Reduce Bridge Icing by Improving the Bridges' Surface Thermal Emissivity.

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Abstract

Bridge icing is a major safety concern. In cold climates, bridge decks usually reach the freezing temperature before the adjacent roads. This "preferential icing" increases the possibility of cars having accidents over bridges. The objective of this research is to decrease preferential icing over bridges. This research investigates optimizing the bridge's surface thermal properties in order to keep the bridge deck surface temperature from reaching the freezing point before the adjacent roads. Field data and thermal transfer simulations were used to investigate the effect of surface reflectancy, moisture transfer and wind on the freezing of bridges and roads. First, the Energy-Plus computer simulation model was used to simulate a typical bridge and road structure in a relatively cold climate. These computer simulation models were validated with field readings. Then, different surface properties of the concrete bridge deck were tested and integrated to match the freezing cycle of the bridge deck with the adjacent road surface.

This research has shown that reducing reflectancy and emissivity of the bridge deck surface would reduce the freezing cycle of the bridge deck. This research also concluded that optimizing the surface properties and the exposure of bridges' decks should lower the traffic accidents due to preferential icing (icing of bridge surface before adjacent roads).

Introduction

Travel is hazardous during periods of snow, sleet and freezing rain. Perhaps the greatest danger is the occurrence of preferential icing of bridges, where bridge decks become icy and slick while adjacent roadways remain clear. Some drivers crossing iced bridges lose control of their vehicles. Single or multiple vehicle accidents often result. The risk of mishap is worse when other non-ideal conditions exist such as low visibility conditions especially during bridge/roadway maintenance operations. Minimizing bridge deck icing is a high priority.

By far, the most common mitigation method for bridge deck icing is the applications of salt, sand or other gritty material. Salt applied to a bridge deck prior to icing can prevent preferential icing. However, salt and sand are usually spread only after ice has already formed on a bridge deck. Money is wasted if salt or sand is distributed too early and later found unnecessary.
A second method to mitigate bridge icing is a heating system installed in the bridge deck. This method prevents icing without the disadvantages salting or sanding the bridge deck. Bridge deck

heating systems may use either embedded electric resistance wire or embedded hydronic tubing. Bridge deck heating systems using embedded electric resistance wire method tend to be extremely expensive to operate [1].

A third method to prevent bridge icing is the application of "phase-change thermal energy storage" to delay the onset of ice formation on pavement systems. An example of this method involves adding tetradecane paraphin to the concrete mix. This additive enhances the thermal storage capacity of the concrete, and minimizes the surface heat loss by maintaining the exposed surface only slightly above the freezing temperature of water [2].

A fourth method of preventing ice forming on bridge decks is installing sophisticated defrosting spray systems. These systems use a defrosting agent. Results can be monitored using infra-red cameras and heat censors. However, this system is also expensive and requires extensive maintenance.

Little research has been done to investigate the holistic mechanism of heat and moisture transfer in bridge decks taking into consideration thermal transfer, thermal storage, weather exposure, solar radiation and evaporative cooling. The combination of these factors has a significant effect on the freezing of bridge decks. Furthermore, some researchers suggest that bridge freezing occurs more frequently than adjacent roads because the bridge deck does not have the ground heat source that the adjacent roads have. However, the lack of ground heat source was not the only significant factor that contributes to differential icing of the bridge decks. For example, urethane foam is used to insulate the bottom of bridges' decks. This technique was tested in Missouri and Nebraska. These tests showed that insulating the bottom of bridges was not effective in reducing freeze/ thaw cycles in bridge decks, and the salt usage was same as in the un-insulated deck [3].

Several design and construction elements significantly contribute to bridge freezing. The following are some of these elements:

1. Bridge location: bridges which are constructed over rivers or valleys are usually more exposed to draft than the adjacent roads, and the bridges which span over intersections are also exposed more than the adjacent roads supported by the ground. This exposure increases convection heat loss from the bridge surfaces. Furthermore, since bridges are usually free standing structures, bridge surfaces face the black sky during the night. This exposure increases the heat loss due to higher long wave emittance from bridge surfaces including the bridge deck. Adjacent roadways however, are usually more protected by the surrounding hills, buildings or trees.

2. Bridge deck surface properties: many bridge decks are composed of reinforced concrete slab over steel beams. The white concrete has a solar reflectancy of 72.8%, and a heat transmittance of .9 [4] This surface property, the light color, is considered one of the best surface treatments for reducing solar gain during the day and emitting heat during the night. Thus, the white concrete reduces bridge surface temperatures significantly during the night. Furthermore, concrete has relatively high moisture and water transfer rates

when compared to asphalt on adjacent roadways. This moisture transfer property also contributes to heat loss from the bridge deck due to evaporative cooling.

Previous research thoroughly investigated appropriate use of surface emissivity to modify heat gain or loss. Most of this research focused on building surfaces. For example, a study showed that in hot climates, changing the roof emissivity from 0.9 (emissivity of most nonmetallic surfaces) to 0.25 (emissivity of fresh and shiny metallic surfaces) can result in a net 10% increase in annual utility bills. In cold climates with no summertime cooling, the heating energy savings resulting from decreasing the roof emissivity can be up to 3% [5].

Research Scope

This research addressed the mitigation of preferential icing over bridges by improving the thermal characteristics of bridge surfaces and reducing the draught effect.

In major storms, ice forms over both roads and bridge decks. In these cases preventing ice formation only on bridges will not reduce risk, since the adjacent roadways will still be covered with ice. Preferential icing on bridges represents a greater risk, that is when ice is formed on bridge decks while adjacent roadways are still ice free. Therefore, research should target the freezing cycles in which the bridge deck surface temperature reaches the freezing point before the adjacent streets.

To maintain the bridge surface temperature equal or above the adjacent road temperature, this research studied the effects of using commercially available durable low-emissivity materials on bridge decks. These materials have a high temperature tolerance, low emissivity, excellent adhesion, UV resistance, flexibility and weather-durability [6]. Lab tests showed that such materials can reduce the emissivity of the white concrete to .37 and has a diffused reflectance of 0.66 [6].

Research methodology

Field monitoring and computer simulation were used to monitor the ice formation on bridge decks, and test the proposed passive bridge icing prevention techniques.

First; a field data recording system was installed on an existing bridge in Virginia which experienced winter icing. Field data collected included bridge surface temperature, air temperature, precipitation, and wind velocity. A data logger was connected to thermocouples which were secured on the bridge deck as well as the adjacent roadway surface. These thermocouples measured the temperature of the bridge deck and the adjacent road surfaces. Other thermocouples measured air temperature in the vicinity of the bridge. A precipitation censor and a wind velocity censor were also installed and connected to the data logger. Field data were collected for an entire winter season. Secondly, a statistical analysis was performed to predict the relationship between air temperature, precipitation, and wind speed as independent variables, and the bridge freezing as the dependent variable.

Second; the bridge and road construction were simulated using Energy Plus. Energy Plus is the official Department of Energy building energy simulation program for modeling heat transfer, solar radiation gain and loss, moisture transfer, draft effect on heat gain and loss from building envelop, and other energy flows. It is based on the most popular features and capabilities of BLAST and DOE-2 simulation software. The simulation was used to predict the bridge surface temperature during the winter season. The weather data of Roanoke city in Virginia was used for the simulation. Roanoke is a mountainous area which has a relatively cold climate in winter and moderate climate in summer. The simulation results were synchronized and validated with the field data collected on the test bridge.

Third; low heat emissivity materials were applied on the bridge deck surface. The simulated bridge surface temperature and the actual bridge deck surface temperature under the new surface properties were analyzed and compared.

Results

During the winter season, the actual freezing cycle conditions on the bridge deck and the adjacent roadway surface were as follows:

The amount of time the surface of the road adjacent to the bridge was at or below the freezing point was 1010 hours. The amount of time the surface of the white concrete bridge deck reached the freezing point was 1509 hours. These results suggest that the bridge surface is frozen 499 hours more than the adjacent road. As discussed early, the preferential icing is the major problem in bridge icing. So, if we manage to reduce the bridge surface freezing hours to match the adjacent roads freezing hours, then we might reduce the number of the car accidents resulting from preferential icing.

After applying the commercially available a low- emissivity treatment (0.37emissivity and 0.66 reflectancy) onto the bridge deck, the bridge surface was frozen for only 940 hours. These results show that the freezing time of the bridge deck was reduced by 38% when the low-emissivity treatment was used. The bridge was also frozen 70 hours (or 7%) less than the adjacent roadway surfaces. Thus, the bridge surface was frozen for less time than the adjacent roadway, indicating that there was a reduction in preferential icing problems on the bridge. When considering the potential surface treatment (paint) quality deterioration over time, the computer simulation results still show that a bridge surface with a residual emissivity of 0.5, and a solar reflectancy of 0.58 will freeze less frequently than the adjacent roadway surfaces (Figure 1, 2, 3).

A careful look at the simulation results showed that the ground temperature under the adjacent roadway is not the most significant factor in the bridge/road freezing as is widely believed. The daily temperature fluctuation of the roadway surface and the bridge deck surface was significant, and the heat transfer from the ground below the road to the road surface is marginal as shown in (Figure 4).

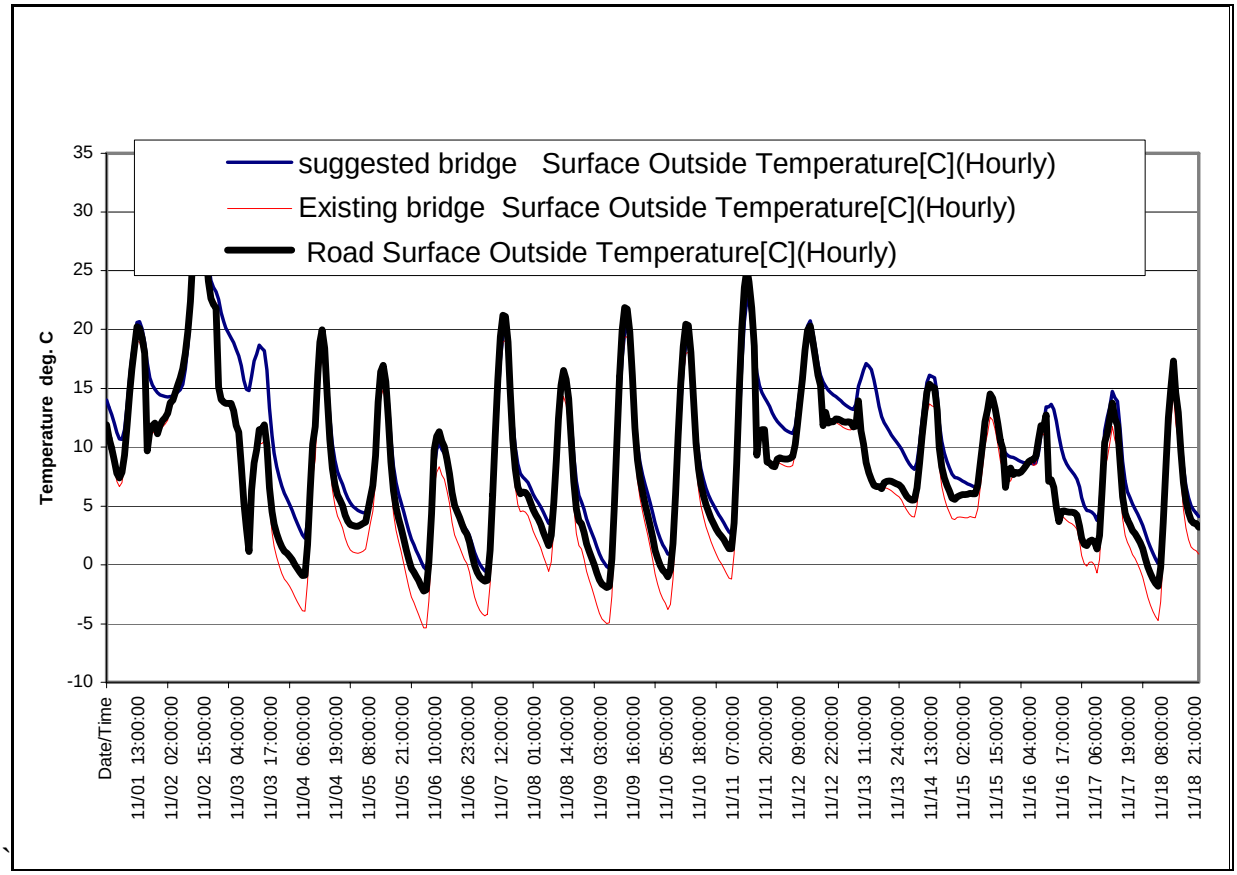

Figure 1. Comparison Between Existing Bridge Performance, Suggested Bridge Performance, and the Adjacent Road.

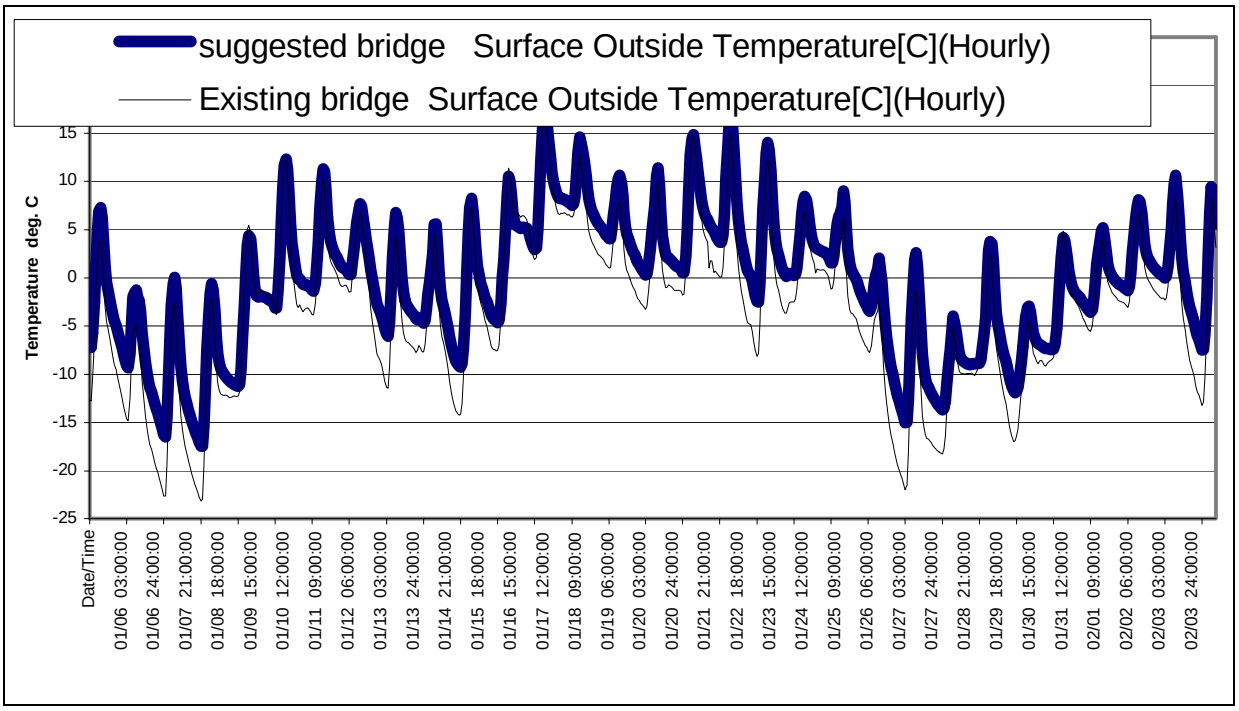

Figure 2. A Comparison Between Existing Bridge Performance, and the Suggested Bridge Performance

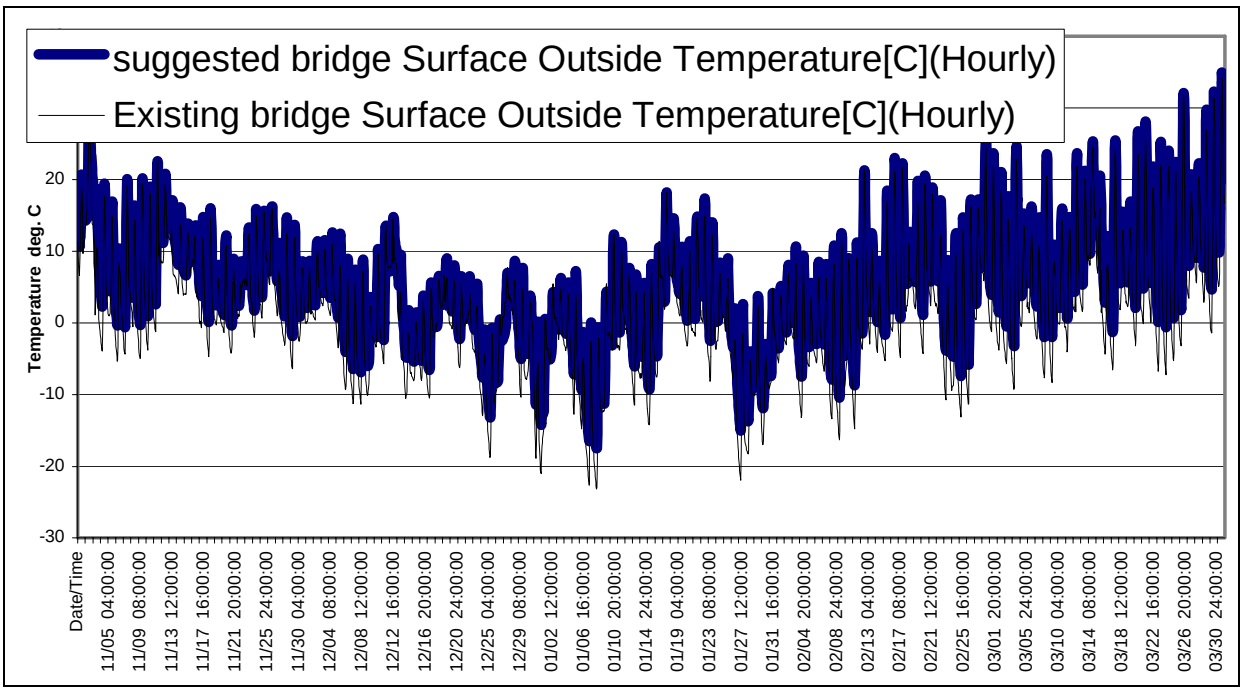

Figure 3. Overall Existing Bridge Performance and the Suggested Bridge Performance during the winter season.

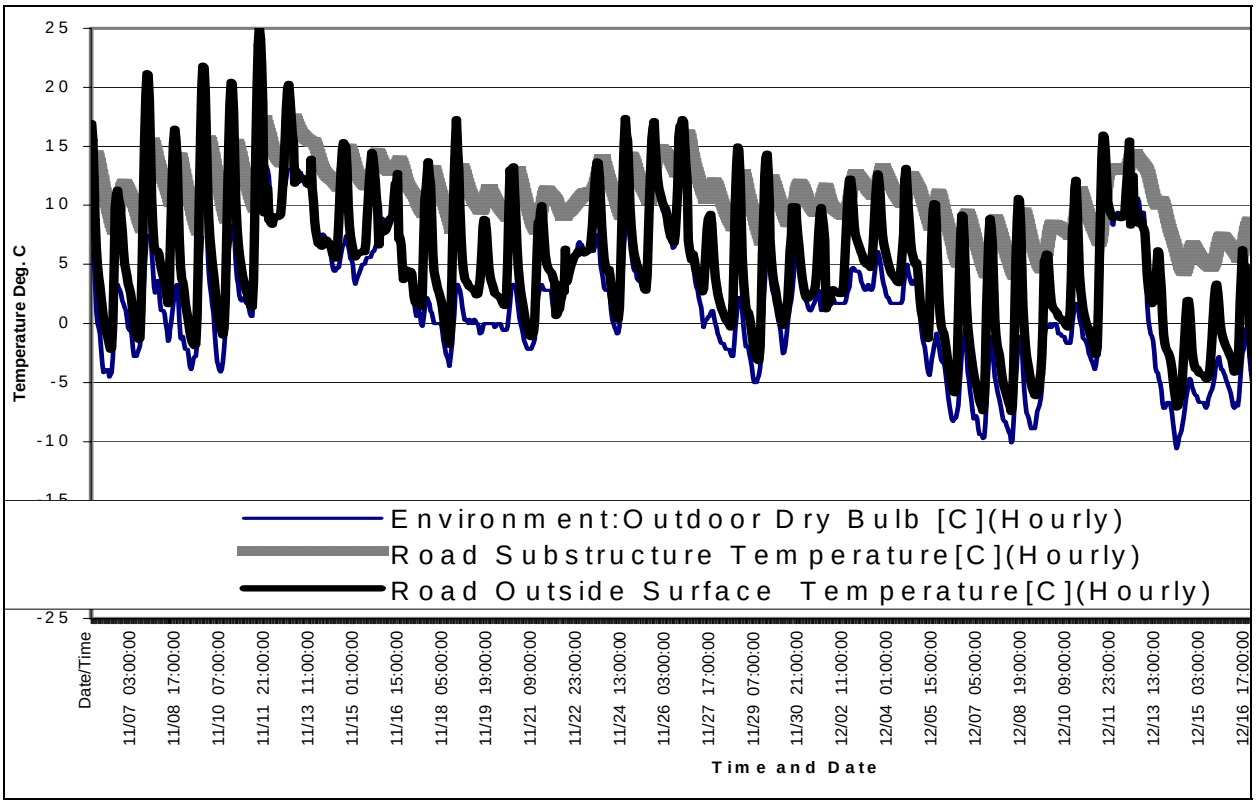

Figure 4. The Relationship Between Su-grade Temperature, Road Surface Temperature and Outside Air Temperature.

Conclusions

This research suggests a passive solution to prevent differential icing of bridge deck surfaces vis-à-vis adjacent roadway surfaces by changing the bridge surface emissivity. The research results proved that applying low- emissivity paint on the concrete surface of bridges can decrease hazardous bridge icing. The discussed icing prevention method does not require high-tech solutions, excessive running cost, extensive maintenance, or high initial installation cost. The proposed ice prevention method reduces the amount of resources required to salt and sand bridges, thereby decreasing bridge maintenance costs, as well as reduce the impact of bridge maintenance on the environment. Most of all, the proposed solution will save the lives of many people every year due to the reduction of car accidents resulting from preferential icing.

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Biography

DR. HUSSEIN ABAZA is currently an Assistant Professor at the Department of Construction Management at East Carolina University. He is an internationally recognized in heat and moisture transfer analysis and simulation. Dr. Abaza has over 16 years of experience in design and construction of energy efficient buildings. Dr. Abaza's work was featured in several TV programs.

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