Peer-reviewed Conference Contribution

Design a geothermal bridge deicing system for an in-service bridge

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Deicing on bridge deck surfaces is essential to ensure the safety and mobility of motorists during severe winter weather. Conventional snow/ice removal chemicals such as salt cause bridge corrosion and provoke environmental issues. Therefore, a new external geothermal heating system for bridge deck deicing and snow melting has been proposed, which can be installed onto in-service bridges. Conventional hydronic heating systems are developed based on the hydronic loops embedded inside bridge decks in the construction phase and have been studied by different research groups [1–3]. However, there is a greater need for deicing the in-service bridges. Therefore, an external heating system has been developed by attaching the hydronic loops to the bridge deck's bottom surface, which is usually covered completely with insulation materials such as geofoam, spray foam, and fiberglass [4]. To provide access to the bottom surface of the bridge deck for bridge inspection, a new external-geothermal hydronic heating panel system has been developed in this study.

Studies on geothermal bridge heating systems mainly focused on energy analysis of the existing systems, thermal effects of control logic, and the development of models to simulate bridge heating systems neglecting the piping network. This study presents the design of a bridge external heating system for an in-service bridge located in the Dallas/Fort Worth Metroplex in North Texas, USA, to maintain high heating efficiency. The geothermal deicing system includes geothermal heat pumps, ground loops, and bridge loops. The required heat flux on the bridge deck surface to prevent ice formation is calculated based on the local weather data to determine the number of heat pumps. According to the total heating load determined from the design heat flux, geothermal water-to-water heat pumps are sized given the ground temperature profile and thermal conductivity test results. The pipe network is designed based on the target flow rate and standard parameters for pipe materials using Taco Hydronic System Solutions software. Figure 1 illustrates the heating system's schematics. Only one bridge span is shown in the figure. One bridge span includes four heating panels with a 6-inch gap between each panel as the access for bridge inspection. The control room hosts heat pumps, flow centers, manifolds, control, and monitoring instrumentation. The ground loop arrays are not shown in the figure.

The deicing system design procedure consists of three phases: (1) selection of design weather condtions based on historical weather data, (2) calculation of the required heat flux on the bridge surface, and (3) sizing of ground loop heat exchangers (GHEs). The final design decisions stem from the integrations of the three phases. First, design weather conditions are selected based on realistic winter storm scenarios. Second, the required heat flux, 80 Btu/hr.ft2, on the bridge deck surface to prevent ice/snow formation is determined by considering previous design values, historical winter storms, and heat flux calculations by ASHRAE [5]. Lastly, based on the required heat flux, the GLHEs are sized using the design software GLHEPRo developed by Spitler et al. [6]. Inputs to the model, including the heating loads, the thermal recharge rates, a description of the ground thermal properties, a description of the borehole geometry, the fluid physical and thermal properties, and a description of the heat pump, are summarized in Table 1. The ground thermal properties are determined based on field thermal response tests. A 30% propylene glycol solution is specified as the heat transfer fluid. A borehole diameter of 15.24 cm, an HDPE single U-tube with a nominal diameter of 3.18 cm, and thermally enhanced grout are also specified.

DOI: https://doi.org/10.59490/seg23.2023.547

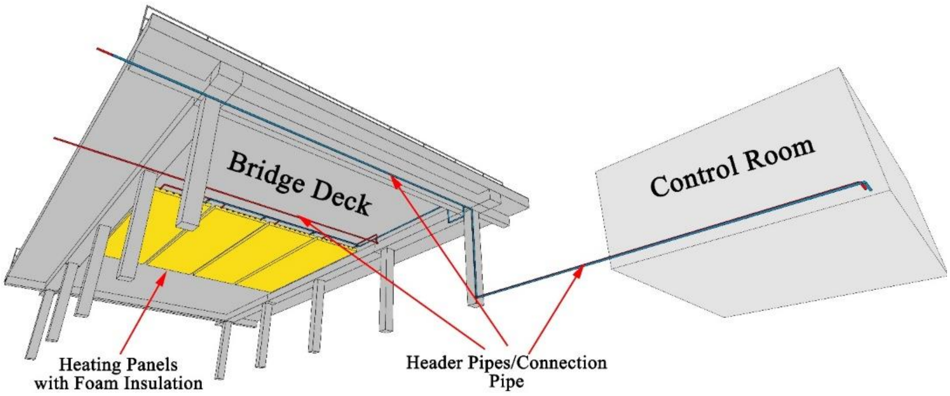

Figure 1: Schematics of the geothermal bridge deicing system.

Aside from heating system design, pipe network design is critical to maintaining the target flow rate for every pipe branch. Therefore, pipe hydraulics is analyzed for pressure loss to ensure sufficient head pressure for the entire pipe network. This study evaluated piping network design based on target pressure loss and common design parameters such as pipe materials and installation types. The pipe network design results show that the final system consists of 4 heat pumps and 10 water pumps. Combinations of pipes in parallel and series are arranged for efficiency and operational safety. The heat pumps are designed to supply fluid to the bridge deck at approximately 38 ℃ with a total flow rate of 302.8 l/min. The borehole field configuration selected consists of 16 boreholes, each 91.5 m deep and a design flow rate of 18.92 l/min. The borehole field will supply fluid to the heat pumps at a minimum temperature of 18 ℃. The geothermal bridge deicing system is currently being installed onto the bridge and is expected to be completed by the summer of 2023.

Table 1. Summary of heating system design parameters.

Flat Slab Bridge Information				
Number of Lanes	Number of Spans	Deck Area (m^2)	Exposed Bottom Surface Area (m^2)	Bridge Deck Thickness (cm)
4	8	891.9	803.6	46.7
Required Heat Flux and Heating Load				
Required Heat Flux (W/m^2)	Heated Area (m^2)	Peak Heating (Kw/h)	Monthly Snow/Ice Hours (h)	Total Monthly Heating (kW)
252.4	401.8	101.4	20	2028
GLHE Design Parameters				
Minimum Entry Water Temp. (℃)	Ground Temp. (℃)	Flow Regime	k_{grout} (W/(m·K))	k_{soil} (W/(m·K))
10	21.4	Turbulent	2	1.7
Final Recommended Size of GLHE				
Number of Bore-holes	Depth of Each Bore-hole (m)	Borehole diame-ter (cm)	Single-U pipe Diameter (cm)	Header Pipe Diameter (cm)
16	91.5	15.24	3.18	5.08
Pipe Network Design				
4 water-to-water Heat Pumps	Max Flow Rate (l/min)	Pumps	Flow Rate for each GLHE (l/min)	Flow Rate for each Heat Pump (l/min)
7.5 Ton	302.8	10	19	75.7

Acknowledgments

The authors appreciate the financial support of this study from the Texas Department of Transportation (TxDOT) and the support from the research program manager Shelley Pridgen.

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