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Construction Techniques for Electrically Conductive Heated Pavement Systems

Hesham Abdualla
Iowa State University, abdualla@iastate.edu

Halil Ceylan
Iowa State University, hceylan@iastate.edu

Kristen S. Cetin
Iowa State University, kcetin@iastate.edu

Sunghwan Kim
Iowa State University, sunghwan@iastate.edu

Peter C. Taylor
Iowa State University, ptaylor@iastate.edu

See next page for additional authors

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Abstract

Ice and snow accumulation on airport paved surfaces has the potential to cause fatal accidents and monetary loss due to flight delays and cancellations. Traditional de-icing methods involving the application of chemicals or salt and employing large machines can create negative environmental and structural impact on airport infrastructure systems. These methods are also considered to be labor intensive and a safety hazard, especially in congested areas such as aprons. Heated pavement systems using electrically conductive concrete (ECON) have been proposed as a promising alternative technology for preventing ice accumulation and mitigating the adverse effects of using traditional snow removal methods. The objective of this study is to present information and experience about the design, construction procedures, and performance of heated pavement systems using jointed plain concrete pavements for the construction of large-scale heated airport pavements. It is based on detailed field demonstration of the electrically conductive concrete (ECON) heated pavement system (HPS) at the north general aviation (GA) apron of the Des Moines International Airport (DSM) in Iowa, in collaboration with contractors, and airport staff representatives. The expected outcome of this study will help the construction industry to better understand optimal ECON construction methods.

Disciplines

Civil and Environmental Engineering | Construction Engineering and Management | Electrical and Computer Engineering | Transportation Engineering

Comments

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Authors

Hesham Abdualla, Halil Ceylan, Kristen S. Cetin, Sunghwan Kim, Peter C. Taylor, Mani Mina, Bora Cetin, Kasthurirangan Gopalakrishnan, and Sajed Sadati

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Hesham Abdualla[1], Halil Ceylan[2], Kristen S. Cetin[3], Sunghwan Kim[4], Peter C. Taylor[5], Mani Mina[6], Bora Cetin[7], Kasthurirangan Gopalakrishnan[8], and Sajed Sadati[9]

[1]Graduate Research Candidate, Department of Civil, Construction and Environmental Engineering (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-708-4327; email: abdualla@iastate.edu
[2]Professor, (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-294-8051; Fax: 515-294-8216; email: hceylan@iastate.edu
[3]Assistant Professor, (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-294-8180; email: kcetin@iastate.edu (**Corresponding Author**)
[4]Research Scientist, (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-294-4698; Fax: 515-294-8216; email: sunghwan@iastate.edu
[5]Director, National Concrete Pavement Technology Center, Ames, IA 50011-8664; Phone: 515-294-9333; email: ptaylor@iastate.edu
[6]Associate Professor, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011-2522; Phone:515-294-3918; email: mmina@iastate.edu
[7]Assistant Professor, (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-294-2140; email: bcetin@iastate.edu
[8]Research Associate Professor, (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-294-3044; email: rangan@iastate.edu
[9]Graduate Research Student, (CCEE), Iowa State University, Ames, IA 50011-3232; Phone: 515-708-4327; email: ssadati@iastate.edu

ABSTRACT

Ice and snow accumulation on airport paved surfaces has the potential to cause fatal accidents and monetary loss due to flight delays and cancellations. Traditional de-icing methods involving the application of chemicals or salt and employing large machines can create negative environmental and structural impact on airport infrastructure systems. These methods are also considered to be labor intensive and a safety hazard, especially in congested areas such as aprons. Heated pavement systems using Electrically Conductive Concrete (ECON) have been proposed as a promising alternative technology for preventing ice accumulation and mitigating the adverse effects of using traditional snow removal methods. The objective of this study is to present information and experience about the design, construction procedures, and performance of heated pavement systems using jointed plain concrete pavements for the construction of large-scale heated airport pavements. It is based on detailed field demonstration of the electrically conductive concrete (ECON) heated pavement system (HPS) at the north general aviation (GA) apron of the Des Moines International Airport (DSM) in Iowa, in collaboration with contractors, and

airport staff representatives. The expected outcome of this study will help the construction industry to better understand optimal ECON construction methods.

INTRODUCTION

Background

The effects of ice and snow on airport pavement, including runways and aprons, have the potential to cause thousands of flight cancellations or delays. Moreover, snow and ice can cause hazardous conditions that can lead to airplane incidents and accidents (McCartney 2014 and Hatch et al. 2015). The use of traditional de-icing methods involving the application of chemicals or salt and employing large machines can result in negative environmental and structural impact on airport infrastructure systems and is typically costly and time-consuming (Anand et al. 2016). Such methods typically require temporary closure of airport operations and are difficult to use in congested areas (FAA 2016).

Electrically-conductive concrete (ECON) heated pavement systems are being considered as an alternative option to traditional methods because they have potential to melt ice and snow in a stipulated time frame and to overcome the drawbacks of using traditional de-icing methods (Gopalakrishnan et al. 2015; Abdualla et al. 2016; Sassani et al. 2017).

Although some previous studies have mainly focused on field implementation of ECON on bridge structures (Maggenti et al. 1996 and Tuan 2008), none of them so far have investigated systematic design and construction practices of ECON HPS for airport pavement applications.

Description of the Project

The work of this study included field demonstration of ECON HPS at the north general aviation (GA) apron of the Des Moines International Airport (DSM) in Iowa as a part of the reconstruction of this apron area. The existing concrete of the apron was removed and replaced due to being distressed. During the initial plan of the reconstruction, two ECON slabs were selected for the ECON HPS field implementation. These slabs were located near an existing power supply located approximately 4.57 m away. Each slab was 4.57 m long × 3.8 m wide × 19 cm thick. The ISU research team provided the detailed design and construction plan for the ECON HPS and was in charge of the planning, construction, and post-construction of ECON slab operations.

Purpose and Overview of the Paper

The objective of this study is to present information and lessons learned about the first field implementation of ECON HPS at a U.S. airport. This information was developed from an extensive research study, combined with the experience of researchers and stakeholders, including the Federal Aviation Administration (FAA), the airport owner, the contractors, industry representatives, and Iowa State University (ISU) researchers, performed to identify good construction practices and develop guidance for construction of ECON HPS at airports.

Scope

This paper discusses the planning, design, construction considerations, and performance of the first ECON HPS at a U.S. airport. The challenges and solutions on taking a prototype small-scale ECON heated concrete slab developed by ISU and implementing it full scale in the airport were identified and discussed with the DSM airport owner and with FAA. With support from the FAA and the airport owner, the ISU research team developed design alternatives for a selected location, carried out construction, and documented lessons learned for application to real-world implementation of ECON HPS. The heating performance and energy consumption of the constructed ECON HPS was evaluated and discussed.

PLANNING CONSIDERATIONS

To achieve a successful plan for demonstrating the performance of ECON HPS ranging from small-scale to full-scale implementation in a real airport, the ISU research team extensively communicated with the stakeholders, including the FAA, the DSM airport owner, the contractor, and industry representatives. In September 2016, a meeting among the ISU research team, the FAA, and the airport owner, was held to discuss the feasibility of implementing the ECOH HPS (Figure 1a and 1b) was held at the DSM airport. The ISU research team presented the results of this technology, based on performance of a prototype small-scale ECON heated concrete slab using a newly-developed ECON mix design for airport application that both conformed to the FAA specifications and identified the benefits of using such technology at a real airport (Abdualla et al. 2016 and Sassani et al. 2017).

Given the promising results from a set of previous ISU research studies (Abdualla et al. 2016 and Sassani et al. 2017), both the airport owner and the FAA demonstrated interest in providing their assistance and support in taking this technology developed in-house and implementing it full-scale on-site at the DSM airport. Both the airport owner and ISU research team identified the associated implementation challenges and potential solutions related to aspects such as electrical work, IT support, installation of the ECON HPS components, material selection, and operating and monitoring the ECON HPS during winter conditions.

The ISU research team also interacted with the concrete mix plant, the construction contractor (Kingston Services LLC), and the design contractors (Foth Infrastructure and Environment, LCC) regarding the reconstruction project of the GA apron area in DSM to identify design parameters of the ECON mix and preferred construction procedures at the DSM airport (Figure 1c and Figure 1d).

ISU also provided a systematic 3-D visualization of the ECON construction to facilitate the ECON construction sequence and educate the project contractors with respect to achieving the highest quality ECON construction at DSM airport.

Well-organized coordination among the airport owner, the FAA, and the contractors was of great help in facilitating the ISU research team delivering the details of the final product from start to completion, through considering and overcoming all the potential problems likely to be encountered in the construction implementation at the DSM airport and to provide detailed schedules produced from identification of the activities during the construction work critical to meeting the contractor’s project schedule.

(a) (b)

(c) (d)

Figure 1. ISU research team meeting with stakeholders: (a) ISU team meeting with airport owner, (b) field visit at the DSM project site, (c and d) ISU research team and consulting company meeting with a concrete mix plant

DESIGN CONSIDERATIONS

The reconstruction of the GA apron with new Portland cement concrete (PCC) pavements with construction joint type D was completed because the ECON slabs were to be constructed at a different time (Figure 2). The ECON HSP structures were two-layer 19-cm-thick slabs comprised of a 9-cm ECON top layer and a 10-cm P-501 PCC bottom layer, a 20.3-cm P-209 aggregate base course, and subgrade. Each ECON slab was 4.57 m long × 3.8 m wide.

A comprehensive review of FAA specifications was carried out during the design of the ECON HPS, in which the producers of the ECON, the ISU research team, identified the proper material selection, the electrode configuration system (Abdualla et al. 2017), the construction techniques, the sensors, and the remote control system and electrical power design needed to achieve satisfactory performance.

The FAA prohibits using embedded metal materials such as steel fibers or steel shavings for conductive paving materials for airport application because such materials have the potential to corrode and expose the pavement surface, leading to creation of foreign objective debris (FOD) that could damage aircrafts. To this end, the ECON mixture was developed using 1% by volume of carbon fibers in the concrete mix to eliminate such problems (Sassani et al. 2017).

The ECON slab was designed with six electrodes to support the flow of electricity in the ECON layer to generate resistance heat. The spacing of the electrodes was designed to be 1 m apart to meet the required power density that can either be numerically estimated or obtained using ASHRAE steady-state energy balance equations (ASHRAE 2015 and Abdualla et al. 2017). There was a concern with respect to selecting a proper electrode material that would eliminate any potential corrosion problems; stainless steel was selected because of its superior corrosion resistance compared to galvanized steel. Galvanized steel is manufactured by coating steel with a layer of zinc to protect it from corrosion, but the protection layer could possibly degrade or peel off because of electrochemical phenomena (Yadav et al. 2004).

A key consideration during the ECON HPS design was the use of two-lift approaches to facilitate the installation of the electrode and sensor systems prior to placing the ECON layer and to save on construction costs (Gillen et al. 2012). Temperature and strain gage sensors were used to monitor temperature and strain changes during the ECON HPS operation. A remote-control system designed to operate the ECON HPS and was connected with the electrical power supply to turn the ECON system on/off based on a chosen setpoint temperature located at 1cm below the surface. Two on-site surveillance cameras were used to remotely monitor the ECON HPS so that the ISU researchers could manually operate the ECON HPS according to actual weather conditions at the project site if needed.

The ISU research team designed and provided the required power values (i.e., voltage and current values) and electrical sensors (electric current and voltage sensors) to monitor voltage and current changes, the electrode configuration for the ECON HPS, and the PVC conduit housing the electrical and sensor wires. Electrical work required included wire connection to electrodes, circuit breakers, contactors, electrical sensors, PVC conduit, and power-panel installation. This work was completed by the airport electrical engineers with assistance of the ISU research team.

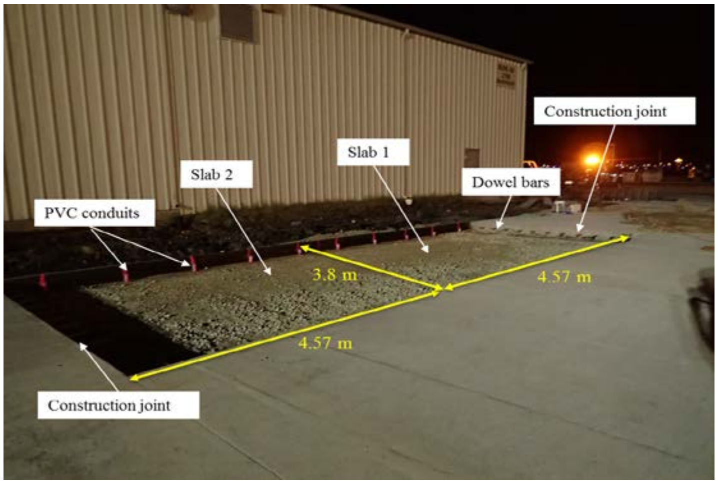


Figure 2. ECON HPS construction location at DSM

CONSTRUCTION CONSIDERATIONS

Construction of the ECON slabs at the DSM site is shown in Figure 3. In conformance with the design plan, the ECON HPS were constructed into two stages. A 10-cm P-501 PCC layer was first placed on the prepared subbase and its surface roughened using brooms to provide a sufficient bond with the ECON layer. The dowel bars of the construction joints were covered by a 10-cm P-501 PCC layer so that electrodes could be easily installed on top of the surface of the PCC layer.

Angle-shaped electrodes with 13 19 mm holes were used to provide sufficient interaction and bonding with the ECON. These electrodes were to be connected to an AC power supply to power the ECON layer. There was a concern that angle-shaped electrodes could initiate cracks because of the sharp edge of the angle shape, so alternative options were discussed, including using stainless-steel rebar or placing fiberglass rebar on top of the angle-shaped electrodes to resolve this concern. To this end, the ISU research team investigated the use of a fiberglass rebar option, and this was ultimately selected as the desired option. 6.4 mm diameter fiberglass rebar was continuously placed perpendicular to the top of the electrodes to prevent any potential cracking due to electrode shape and environmental load effects. The fiberglass rebar elements were secured using nylon cable ties and placed 38 cm apart.

A 9 cm ECON layer was placed after securing the electrode and sensor systems and verifying the wire connections to the electrodes by turning on the ECON HPS. This was followed by thorough cleaning of the electrodes and saturating the P-501 PCC layer. The mixture material properties (i.e., aggregate type and gradation, cement, etc.) were the same for both layers to minimize stress at the bond line between them (Harrington and Gary 2014). During placement of the ECON layer, care was taken to avoid damaging electrical components such as electrodes, temperature sensors, and others embedded in the ECON layer. The ISU research team was at the DSM airport site job to monitor, assist, document, and take samples of the ECON mixture for evaluating ECON properties. A vibrating truss screed was used to pave the ECON layer because the area was relatively small. Both layers – the ECON and PCC layers – were saw-cut at the joints to create a monolithic structure and ensure that both layers moved together (Harrington et al. 2007).

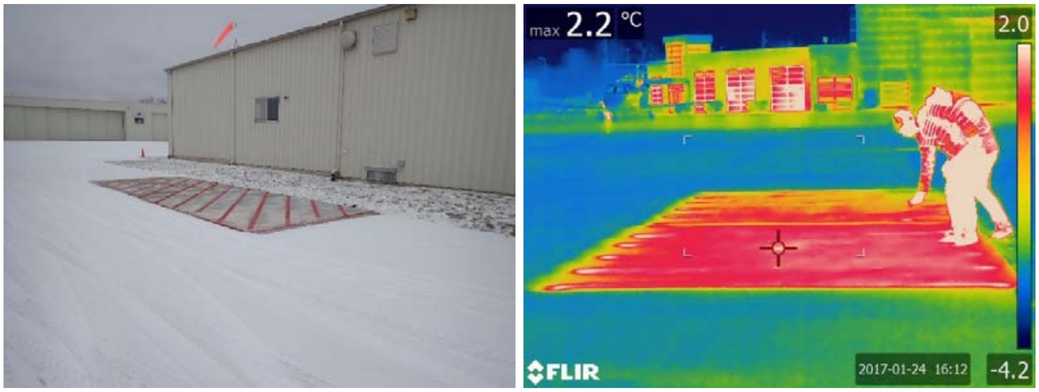
Figure 3. ECON HPS construction procedure at DSM

OTHER ISSUES TO CONSIDER

Security consideration related to accessing the ECON HPS site was discussed with the airport owner so that members of the ISU research team would be permitted to enter secure areas. With the airport owner's assistance, the ISU research team representatives acquired permission badges for accessing the job site at assigned gates. Each badge holder could escort other research team members and ensure that all individuals being escorted remained under control at all times. Use of such badges provided great benefits and allowed the ISU research team to monitor and document the ECON slab HPS during cold weather conditions or snowfall events.

PERFORMANCE

Figure 4 illustrates the performance of the ECON slabs. The ECON HSP was tested on December 10, 2016 (Figure 4a) for its capability to prevent snow and ice accumulation on the ECON slabs. The ECON HPS was turned on before the snowfall event, and began to increase the surface temperature to above the freezing point, to a level of 2-4 ^{o}C, to sufficiently melt snow that touched the slab surface, while 3 cm of snow was allowed to accumulate on the remaining area of the apron. The ECON HPS was equipped with electrical sensors – both current and voltage – to evaluate the energy consumption of the slabs. An AC voltage of 210 V was applied to the ECON slabs through the embedded electrodes and the current flowing into the ECON layer was measured during its time of operation. The energy density and consumption required to melt a thickness of 3 cm of snow were 330 W/m^2 and 2.3 kWh/m^2. An infrared (IR) thermographic camera was used to capture the heat distribution (Figure 4b) of the ECON surface during January 2017. The IR images, taken on different days depending on the availability of the IR camera, exhibited even heat distribution throughout the ECON slabs.



(a) (b)

Figure 4 ECON HPS performance results at DSM: (a) ECON performance result in December 10, 2016, (b) infrared thermographic image results in January 01, 2017

SUMMARY AND RECOMMENDATIONS

Summary

The goal of this study was to identify and document the useful information and experiences related to the first field implementation of an ECON HPS at a US airport (constructed at the north general aviation apron at DSM airport). Such information, gained through a comprehensive study and communication with stakeholders, can establish the best design and construction practices to help the construction industry in improving heated pavement specifications for airport applications.

Lessons Learned

While the two-lift paving technique was the best approach for constructing ECON slabs, it was challenging to achieve wet-on-wet paving because electrode installation required extra time for anchoring on the bottom lift that should be stiff to support the electrodes. For mass paving of ECON materials, slip-form or laser-screed paving would be the best option for enhancing the construction process. Proper selection of materials for ECON HPS components, including ECON mixture and electrodes, can enhance the performance and increase the service life of ECON HPS. For example, galvanized steel was not recommended for use in electrodes because the coated material (i.e. zinc) protecting the steel from corrosion could eventually degrade and peel off when applying electrical power. With regard to the ECON mixture, steel fibers or shavings were avoided in the ECON mix for airport application due to the potential corrosion problems.

The ECON system prevented ice and snow accumulation on the ECON surface slabs since the ECON surface was heated in advance before snowfall began. The time required to heat the ECON surface above freezing point (i.e., 1~2 ^{o}C) is highly dependent on the weather condition such as ambient temperature, wind speed, etc. and it can be estimated from data-driven models using historical experimental data, or through physics-based thermodynamic models such as finite element (FE) model simulation. The use of on-site surveillance cameras were to monitor the ECON slab site to better operate and control the ECON system. The energy consumption of the ECON HPS which prevented 3 cm thick snow accumulation on the surface over 7 hours was 2.3 kWh/m^2. This provides a promising cost-effective and environment solution in comparison to the use de-icing chemical agents and employing heavy machinery.

Recommendations for Future Phases and Research Directions

In the next step of this study, the ISU research team will continue to investigate the performance of ECON slabs during upcoming snow events to evaluate ECON slab efficiency and to obtain historical performance data. The authors will also investigate the performance of stainless steel rebar for electrode application when compared to angle-shaped electrodes with respect to bonding with the ECON layer, size effects, and heating efficiency, The expected benefit of using rebar as electrode will mitigate the problem associated with potential cracking that may occur when angle-shaped electrodes are used.

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