Self-Heating Electrically Conductive Concrete Demonstration Project

tech transfer summary

This project demonstrated a full-scale field implementation of an electrically conductive concrete heated pavement system as an improvement or an alternative to conventional snow removal operations by constructing 10 test slabs with different electrode design configurations.

October 2021

RESEARCH PROJECT TITLE

Self-Heating Electrically Conductive Concrete Demonstration Project

SPONSORS

Iowa Highway Research Board (IHRB Project TR-724)

Iowa Department of Transportation (InTrans Project 17-610)

PRINCIPAL INVESTIGATOR

Halil Ceylan, Director
Program for Sustainable Pavement Engineering and Research (PROSPER)
Institute for Transportation
Iowa State University
515-294-8051 / hceylan@iastate.edu
(orcid.org/0000-0003-1133-0366)

CO-PRINCIPAL INVESTIGATORS

Sunghwan Kim, PROSPER Associate Director
(orcid.org/0000-0002-1239-2350)

Peter Taylor, Director
National Concrete Pavement Technology Center, Iowa State University
(orcid.org/0000-0002-4030-1727)

Mani Mina, Associate Professor
Industrial Design and Electrical and Computer Engineering, Iowa State University
(orcid.org/0000-0002-1500-9492)

RESEARCH ASSISTANTS

Amir Malakooti, Sajed Sadati, and Wei Shen Theh

MORE INFORMATION

intrans.iastate.edu

PROSPER, Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-3230

The Program for Sustainable Pavement Engineering and Research (PROSPER) is part of the Institute for Transportation (InTrans) at Iowa State University. The overall goal of PROSPER is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems.

IOWA STATE UNIVERSITY

Institute for Transportation

Objective and Goals

The primary objective of this research was to construct, demonstrate, and monitor a full-scale field implementation of the largest-to-date operational, electrically conductive concrete (ECON) heated pavement system (HPS) using different electrode configurations. The goals of the project included the following:

- Develop a cost-effective methodology for producing ECON for snow and ice removal applications on Iowa pavements
- Gain an understanding of ECON and its properties
- Better understand the challenges and issues with full-scale implementation of an ECON HPS
- Evaluate the thermal and energy performance of different design configurations under real winter conditions

Problem Statement

Transportation agencies at all levels are always in search of innovative, implementable, and cost-effective solutions to address winter pavement maintenance. Considering the economic implications of even partially shut-down bridges, roadways, and highways due to snow and ice accumulation, combined with the negative environmental impacts of applying deicing salts to pavement surfaces during these events, agencies face a critical need for an improvement or an alternative to snow and ice removal technology that is dependable, fast, cost-effective, and has minimal impact on the environment.

Background

Snow and ice removal are expensive components in winter road maintenance for the Iowa Department of Transportation (DOT) as well as counties and cities in Iowa. The Iowa DOT, alone, is responsible for snow and ice removal on more than 9,000 miles (14,000 km) of Iowa highways, uses approximately 900 snowplow trucks, and uses approximately 200,000 tons (181,000 metric tons) of rock salt each year to make and spread brine and salt to treat and help remove snow and ice from Iowa roadways for traveler mobility and safety.

One promising option being explored as an improvement to current snow and ice removal practices for pavement systems is a self-heating pavement system. An ECON HPS utilizes the inherent electrical resistance of concrete to maintain the pavement surface at above-freezing temperatures and thus prevent snow and ice accumulation on the surface.

Such a sustainable concrete pavement system improves its infrastructure resiliency by allowing it to be safe, open, and accessible during even harsh winter storms.

A number of studies have investigated the prospect of developing an ECON by adding conductive materials (e.g., fibers, powders, and solid particles) to conventional concrete. These studies have established, at least at the proof-of-concept level, that an ECON has several innovative applications such as electrical heating for deicing of bridges, sidewalks, and pavements; sensing and monitoring; and electromagnetic interference shielding.

Research Description

1. The research team conducted a comprehensive literature review on concrete heated pavement technologies as well as studies on the previous successful full-scale implementation of innovative pavement technologies.

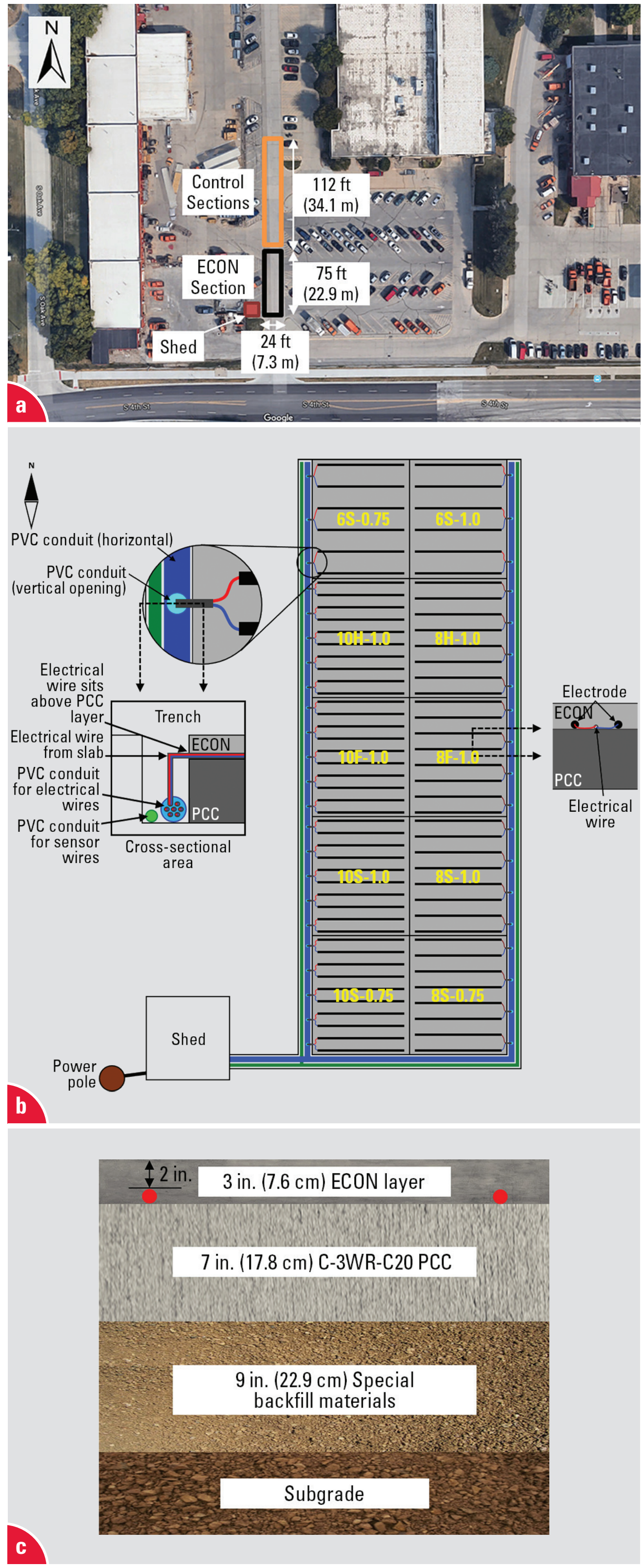
2. The project team conducted several laboratory investigations related to ECON technology prior to the full-scale demonstration. These experiments included the following:
   a. The team used water tests—as a quick, nondestructive, and cost-effective method—to study the effects of different electrode sizes and geometries on thermal performance.
   b. Using the results from those tests, the researchers developed finite element (FE) models to further predict electrical and thermal performance of different electrodes.
   c. The team also evaluated mechanical, electrical, and thermal properties of different electrodes in ECON prototype test slabs

3. While analytical studies have been investigated on ECON heated pavement systems, some aspects of heated ECON pavement construction can only be investigated through analytical and numerical modeling because experimental studies to investigate these issues are cost-prohibitive. Thereby, the research team pursued thermal and electrical performance prediction using conventional FE analysis modeling tools.

4. Given that optimization of ECON mix design to achieve high conductivity and at the same time maintain adequate mechanical properties (workability, strength, and durability) is a challenging task, the team developed a modified ECON mix design and tested the ECON mechanical, electrical, and thermal properties.

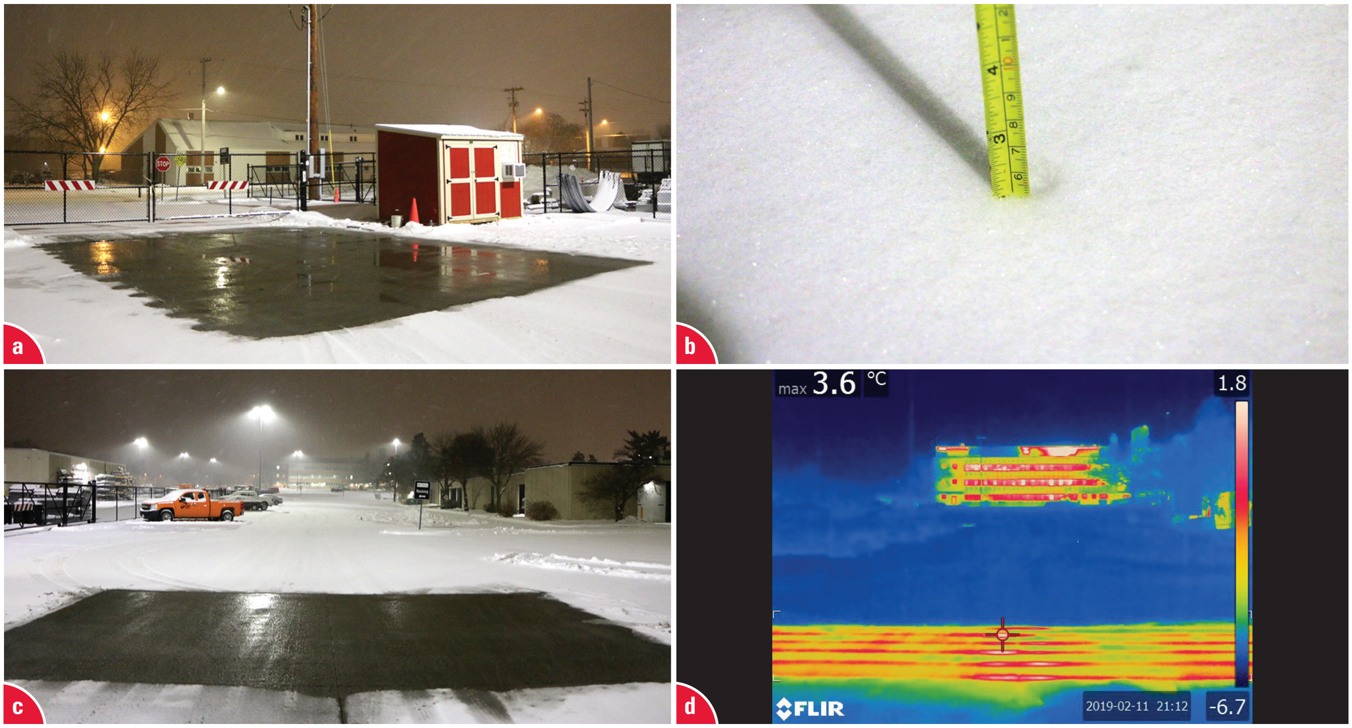
5. The ECON HPS field demonstration was located in the south parking lot of the Iowa DOT headquarters in Ames, Iowa, during October 2018. As part of a reconstruction project, 10 ECON HPS test slabs were constructed. Each of the 10 ECON HPS slabs had different electrode configurations with different spacings, sizes, and shapes to evaluate their effect on energy and thermal performance.

6. The overall performance of the ECON HPS test slabs was monitored during the 2018–2021 winter seasons using embedded sensors and thermography to evaluate different design configuration performance during real-world snow and ice events in Iowa.



ECON HPS test site: (a) construction location, (b) plan view, and (c) cross-section view

ECON HPS construction steps: (a) place C-3WR-C20 portland cement concrete (PCC), (b) screed PCC layer, (c) install electrodes, (d) place polyvinyl chloride (PVC) conduit, (e) clean the surface, (f) connect electrical wires to the electrodes, (g) place and compact ECON layer with vibrating screed, and (h) spray curing compound on surface



ECON HPS heating performance: (a) southside slab performance, (b) 2 in. (5 cm) of snow accumulation on surrounding slabs, (c) northside slab performance, and (d) infrared thermography

Key Findings

Pavement Findings

- Ten ECON HPS test slabs with different electrode configurations were constructed. All the test slabs showed promising snow- and ice-free capabilities through various winter weather events.
- The power density range for all the slabs was between 10.2 W/ft^2 (109.8 W/m^2) and 45.7 W/ft^2 (491.5 W/m^2), with an average of 24.6 W/ft^2 (265.1 W/m^2).
- The falling weight deflectometer test showed that the average heated pavement deflections were about 10% lower than that of the regular concrete pavement slabs, which indicates that the heated slabs are stiffer with a higher modulus.
- The best operation practice of heated pavements is to turn the system on before the snow event starts. Therefore, the snow accumulation will not occur, and the operation time and consequently the operation cost will decrease.
- A theoretical formulation was developed to describe ECON HPS thermal behavior.

Electrode Findings

- Testing electrodes in water for monitoring temperature increase rate is a faster, repeatable, nondestructive, and cost-effective method for identifying favorable electrode sizes and comparing electrode performance for use in an ECON HPS.
- Based on the theory, the laboratory studies, and the FE models, the temperature increase rate of an electrode is influenced by its surface contact area (perimeter).
- Considering the initial costs of the electrodes, flat bar and smaller diameter electrodes were found to be more cost-effective than the larger electrodes due to the lower cost of smaller sized electrodes relative to the temperature increase rate associated with them.
- An increase in electrode size resulted in an increase in energy conversion efficiency.

Operational Findings

- A programmable logic controller (PLC) system was designed, programmed, and implemented in the construction, and it showed a promising and robust remote-control system that can be used with ECON HPS technology.
- Using multiple voltages with the PLC device gave ECON HPS users control over snow and ice melting speed.

Implementation Readiness and Benefits

This project successfully demonstrated a full-scale implementation of an ECON HPS, which could spur interest in further projects using this technology in other critical areas of Iowa transportation infrastructure systems. The findings of this study will facilitate the design of ECON heated pavement systems and provide detailed information on the construction steps.

An ECON HPS is expected to result in expedited, efficient, and cost-effective snow removal operations that can reduce traffic delays and costs as well as prevent traffic safety issues (death and injury), pavement damage, vehicle repairs, and environmental contamination (resulting from the use of large quantities of deicer salts) in the future.

The versatility of the ECON HPS technology demonstrated in this study is such that it can eventually be custom-designed and optimized for each specific transportation infrastructure application depending on need and interest. This versatility stems from the fact that the ECON HPS technology can be implemented as either a conductive concrete surface for a new construction project or a conductive concrete overlay on top of an existing structure for a rehabilitation project.

Recommendations for Future Demonstrations

The ECON HPS design requirements and considerations are somewhat different for each specific application, warranting detailed research investigations before being fully implemented in each situation. The following prioritized application areas, and the rationale for their prioritization, are recommended for future ECON HPS studies and implementation:

- **Bridge decks**
  - Bridges are the first locations in a highway system to freeze during the winter season. Thin layers of black ice and frost form on top of the bridge deck, potentially resulting in vehicles sliding off the bridge and causing fatal crashes. Many highway agencies dedicate portions of their winter maintenance budget for deicing these locations (so-called frost-runs) to mitigate this hazard. Entrance and exit ramps in the highway system are also potential winter hazards, due to higher vehicle speeds and potential for sliding off the ramps.
  - Given these frost-run operations are typically on bridges located over a body of water, which results in a direct chloride load into the stream/water system, heated-bridge technology can mitigate direct chloride load into nearby water bodies.
  - During this study, several agencies, such as those in Iowa and Wisconsin, have expressed strong interest in implementation of heated-bridge technology.
- **Rest areas**
  - Rest areas, specifically in interstate highway systems, experience high foot traffic throughout the year, and they are typically located in areas that are not easily accessible to winter maintenance crews to clear the snow and ice in a timely manner.
  - ECON HPS technology is in full compliance with the Americans with Disabilities Act (ADA) mission to ease the commute of individuals with disabilities, especially during the winter season. Based on data from the U.S. Bureau of Labor Statistics, about 25% of snow- and ice-related falls occur in parking lots. In addition, this technology will mitigate the slip and fall hazard due to refreeze of melted snow, specifically in parking lots. Snow and ice can cause significant hardship for individuals with disabilities, and implementing heated pavement on ADA-compliant parking lots and ramps could be a way to help mitigate this hardship. In addition, the Iowa DOT receives dedicated funding for ADA compliance projects that can be used to further implement ECON HPS technology, facilitating the contribution of people with disabilities to our society.

Reference

Malakooti, A., W. S. Theh, S. Sadati, H. Ceylan, S. Kim, M. Mina, K. Cetin, and P. C. Taylor. 2020. Design and Full-Scale Implementation of the Largest Operational Electrically Conductive Concrete Heated Pavement System. *Construction and Building Materials*, Vol. 255, Article no. 119229, pp. 1–11.