Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Combining Specific Heat of Concrete and Actuator Placement Optimization for Self-Powered Ice-Melting Precast Concrete Bridge Panels
#UI-24-EP-01

Quarterly Progress Report
For the performance period ending *[Insert date]*

Submitted by:
Ann C. Sychterz, asycher@illinois.edu
Assistant Professor, Department of Civil and Environmental Engineering
Faculty Affiliate, Department of Mechanical Science and Engineering
University of Illinois Urbana-Champaign

Collaborators / Partners:
Jacob Henschen, jhensche@illinois.edu
Assistant Teaching Professor, Department of Civil and Environmental Engineering
University of Illinois Urbana-Champaign

Submitted to:
TRANS-IPIC UTC
University of Illinois Urbana-Champaign
Urbana, IL

TRANS-IPIC Quarterly Progress Report (Section 1 – 7, 5 pages max.):

Project Description:

1. Research Plan - Statement of Problem
   Pavement deicing represents a substantial cost to every municipality and a danger to motorists. These dangers are more significant on bridge decks due to the lack of ground insulation and the fact that concrete, commonly used on bridge decks, readily freezes from exposure and requires a substantial amount of heating energy to prevent freezing. These factors are the main contributors to why heated concrete pavements have not been feasible in the past.

Figure 1. Motivation for the proposed work, (WSB Radio, 2024)

2. Research Plan - Summary of Project Activities (Tasks)
   The objectives of this proposed work are to (1) interrogate the specific heat of concrete formulations incorporating alternative embedded elements (2) model the thermal transfer properties of the various materials, and (3) compare the experimental and modeled thermal properties to determine the optimum combination of constituents.

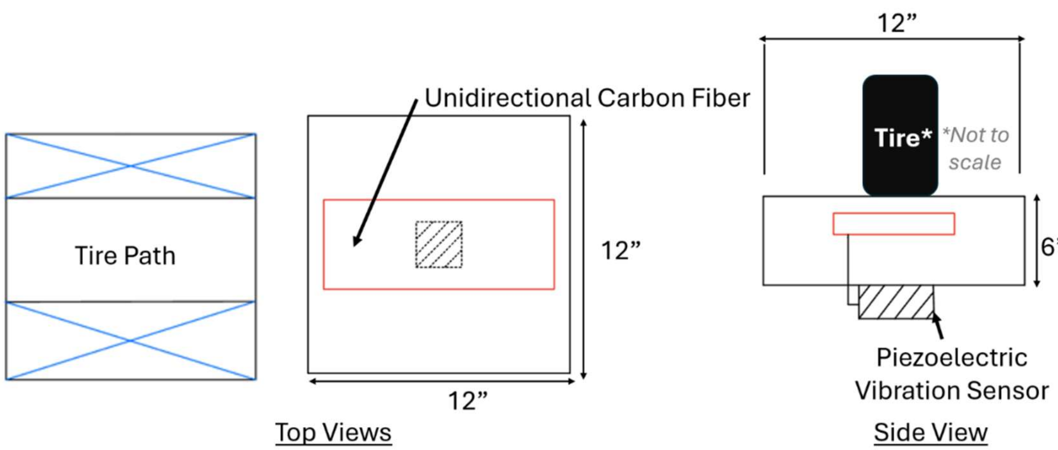

Figure 2. Schematic of the Working Self-Powered De-Icing Concrete Specimen

Project Progress:

3. Progress for each research task
   Task 1: Specific heat of concrete formulations – 70% complete
   Task 2: Develop heat generation system for de-icing – 60% complete
   Task 3: Test protype and compared with target results – 30% complete

4. Percent of research project completed

Task 1 – Concrete for optimizing specific heat [70% complete to date]

In this task, the research team has explored several strategies to lower the specific heat properties of concrete specimens. These trials have included the use of metallic fibers, low w/cm formulations, and the use of mineral admixtures. The test matrix has included a range of these variables to determine which aspect is the most significant and if there is an interactions with these mixture parameters.

The next phase of testing will include measurements of specific heat. A semi-adiabatic calorimeter designed for concrete will be used to assess the specific heat. Alternate measurement methods will also be explored to verify these results since there is not an accepted standard to measure specific heat of concrete. Based on the results from this testing, an optimal mixture will be selected to embed the heating element and energy-harvesting system being developed in Task 2.

Task 2 - Energy Harvesting System [60% complete to date]

At this stage of the project, the team is working on printing and laser cutting the housing/mounts for the piezoelectric sensors. A CAD model of the housing and mounts assembly is shown in Figure 3.

Two piezoelectric harvesters are at the same distance, and one is further back. A magnet will be attached to a connecting beam between the two piezoelectric harvesters at the same level and another magnet will be attached to the singular harvester to maximize deflections. The mounts holding the piezoelectric harvesters were designed with angled braces to keep one end of the

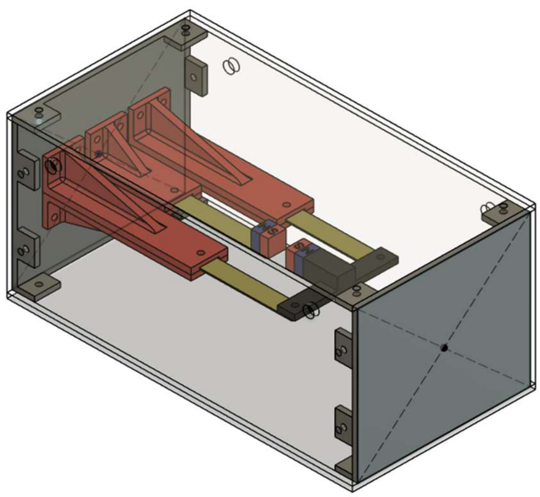

Figure 3. CAD model of piezoelectric mounts and housing

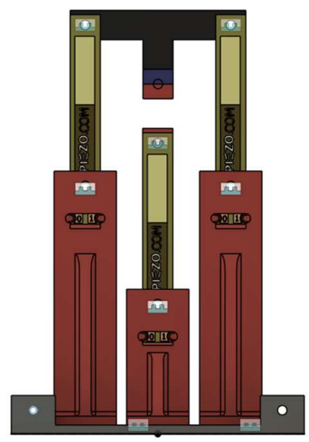

Figure 4. CAD model of piezoelectric mounts underside

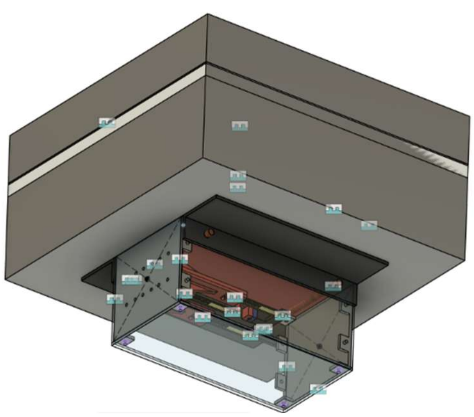

Figure 5. CAD model of the piezoelectric housing box attached to underside of concrete with dowels

Figure 6. Piezoelectric harvesters in the mounts

harvester still while the other end deflects. The underside of the mounts has an opening for the wires of the piezoelectric harvesters to exit and reach the bread board as seen in Figure 4. The box will be connected to the bottom side of the 12” x 12” x 6” concrete slab using dowels. Two angle brackets will be attached to the underside of the concrete slab with epoxy and the box will fit between these two brackets shown in Figure 5. This method was utilized due to this being a proof-of-concept model allowing us to easily remove the box during testing. We opted to make the box out of separate pieces attached by screws and nuts to allow us to access the inside. Preliminary soldering and testing have been done to ensure the piezoelectric harvesters are generating current and printing tolerances as shown in Figure 6. Two wires were soldered to the piezoelectric to later connect to a breadboard circuit. The next step would be to print all the pieces of the box and assemble it with the piezoelectric harvesters in the mounts. Then, connect the sensors to the circuit and heat generation to measure how much energy it will generate.

Task 2.1 - Circuit Construction [80% complete to date]

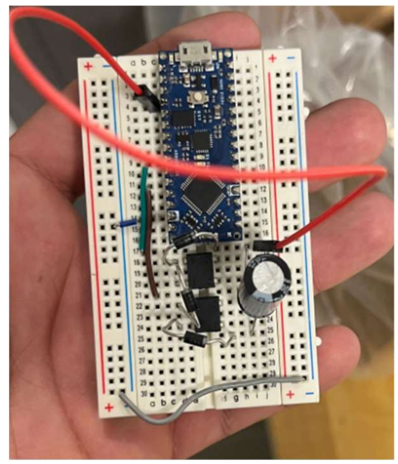

Figure 7. AC to DC circuit

An Arduino circuit is being built and tested to convert the AC current generated from the energy harvesters into DC current which will power the system’s heating element. The circuit utilizes two full bridge rectifiers, three diodes, and a 100μF capacitor as shown in Figure 7. The two outermost piezoelectric harvesters will be connected in parallel to one of the bridge rectifiers, while the inner harvester is connected to the other bridge rectifier. The full bridge rectifiers serve to convert the AC current generated when the harvesters vibrate into DC current. Then three diodes are placed in series on the DC side of the bridge rectifiers to ensure that the current only flows into the capacitor. The 100μF is in place to “smoothen” the DC voltage output that the system’s heating element will receive. To continuously measure and record the output voltage generated, the capacitor’s anode is connected to an analog pin of an Arduino Nano Every. At the time of this report the circuit has only been tested preliminarily with only one energy harvester connected. Before the proper data collection of the system’s capabilities can begin, the housing and mounting of the harvesters must be completed. Once those two aspects are completed, we will be implementing the use of a shaker table at different frequencies to replicate the conditions expected when a bridge undergoes vibration.

Task 2.2 - Heat Generation System [40% complete to date]

The heat generation subsystem is currently in the testing phase. Inspired by relevant literature reviews, the materials that are being tested are a unidirectional carbon fiber (CF) plate, a woven CF fabric, calcium silicate plate, and copper slabs. Additionally, we received a woven carbon fiber mat from the materials lab on campus to alternatively test the developed system. The initial design involved aligning the copper slabs and CF plate in an electrical circuit allowing for the system to heat up to around 80°C. To maximize heat transfer towards the surface of the concrete, the CF plate was placed on top of an insulating calcium silicate plate. This system was to be imbedded two inches below the surface of the concrete allowing for the heat to be conducted upwards to the surface of the concrete. A schematic and CAD model for this subsystem can be found in Figure 8. respectively. Preliminary testing showed that this configuration wasn’t performing as expected.

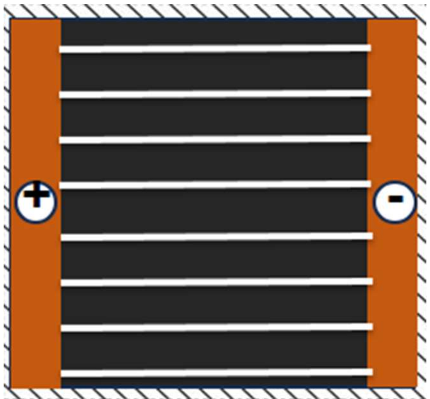

Figure 8. Unidirectional Carbon Fiber Schematic

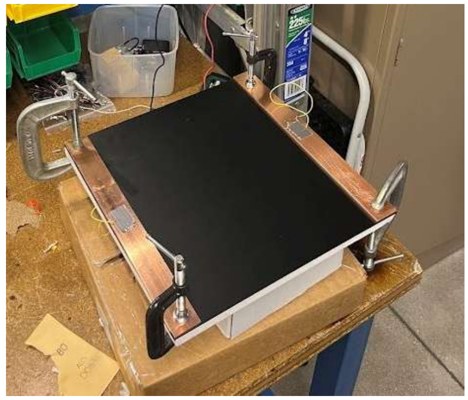

Figure 9. Unidirectional Carbon Fiber Plate Testing Setup

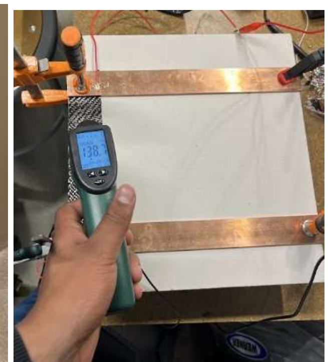

Figure 10. Carbon Fiber Fabric Testing Setup

Task 3 – Prototype Testing [30% complete to date]
Instead of the carbon fiber plate heating up via joule heating, only the copper was heating up when connected to power, Figure 9. The system started at around 23°C. After 40 minutes of connecting the system to 30W of power, the copper increased to around 32°C while the CF plate only heated up to around 25°C. It is believed that this is due to the purchased carbon fiber plate having too low of a resistance, allowing current to pass through without yielding a noticeable heat output. Alternative testing on a carbon fiber woven fabric has shown to perform better than the plate Figure 10. Based on initial testing with a small portion of fabric, the carbon fiber increased from around 23°C to over 100°C in less than two minutes powered by approximately 30W. The temperature difference will likely decrease as we increase the surface area of the carbon fiber fabric, but these initial tests bode confidence in this setup. The carbon fiber weave has proven to be good for testing purposes but there are some concerns with its durability, especially when setting the concrete. Research is currently being conducted to find alternative materials that provide similar resistive properties. The focus for this sub-team is to continue collecting data with the CF fabric setup and explore more durable materials with similar electrothermal properties. Once a final heat generation setup is determined, the subsystem will be embedded within the concrete ready for final testing. For a video of the working energy harvesting experimental testing as seen in Figure 11, please visit this link: https://drive.google.com/file/d/1iPPTXITOQAOHGUVTbwe65NzRHeAwxA2_/view?usp=sharing

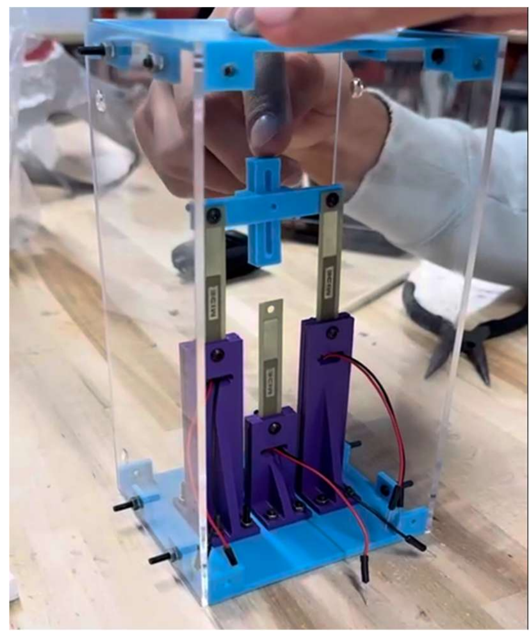

Figure 11: Experimental Piezoelectric Energy Harvesting Device

5. Expected progress for next quarter
   The casting of two specimens will be cast in the concrete lab with the embedded carbon fiber system based on an optimal specific heat formulation. Over the course of the next seven

weeks, the ME470 team will continue to test all subsystems, gather data, and construct a proof-of-concept prototype of the research outlined in this report. The goal is to have tangible power data that is output by the energy harvesting subsystem, and power requirements and de-icing times for the heat generation subsystem. This project is on track to be completed for May 2025.

6. Educational outreach and workforce development
   Since the start of this project in January 2025, no outreach has been conducted. However, it is planned to have student outreach through the Department of Civil and Environmental Engineering for Prof. Sychterz to use the working de-icing prototype for the high school camp over the summer.

7. Technology Transfer
   No new patents or technology transfers have been initiated yet. However, this will be reinvestigated following the completion of the ME 470 Mechanical Engineering Student Design team working prototype demonstration May 2025.

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:
   Hummad, Khuzaima and Sychterz, Ann "Smart Precast Concrete System for Self-Powered Ice Melt", ASME Smart Materials, Adaptive Structures, and Intelligent Systems (SMASIS) 2025, St. Louis, MO, September 2025.

9. Presentations and Posters of TRANS-IPIC funded research:
   Sychterz, A and Henschen J "Smart Precast Concrete System for Adaptive Camber and Ice-Melt", American Concrete Institute Spring 2025, Toronto, Canada.

10. Please list any other events or activities that highlights the work of TRANS-IPIC occurring at your university (please include any pictures or figures you may have). Similarly, please list any references to TRANS-IPIC in the news or interviews from your research.
    The University of Illinois had a strong representation at the Transportation Research Board 2025 conference in Washington, DC. The University of Illinois Urbana-Champaign will be a leader in the projects presented at the TRANS-IPIC UTC 2025 workshop April 22-23 Rosemont IL. Dr. Andrawes, Director of TRANS-IPIC made a great research progress on use of Shape Memory Alloys (SMA) for a large-scale precast prestressed concrete bridge deck system https://www.linkedin.com/feed/update/urn:li:activity:7284761499862999040/.

Appendix 1: Research Activities, leadership, and awards (cumulative, since the start of the project)

A. Number of presentations at academic and industry conferences and workshops of UTC findings
   - No. = 3

B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
   - No. = 3

C. Number of peer-reviewed journal articles published by faculty.
   - No. = 0

D. Number of peer-reviewed conference papers published by faculty.
   - No. = 1

E. Number of TRANS-IPIC sponsored thesis or dissertations at the MS and PhD levels.
   - No. MS thesis = 0
   - No. PhD dissertations = 1
   - No. citations of each of the above = 1

F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
   - Research Tool #1 (Name, description, and link to tool) = Magnetic vibration piezoelectric energy harvesting device
   - Research Tool #2 (Name, description, and link to tool) = Carbon fiber copper sandwich embedded heating device. This acts as part of the circuit
   - Research Tool #3 (Name, description, and link to tool) =

G. Number of transportation-related professional and service organization committees that TRANS-IPIC faculty researchers participate in or lead.
   - Professional societies
     - No. participated in = 7 (ASCE Engineering Mechanics Institute, American Concrete Institute, American Institute for Steel Construction, ASCE Structural Engineering Institute, International Association for Shell and Spatial Structures, Structural Engineering Association of Illinois, American Society for Mechanical Engineers)
     - No. lead = 0
   - Advisory committees (No. participated in & No. led)
     - No. participated in = 0
     - No. lead = 0
   - Conference Organizing Committees (No. participated in & No. led)
     - No. participated in = 2
     - No. lead = 2 (Illinois Structural Engineering Conference, ASCE Structures Congress)
   - Editorial board of journals (No. participated in & No. led)
     - No. participated in =2
     - No. lead = 0
   - TRB committees (No. participated in & No. led)
     - No. participated in = 0
     - No. lead = 0

H. Number of relevant awards received during the grant year
   - No. awards received = 1

I. Number of transportation related classes developed or modified as a result of TRANS-IPIC funding.
   - No. Undergraduate = 0
   - No. Graduate = 1 (contents of CEE 467 Masonry Structures included self-powered de-icing lecture)

J. Number of internships and full-time positions secured in the industry and government during the grant year.
   - No. of internships = 0
   - No. of full-time positions = 0

References:

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