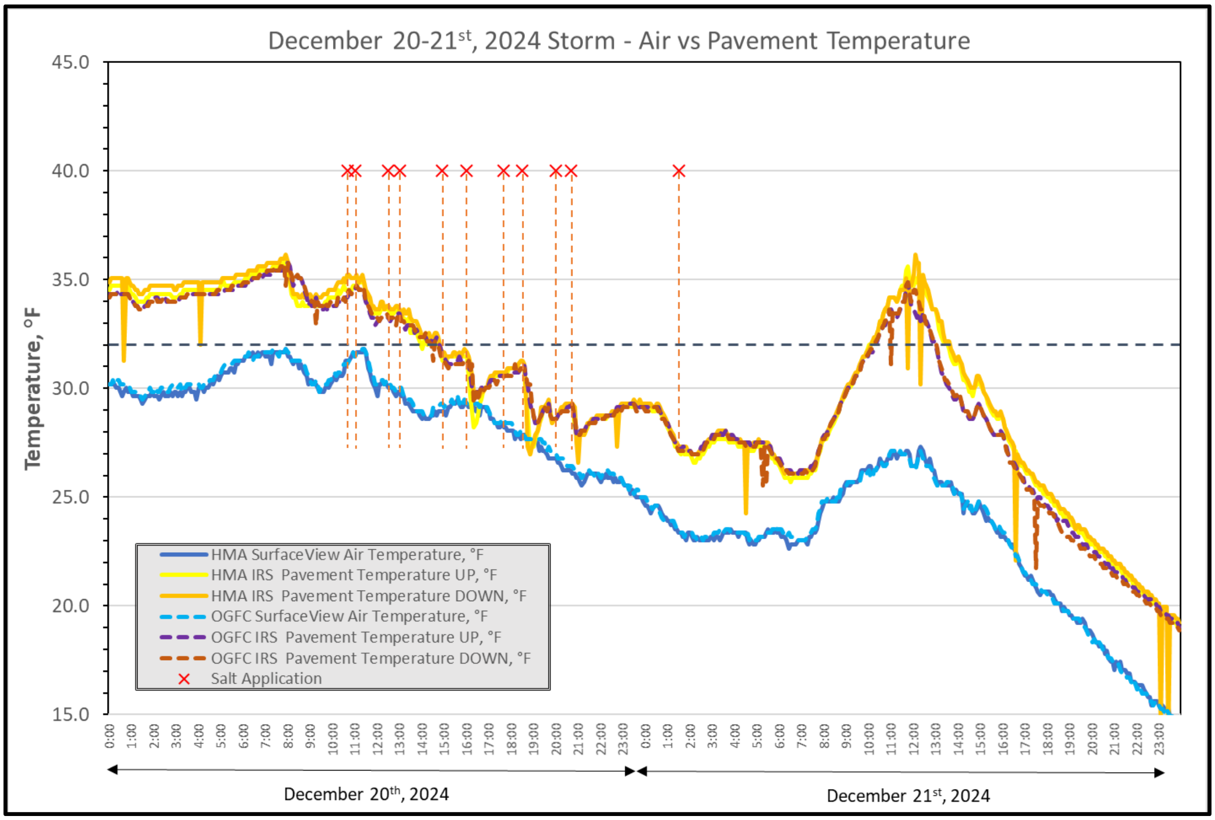


Figure 4.1: Temperature by sensor type - Air versus Pavement (2024)

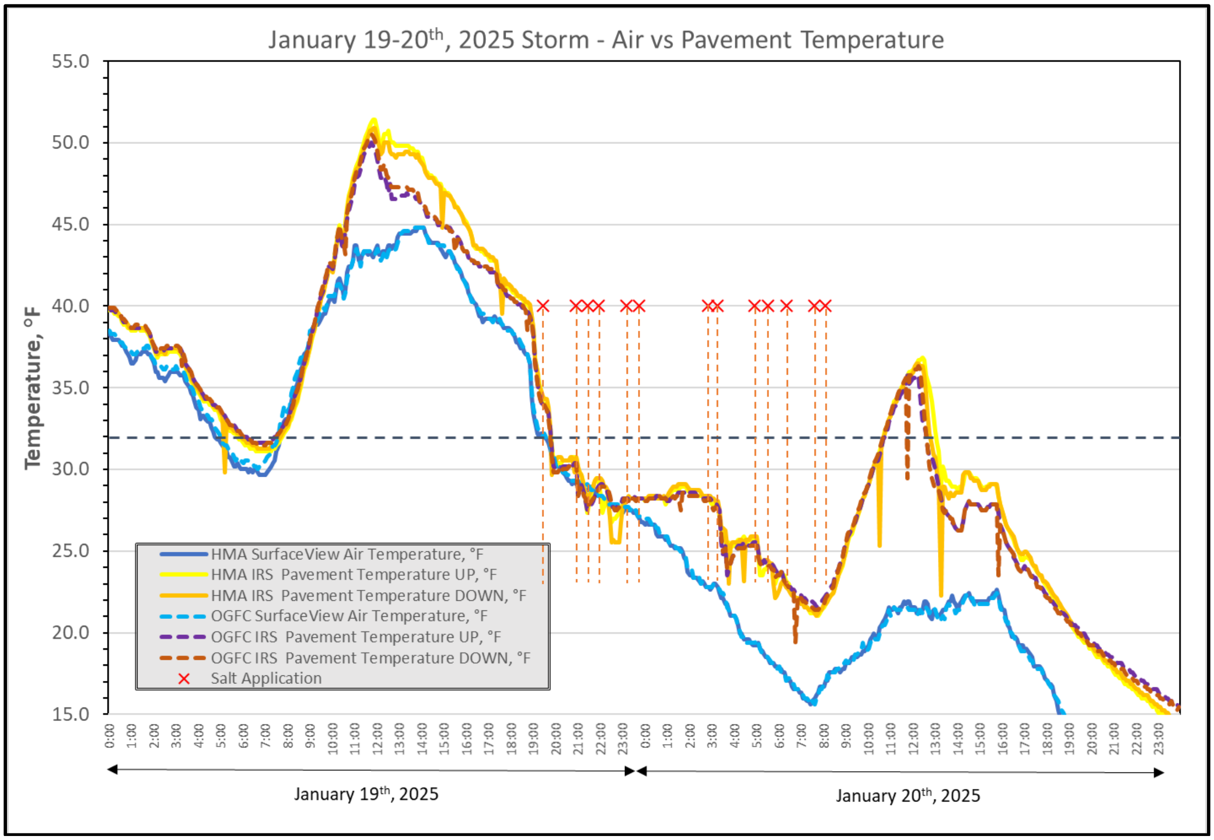


Figure 4.2: Temperature by sensor type - Air versus Pavement (2025)

Figure 4.3 shows a comparison of pavement surface temperature from the invasive sensors (IRS) for both DG and OGFC pavement types. The temperature was similar between both the DG and OGFC mixture types. No data indicated one pavement type was freezing faster than the other, as surface temperature data was generally the same. Analysis of other storm data on different dates provided similar results.

Figures 4.4 and 4.5 show a comparison of water film thickness versus invasive sensor (IRS) friction by pavement surface type. Friction was only of concern when moisture, or water film, was present at the sensor in the pavement. If the pavement were dry, there would be less potential for reduced friction or an icing condition. The data indicated that the friction characteristics of the DG and OGFC pavement types were similar with respect to salt application, and that the water film experienced on both was similar. In Figure 4.5, the incomplete areas, or gaps, in the friction data were common. In consulting with USGS, these gaps occur when the freezing point estimated by the IRS sensor return an unrealistic value. This could be due to build-up of contaminants on the sensor surface. The unrealistic value of freezing point then affects the calculation of friction, which is based on freezing point. USGS applied filters to the data stream to remove such unrealistic data, and thus these data gaps appear.

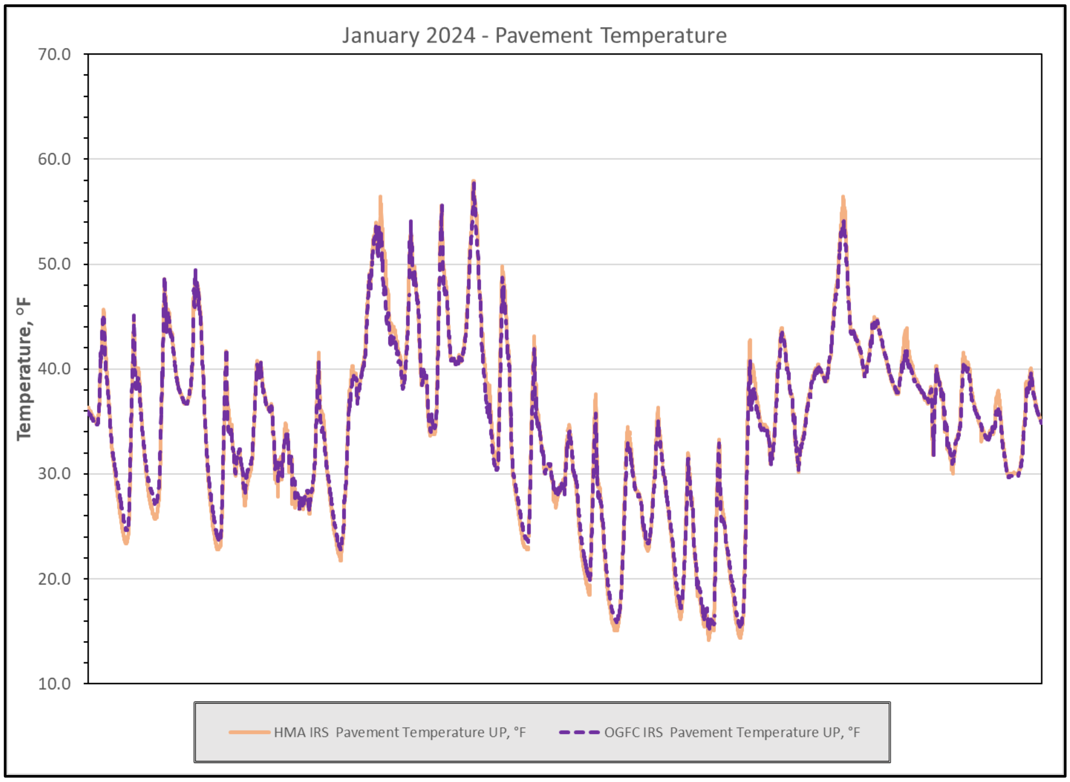


Figure 4.3: Surface temperature – Dense graded vs. OGFC

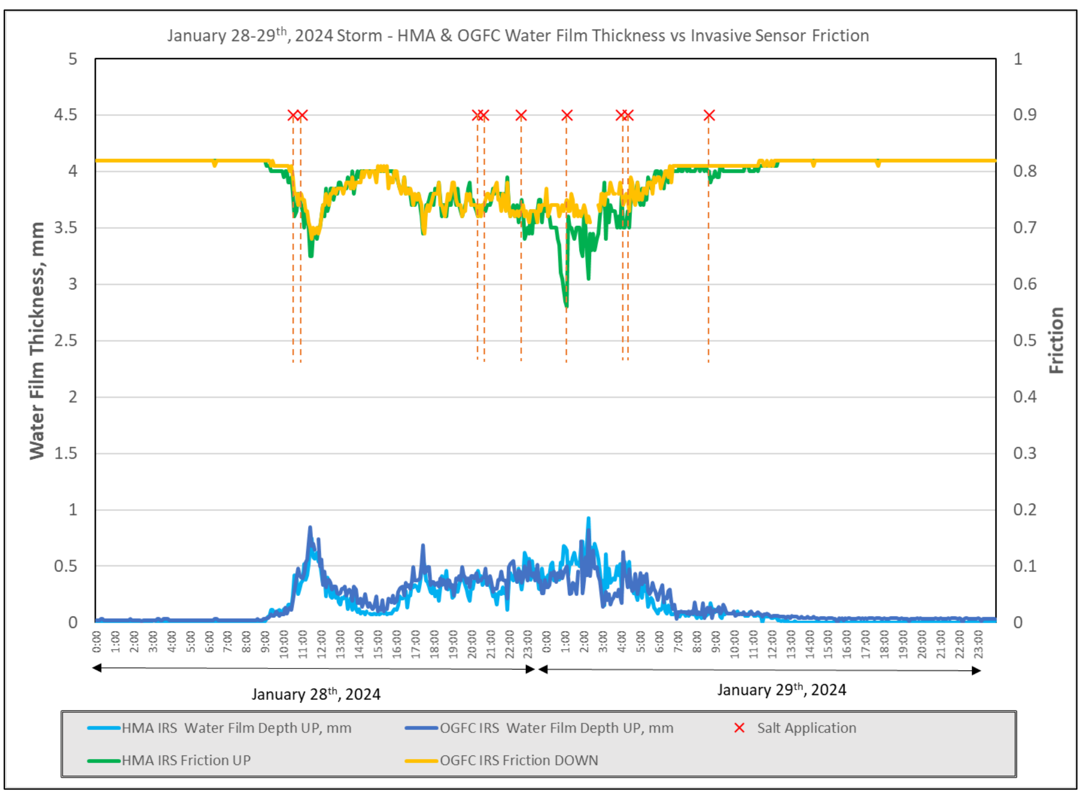


Figure 4.4: Water film thickness versus invasive sensor friction (2024)

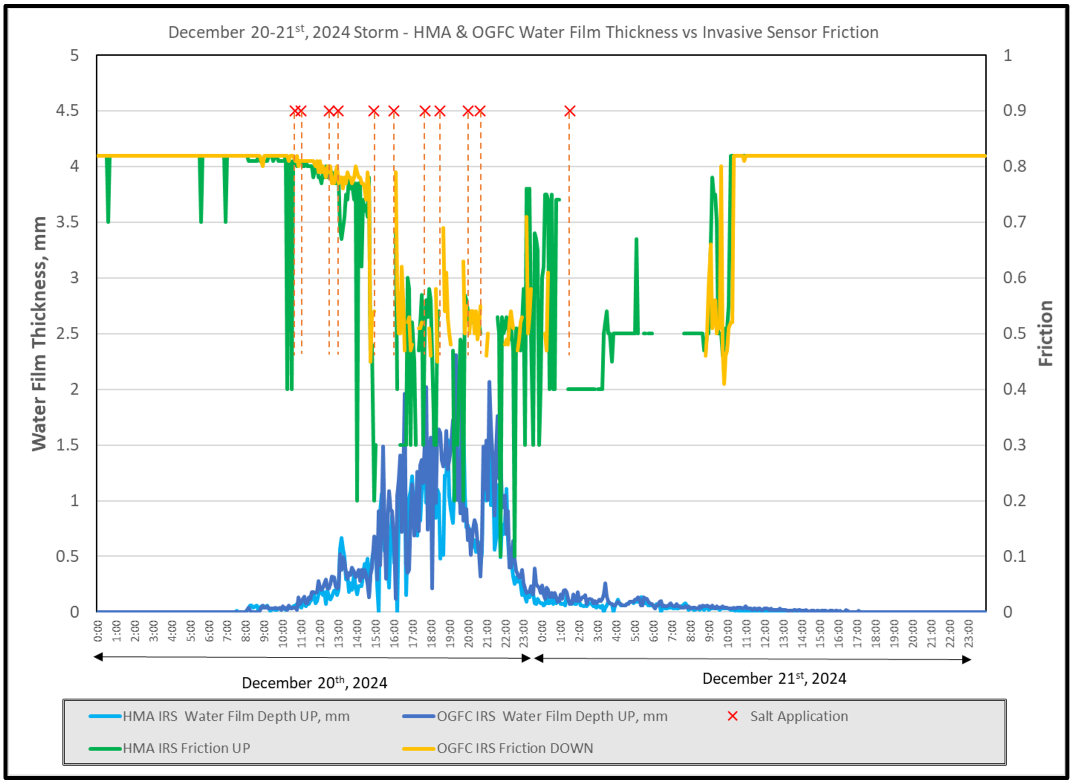


Figure 4.5: Water film thickness versus invasive sensor friction (2025)

Because of the data gaps observed in the invasive sensor friction data, the friction value obtained by the non-contact SurfaceVue10 were plotted similarly versus water film thickness. As shown in Figures 4.6 and 4.7. The data showed agreement with the invasive sensor friction data. The friction characteristics of the DG and OGFC pavement types with respect to salt application were similar.

The data presented in Figures 4.1 through 4.7 show examples of the common trends in the data that was observed after analysis of the indicated storms in Tables 4.1 and 4.2. The winters of 2023-2024 and 2024-2025 were less harsh than historically anticipated for the region, thus yielding limited data to analyze. The original research scope proposed collecting data over three winters, but the invasive sensors were not able to be installed until fall 2023. This eliminated one winter from the study.

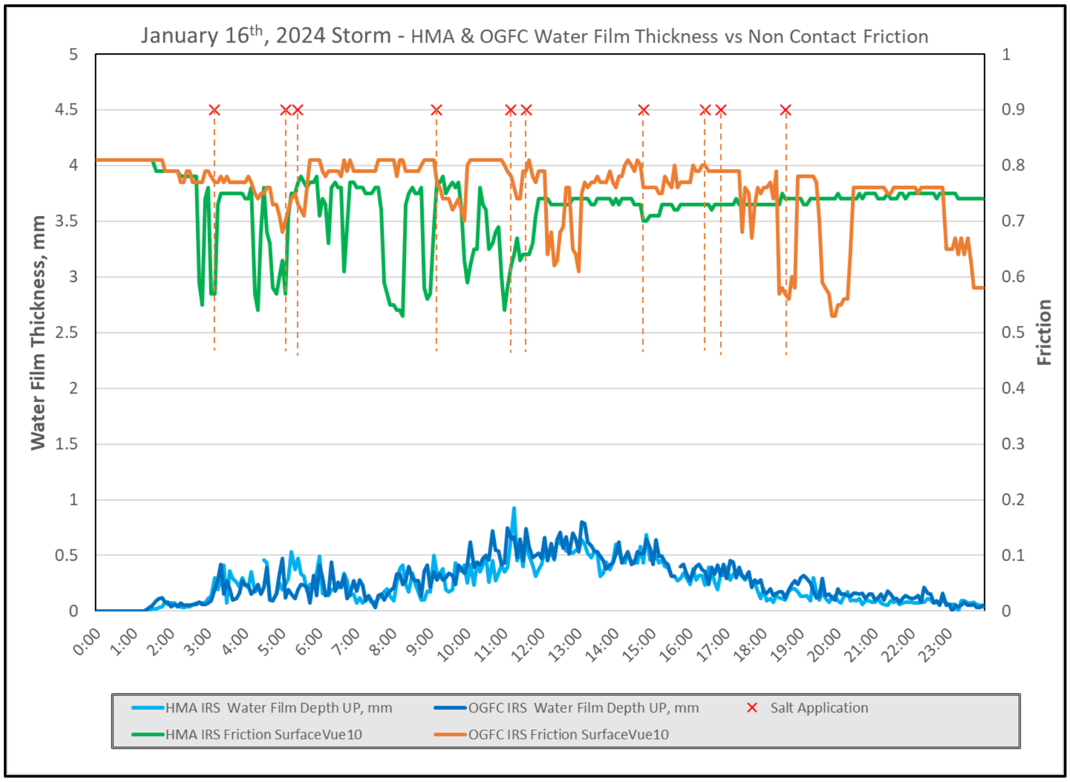


Figure 4.6: Water film thickness versus non-contact sensor friction (2024)

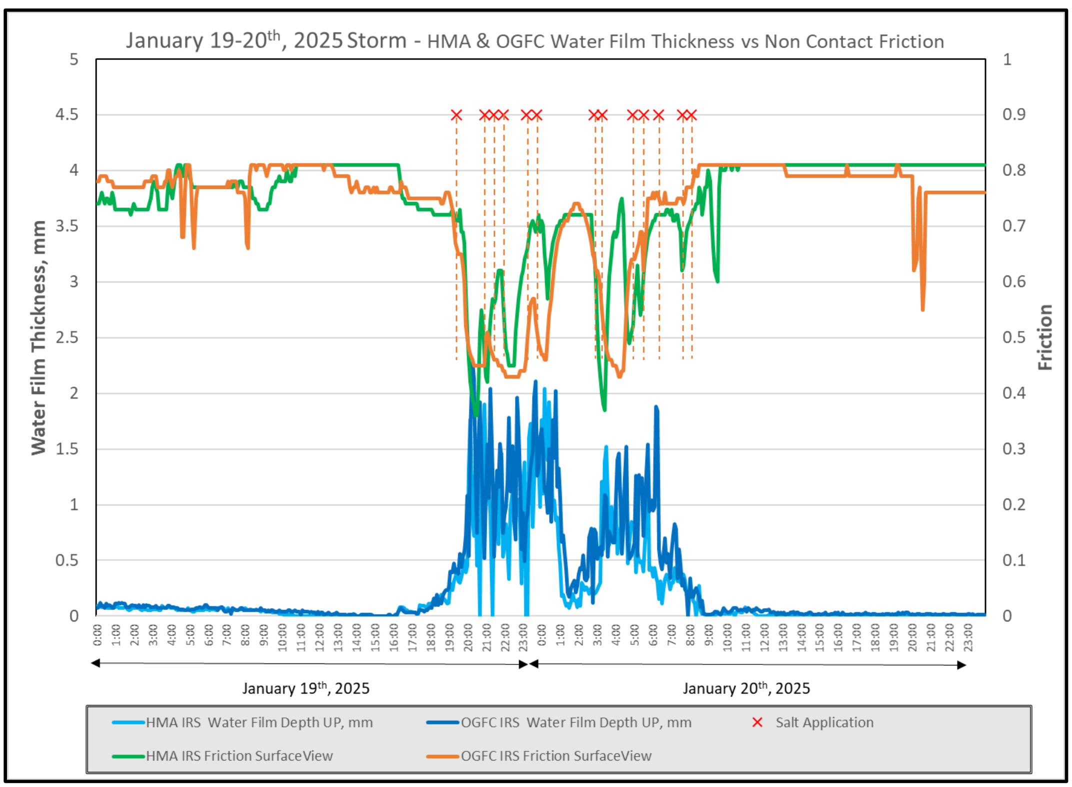


Figure 4.7: Water film thickness versus non-contact sensor friction (2025)

4.3 Direct Friction Measurements

MassDOT's locked wheel friction tester, shown in Figure 4.8, was used to measure the skid number (SN) for both pavement surface types (OGFC and DG) at the field study location on the following dates:

- January 7th, 2024
- January 9th, 2024
- January 16th, 2024
- January 29th, 2024
- February 13th, 2024

The locked wheel friction tester is a standardized device used to evaluate pavement surface friction under controlled conditions. It is widely employed by highway agencies to assess the surface friction of pavements such as dense-graded asphalt, open-graded friction courses, and other surface types for both safety monitoring and research purposes.

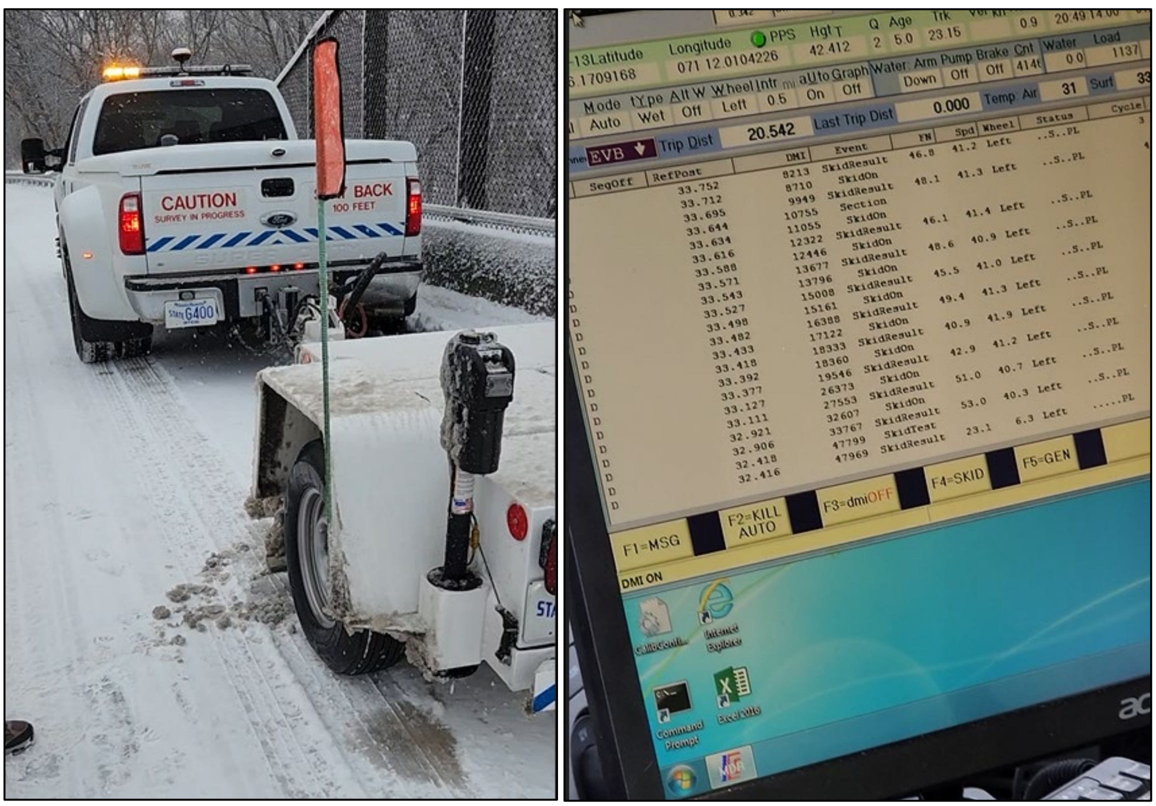


Figure 4.8: MassDOT collection of surface friction data using the locked-wheel friction tester during a winter storm

The device consists of a test vehicle equipped with a smooth or ribbed tire mounted on a fixed axle. During testing, the vehicle is driven at a constant speed of approximately 40 mph while a controlled water spray is applied ahead of the tire to create a uniform wet surface. At a specified point, the test wheel is locked, causing it to skid across the pavement. The longitudinal frictional force generated between the locked tire and the pavement surface is continuously recorded. This frictional force is then divided by the vertical load on the wheel to calculate the Skid Number or SN which is a dimensionless index that typically ranges between 0 and 100. Higher SN values indicate greater surface friction and, consequently, better resistance to skidding. The SN values for both pavement surface types, across the different testing dates, is shown in Table 4.3. The data show consistent trends in skid resistance (friction) between the DG and OGFC surfaces under varying weather conditions.

Table 4.3: Skid Number (Friction) Values Measured by MassDOT's Locked-wheel Friction Tester

Date	Weather Condition	Run Number	Average Skid Number (SN)	
			OGFC	Dense Graded
1/7/2024	Snow	1	46.1	47.1
		2	49.1	48.0
1/9/2024	Clear	1	54.5	55.6
		2	54.9	56.9
		3	55.1	59.7
1/16/2024	Clear	1	51.7	52.7
		2	50.9	53.1
		3	51.8	52.5
1/29/2024	Clear	1	54.2	55.5
		2	54.0	53.9
2/13/2024	Clear	1	52.8	55.0

During testing conducted under snowy conditions on January 7th, 2024, both pavement surface types exhibited lower skid numbers, averaging in the mid-to-high 40's. The OGFC surface (46.1 - 49.1) and the DG surface (47.1 - 48.0) showed nearly comparable friction levels.

Under clear weather conditions (Data collected between January 9th, 2024 to February 13th, 2024), the measured skid numbers increased, reaching the 50's for both pavement surface types. Generally, the DG pavement surface consistently yelided slightly higher SN values (typically 1 to 3 points) greater than OGFC pavement surface, thus indicating marginally higher friction under dry conditions. The increased SN values under clear and dry conditions was expected, as frictional characteristics of both pavement surface types was anticipated to improve.

Overall, the locked-wheel testing results indicated that both pavement surface types provided adequate friction levels (SN > 50) under clear and dry conditions, signifying adequate surface performance in terms of frictional safety. Under snowy conditions for the one winter storm when measurements were collected, both pavement surfaces exhibited nearly comparable friction levels, although the levels of friction were reduced as compared to the measurements obtained under clear and dry conditions. Finally, it should be noted that OGFC surfaces may lose some of their frictional advantage during snowy conditions when open voids become filled with compacted snow or debris. Although the DG surface exhibited slightly higher average skid numbers in this dataset collected, they may perform less favorably under heavy rainfall or when hydroplaning potential is considered. Continuous, seasonal monitoring is therefore recommended to capture the full range of frictional performance for both pavement surface types under varying moisture and temperature conditions.

4.4 Crash Data

Due to the relatively short length of the pavement section at the field project location, the MassDOT PCs indicated that getting any crash data for that specific location would be difficult, if not unrealistic. They proposed to get winter crash data by surface type (DG vs OGFC) for locations throughout Massachusetts. The MassDOT PCs are still in the process of trying to get this crash data for the research team.

4.5 Photographs

The research team did obtain photographs during the winter storms. However, the timing and frequency between weather stations was different, so there were no side-by-side comparisons at the same time for each surface type. The photographs need to be very close in time to be able to discern the “snowy” or “white appearance” that may appear on the OGFC surface after plowing. The research team and USGS had just adjusted the camera settings in the hopes of obtaining better side-by-side photographs for the 2025-2026 winter season.

4.6 Data Analysis

The combined analysis of all the data could not be completed as there were gaps in crash data and photographs. Also, the field instrumentation data and direct friction measurements were limited due to warmer winters. The winters of 2023-2024 and 2024-2025 were less harsh than historically anticipated for the region, thus yielding limited data to analyze. The original research scope proposed collecting data over three winter seasons, but the invasive sensors were not able to be installed until fall 2023. This eliminated one winter from the study. In fall 2024, the research team and MassDOT PCs proposed a no-cost time extension so that another winter of data could be collected. A formal extension request was submitted in early 2025, but there was no formal response to that extension request.

5.0 Discussion

The purpose of this study was to collect and analyze field data to determine whether winter salt applications on OGFC and DG pavements are appropriate, deficient, or excessive. The study aimed to provide MassDOT with evidence-based guidance for optimizing winter maintenance practices for OGFC and DG pavement surfaces.

The combined analysis of all the data could not be completed as there were gaps in crash data and photographs. Also, the field instrumentation data and direct friction measurements were limited due to warmer winters. The winters of 2023-2024 and 2024-2025 were less harsh than historically anticipated for the region, thus yielding limited data to analyze. The original research scope proposed collecting data over three winters, but only two winters of data could be collected. In fall 2024, the research team and MassDOT PCs proposed a no-cost time extension so that another winter of data could be collected. A formal extension request was submitted in early 2025, but there was no formal response to that extension request.

Based on the work conducted to date the following was noted:

- The internet based survey showed that only 12.5% of respondents currently place OGFC in their state. The reasons noted for opting not to use OGFC included snow and ice concerns, durability issues, project failures, cost, and poor performance issues. Survey respondents indicated that they have noticed increased damage to OGFC surfaces as compared to DG surfaces due to normal plowing operation, although frequency of plowing was not increased for OGFC as compared to DG surfaces.

- Field instrumentation data combined with winter maintenance treatment (salt) application data indicated that the OGFC and DG pavement types responded similarly to the winter maintenance in terms of pavement temperature and friction (based on both invasive and non-contact sensors).

- The safety implications related to winter maintenance activities for both OGFC and DG pavement types could not be investigated due to incomplete crash data and limited direct friction measurements. The invasive and non-contact sensors did not indicate a friction reduction for either pavement type, they performed similarly based on the data collected. No evidence was found that OGFC pavement type froze faster than the DG which challenges assumptions about OGFC's vulnerability during winter events.

- The research team was unable to recommended changes to winter maintenance treatment application rate for either pavement type based on this study. Generally the data indicated they perform similarly when the same winter maintenance treatment is applied.

6.0 References

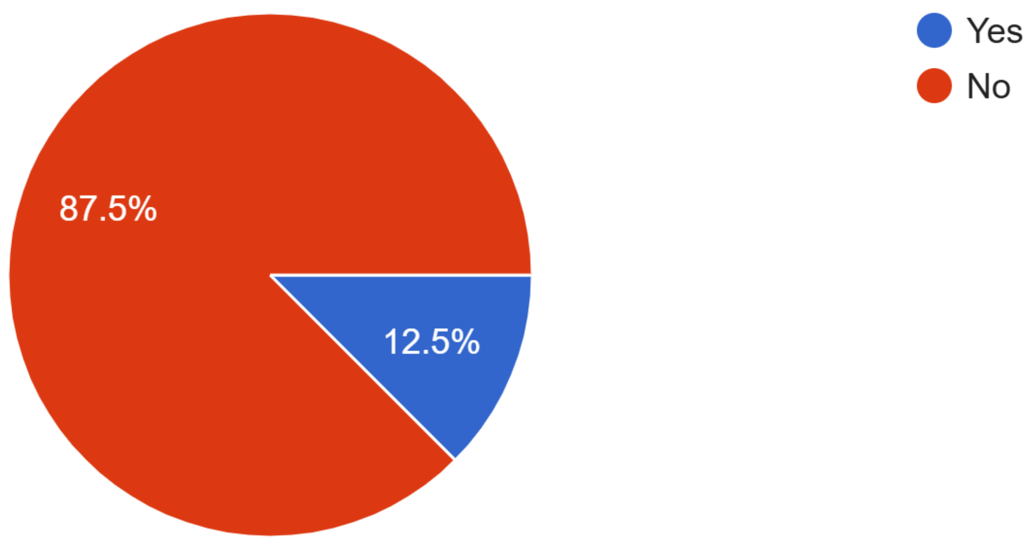
1. Pavement Interactive. "Open-Graded Friction Course (OGFC)" https://pavementinteractive.org/reference-desk/pavement-types-and-history/pavement-types/open-graded-hma/ Last Accessed September 30th, 2025.

2. GEOTAB " Telematics for Winter Operations: How the Massachusetts Department of Transportation balances safety, efficiency, & sustainability." September 2021. https://storage.googleapis.com/geotab_wfm_production_cms_storage/CMS-GeneralFiles-production/NA/White_papers/mass-dot-sustainability-report-whitepaper-2021-english-DS03955-AODA(web-under-5mb).pdf
Last Accessed September 30th, 2025.

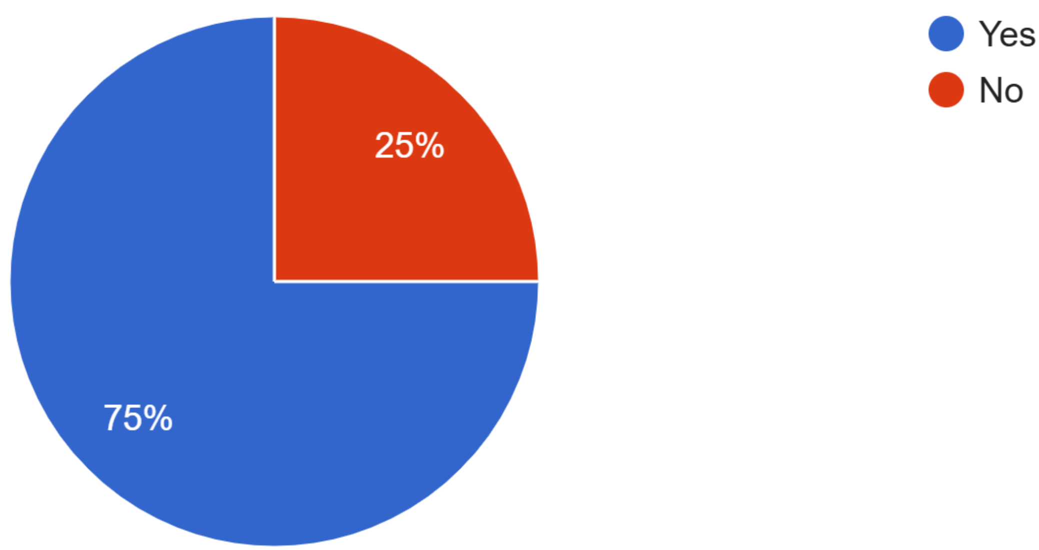
3. Akin, M., Fay, L. and Shi, X. "Friction and Snow–Pavement Bond after Salting and Plowing Permeable Friction Surfaces." Transportation Research Record, 2020, Vol. 2674(11) 794–805.

Appendix A: Survey Results

Question: Does your agency currently place OGFC in your state? (8 responses)



Question: Has your agency previously placed OGFC in your state? (8 responses)



<u>Question:</u> Are there any reasons for opting not to use OGFC? (7 responses)

- Not sure of all the reasons but we were concerned with snow and ice control.
- Durability issues, mainly raveling and delaminating.
- May have been used briefly in the 1960s. Underbody plows peel it off. Not used since.
- Our environment doesn't really drive us to use OGFC, concern with durability, focusing on Superpave HMA dense-graded mix consumed technical resources.
- Last project failed.
- We have to bring in the aggregate from South Dakota and the cost is too high. It was used quite a bit in the 1980s, but we only have a couple miles of it now.
- Last used in 2005 and did not perform as well as our other mixes.

<u>Question:</u> What year did OGFC placement start/stop? (7 responses)

- Started about 10 years ago
- 1998
- 1960s
- 1996/1998
- Before 2000
- One project in 2005

<u>Question:</u> What measures are utilized for winter maintenance of OGFC surfaces? (7 responses)

- Discontinued use of sand.
- None as we don't have any.
- Same as for any other pavement.

<u>Question:</u> With respect to plowing, what is done to reduce/prevent damage to pavement surfaces (both OGFC & DG)? (6 responses)

- We have a number of different cutting edges to choose from for different operator preference.
- Plow use is rare on these surfaces.
- N/A
- None, not used.
- Use of plow shoes.
  Plow balancers are becoming more popular. Some use rubber blades.

Question: What plowing speeds are used (both OGFC & DG)? (5 responses)

- Typically 15 to 20 MPH
- 25
- All plowing is around 30 to 35 mph
- 25-30
- 25-45 mph

Question: What plowing equipment/size(s) are used (both OGFC & DG)? (4 responses)

- 10-14'
- We use multiple combinations of different manufacture steel blades.
- Single axle and tandem plow trucks.
- Primarily 12 ft plows on tandem axle trucks. Usually with wing. Tow plows in some districts.

Question: Has your agency noted any increased damage to OGFC surfaces as compared to DG surfaces due to normal plowing operations?

Yes - 3 Responses

No - 0 Responses

N/A - 3 Responses

Question: Is the frequency of plowing increased for OGFC as compared to DG surfaces? (i.e., increased plowing for OGFC due to "white" or "snowy" appearance).

No - 4 Responses

Yes - 0 Responses

Question: Which anti-icing agents does your agency use for OGFC surfaces? DG surfaces? (5 responses)

- N/A, Salt/Salt Brine, Salt brine mixed with geomelt.
- Brine
- Salt Brine and Liquid Mag Chloride
- Sodium chloride - early application not anti-icing and liquids (NaCl and MgCl2)
- Same for all pavements: rock salt, fine graded salt, salt brine, magnesium chloride brine.
- Anti-icing is done on a fairly limited basis.

<u>Question:</u> What is the rate of application of these anti-icing agents for OGFC surfaces? DG surfaces? (5 responses)

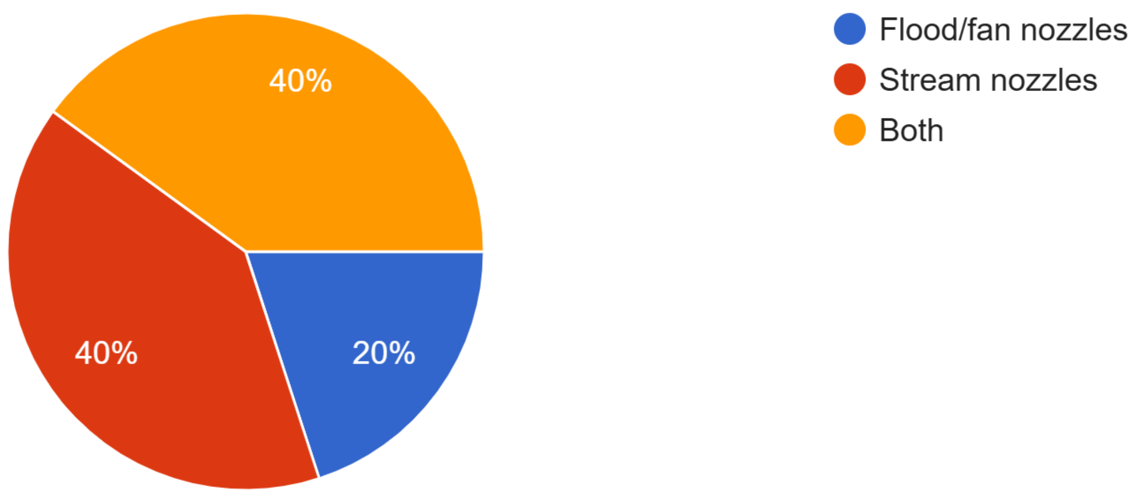
- N/A
- 60 gplm
- 30 to 60 gallon/lane Mile
- N/A- don't perform anti-icing
- Same for all pavements: application rates vary with type of precipitation, temperature, traffic levels, level of service goals.

<u>Question:</u> Are sand or abrasives used by your agency on OGFC surfaces? DG surfaces?

No - 2 Responses

Yes - 4 Responses

<u>Question:</u> When applying liquid anti-icing, which nozzle type do use? (5 responses)



Question: **Larger-grain solid salt is recommended to avoid having salt in the voids of OGFC surfaces. Is larger-grain salt utilized by your agency for this specific purpose?**

No - 3 Responses

Yes - 1 Responses

Question: **What types of deicers are used by your agency (both OGFC & DG)?**

- N/A, same as antiicing
- Brine, Salt, Mag Chloride
- Granular salt
- NaCl
- Same for all pavements: rock salt, fine graded salt, salt brine, magnesium chloride brine.

Question: **What is the application rate of deicers before and during a winter storm for OGFC surfaces? For DG surfaces?**

- NA
- 200-500 lb/LM
- Same for all pavements: application rates vary with type of precipitation, temperature, traffic levels, level of service goals.

Question: **If salt is used as a deicer, is it prewetted or dry?**

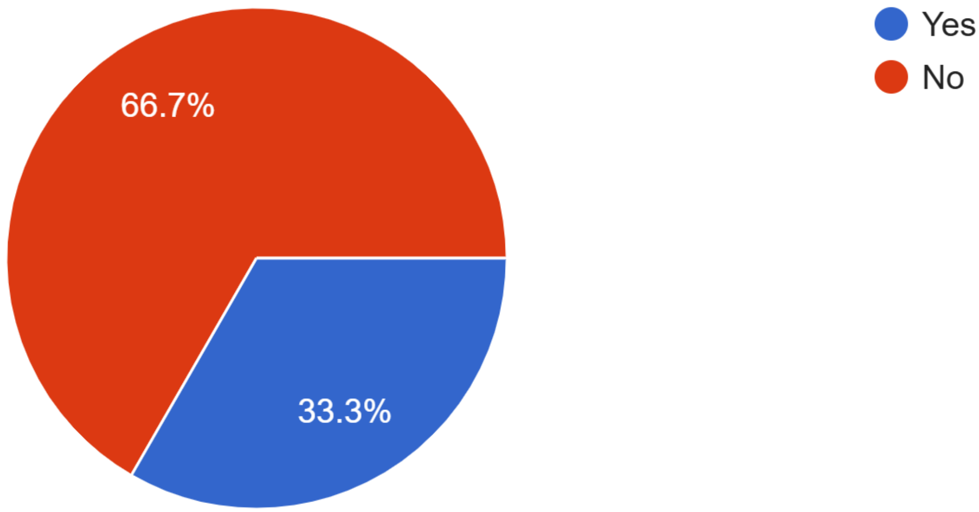
- Prewet
- Dry
- Both
- Both prewetted and dry
- Prewetted
- Prewetted

Question: **Larger-grain solid salt is recommended to avoid having salt in the voids of OGFC surfaces. Is larger-grain salt utilized by your agency for this specific purpose?**

No - 3 Responses

Yes - 1 Responses

<u>Question:</u> Are slurry spreaders used? (6 responses)



<u>Question:</u> Has your agency conducted skid and braking friction tests periodically to measure friction when snow is trapped in the voids of OGFC surfaces to ensure deicers aren't over-applied just because they appear "white" or "snowy" ?

No - 5 Responses

Yes - 1 Response [How often? – "As the crew drives on road."]

<u>Question:</u> Has your agency noted that older OGFC pavements (which may have clogged voids due to sand, grit, etc., from in-service use) ice or frost more quickly than newer OGFC pavements?

No - 3 Responses

Yes - 1 Response

<u>Question:</u> When snow melts, OGFC surfaces appear wetter for longer than DG surfaces. Has your agency conducted any surface friction tests in this scenario?

No - 5 Responses

Yes - 0 Response

<u>Question:</u> Relative to DG surfaces, has there been an increase or decrease in total crashes for OGFC surfaces?

No responses were received to this question.

<u>Question:</u> How many years after OGFC is in-service is the first maintenance conducted?

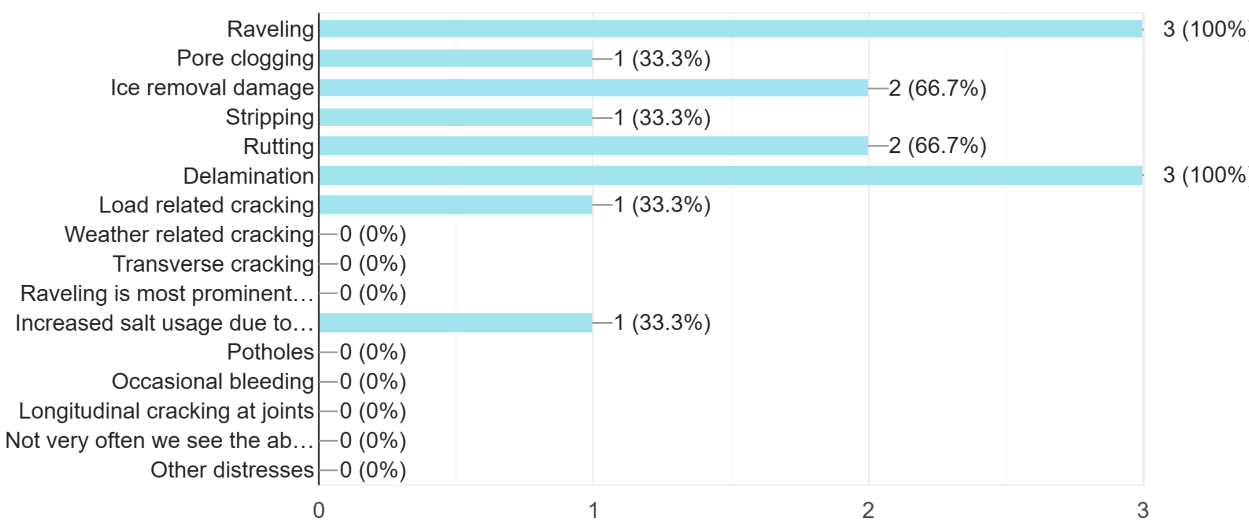
<3 Years - 0 Responses

3-5 Years - 0 Responses

6-8 Years - 2 Responses

>9 Years - 0 Responses

<u>Question:</u> What distresses do you encounter with OGFC? (3 responses)



<u>Question:</u> What measures are taken to deal with pore clogging? (3 responses)