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Heated Bridge Deck Construction and Operation in Lincoln, Nebraska

Construction et exploitation d'un tablier de pont chauffé à Lincoln, Nebraska

Beheizte Brückenfahrbahnplatte in Lincoln, Nebraska, USA

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SUMMARY

The construction and operation of a hydronic bridge/pavement deck heating system are described in this paper. The system is installed in the deck of a 367 m-long by 3.7 m-wide viaduct in Lincoln, Nebraska, USA. The system was monitored and performance evaluated for 12 months following installation.

RÉSUMÉ

Le document décrit le mode de construction et le fonctionnement d'un système de chauffage par circulation de fluide caloporteur pour le tablier d'un pont de 367 mètres de long par 3,7 mètres de large, qui se trouve à Lincoln, dans le Nebraska aux États-Unis. Le système est décrit; il a fait l'objet d'un suivi et d'une évaluation du rendement pendant les 12 mois qui ont suivi l'installation.

ZUSAMMENFASSUNG

Diese Veröffentlichung beschreibt den Bau und Betrieb einer Warmwasserheizung für das Pflaster einer Brückenfahrbahnplatte. Die Anlage ist in das Deck einer 367 m langen und 3,7 m breiten Überführung in Lincoln, Nebraska, eingebaut. Das System wird beschrieben. Die Anlage wurde nach dem Einbau über 12 Monate überwacht und die Betriebsdaten analysiert.

1. INTRODUCTION

Winter conditions impose difficult bridge deck maintenance problems, particularly in areas like Lincoln, in southeastern Nebraska, which has a normal annual snowfall of 881 mm. The maximum recorded snowfall for 24 hours is 264 mm and occurred in 1957. Between October 17 and April 20 each year, 185 days have an average temperature below 273°K *(1)*.

A new 367-m-long elevated pedestrian viaduct (Fig. 1) was constructed in 1992 over several railroad beds. Special Federal funding was available to install heated decks under an Intermodal Surface Transportation Efficiency Act of 1991 program; this deck was eligible and was a particularly attractive candidate because of its central location, heavy bicycle use, and potential use by the physically impaired.

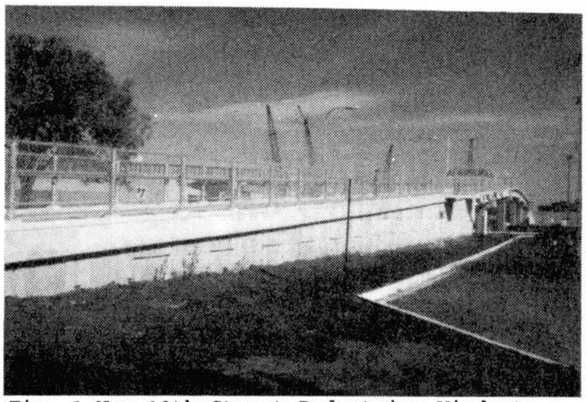


Fig. 1 New 10th Street Pedestrian Viaduct

The structure is a 5-span, 169.8-m-long precast-prestressed-post-tensioned concrete superstructure with an 165-mm-thick by 3.7-m-wide cast-in-place deck. The approaches, supported on mechanically stabilized earth (MSE), are 70.7-m- and 126.5-m-long and have 5 percent grade. The total top surface areas of the south approach, elevated structure, and north approach are 289 m^2, 696 m^2, and 614 m^2, respectively. The highest deck is 8.8 m above the boiler.

2. SYSTEM DESCRIPTION AND COMPONENTS

The hydronic deck heating system was manufactured by Delta-Therm Corporation®. A natural gas boiler heats a propylene glycol and water solution that is pumped on cue through hoses encased in the deck and warms the concrete deck enough to melt snow and ice. The heating system was installed from end-to-end of the viaduct, including approaches. Table 1 lists the major components.

• *Boiler Building*--4.6-m by 7.6-m prefabricated concrete, housing boiler and controls.
• *Hydronic Boiler*--Hamilton Engineering HE-3111 natural gas multitube hot water boiler, 908 kW input and 732 kW output.
• *Pumps*--Three Taco "1600" Series pumps with 1207 kPa operating pressure at maximum 422°K.
• *Polyvinyl Chloride (PVC) Distribution Line*--579 m of 152-mm-diameter Schedule 40.
• *Copper Distribution and Collection Manifold*--One of each at each of the 13 heating zones.
• *Heat Distribution Hose*--13.5 km of Delta-Therm 10-mm-diameter flexible hydronic hose.
• *Expansion Tanks*--802 L total volume.
• *PVC Collection Line*--579 m of 152-mm-diameter Schedule 40.
• *Heat Transfer Fluid*--21 kL, 35% propylene glycol/water, with corrosion inhibiter package.
• *Snow Sensing System*--Delta-Therm SMC 120A snow sensing system, including two deck surface heated moisture sensors and ambient air temperature sensor.

Table 1 Major Components of Heating System

The viaduct is divided into 13 heating zones, each about 121 m^2. The propylene glycol and water solution is heated to 327°K and pumped through the system under a pressure of about 207 kPa. The solution moves from the boiler into the 152 mm-diameter polyvinyl chloride (PVC) pipe for distribution to heating zones. PVC distribution and collection pipes are diagrammed in Fig. 2.

PVC pipes are buried in sand on approaches and supported on hangers under the elevated structure. The coefficient of expansion for the concrete superstructure is 0.0000108/°K; for the PVC pipe, 0.000052/°K. Providing for PVC pipe expansion was a primary consideration because there was potentially 343-mm total movement at each abutment in the PVC. A flexible expansion loop (Fig. 3.) is installed in each PVC near each abutment to accommodate expansion of both the concrete superstructure and the PVC. Each PVC pipe is enclosed in 51-mm-thick fiber-glass insulation beneath the elevated structure. PVC is not insulated in approaches. A PVC bridge pipe and valves, also displayed in Fig. 3, were installed near each abutment to enable shutting off the solution to and from abutment areas.

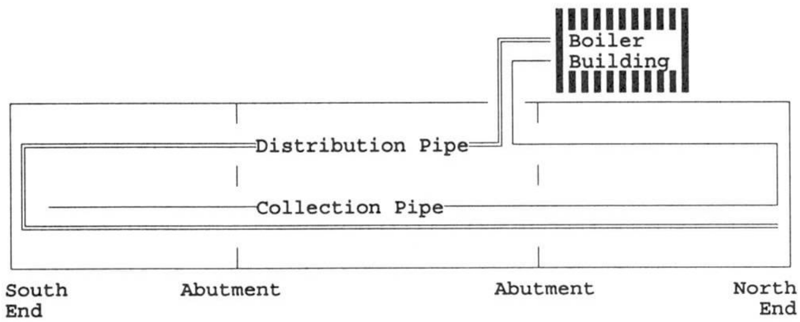


Fig. 2 Distribution/collection Network Schematic

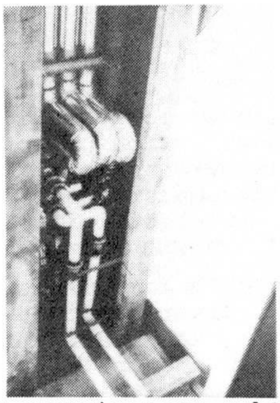


Fig. 3 PVC Expansion Loops and Valves Near Abutments

The boiler and controls are housed in a 4.6-m- x 7.6-m-prefabricated boiler building (Fig. 4) positioned adjacent to the north MSE abutment wall. The boiler was installed before the roof and can be removed through the service doors.

At each heating zone, solution is transferred in a 25-mm-diameter flexible plastic hose from the PVC distribution line to a copper distribution manifold (Fig. 5). The manifold distributes the solution to 10-mm-diameter hydronic rubber hoses spaced at about 114-mm centers within the concrete. These hoses run parallel from the distribution manifold to the extreme boundary of the heating zone and back to the collection manifold (Fig. 6), which is located adjacent to the distribution manifold (Fig. 5). The solution is then transported from the collection manifold to the PVC collection line in a 25-mm-diameter flexible plastic hose. Finally, the solution is returned to the boiler, where it is reheated and recycled (Fig. 7).

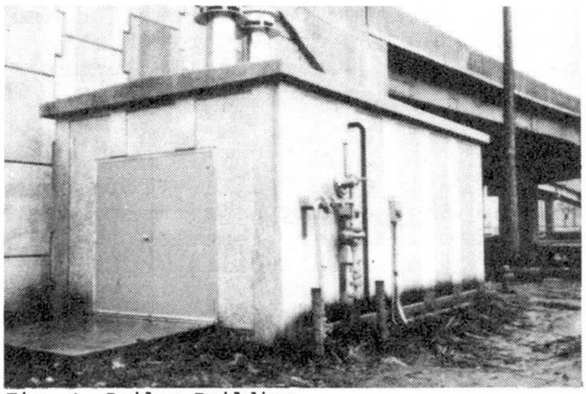


Fig. 4 Boiler Building

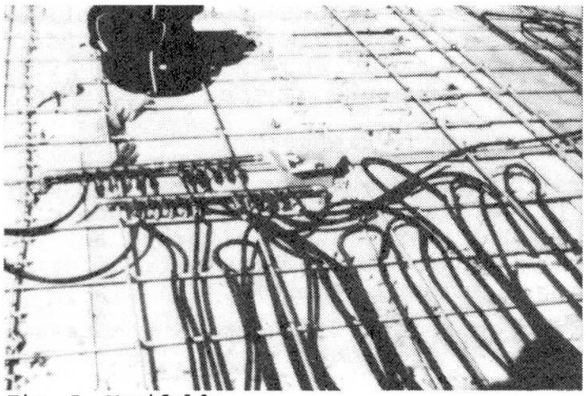


Fig. 5 Manifolds

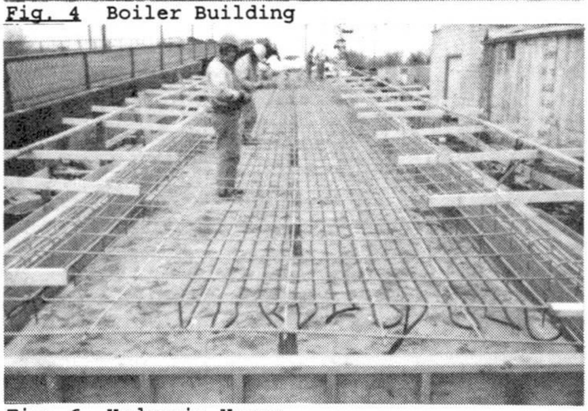


Fig. 6 Hydronic Hoses

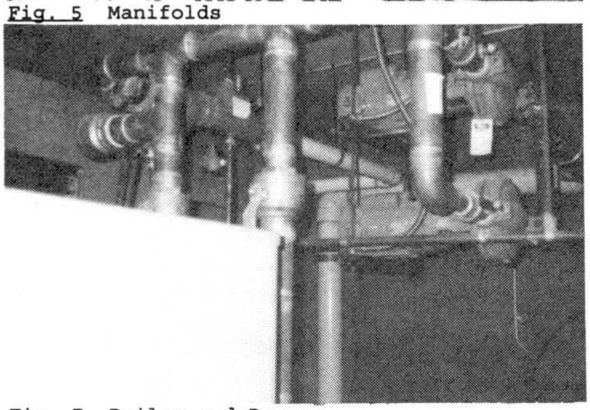


Fig. 7 Boiler and Pumps

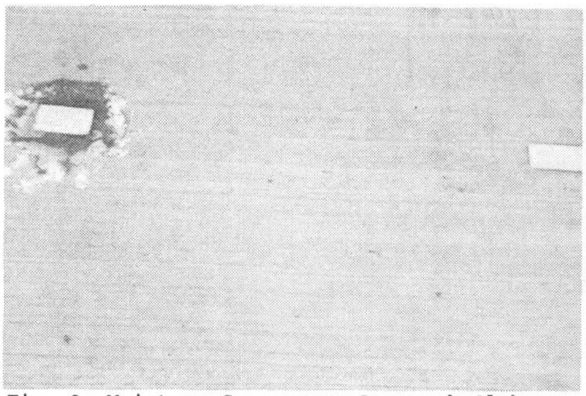


Fig. 8 Moisture Sensors on Approach Slab

The system was designed for a fluid flow rate of 454 L/min and to deliver 473 W/m^2 of heat flux to the deck.

Automatic operation of the system is accomplished by moisture (Fig. 8) and temperature sensors. The system turns on when sufficient moisture collects on the sensing devices to make electrical connection, temperature of the deck is below 277°K, and ambient temperature is below 275°K. Moisture sensors on the deck are heated. The system turns off when the deck reaches a temperature of 286°K. Finally, the system can be turned on and off manually and the boiler shuts off automatically if system pressure decreases below 122°kPa.

3. CONSTRUCTION

The system was installed within the time allowed for viaduct construction without special construction equipment or personnel. Construction personnel were trained and specialized mechanical, electrical, and prefabricated building subcontractors were used. Local utility companies provided metered service at the boiler building (natural gas and 100- ampere, 110-volt electricity). Heating system installation added $161/m^2 to the cost of viaduct construction.

Construction began on the south MSE approach. Heating system components were installed following normal bridge construction sequence. Distribution and collection manifolds were positioned and tied securely in each heating zone. Hydronic hose was connected to nipples on the distribution and collection manifolds with circumference-screw clamps and stretched taut within the heating zone. The single layer of reinforcement was positioned on supporting concrete blocks over the hoses and tied. Hydronic hose was then tied to the bottom of the reinforcement. The heating zones on the elevated structure were similarly installed, with hydronic hose positioned between the layers of reinforcement. When the reinforcement and hoses were taut and tied, hydronic hoses were brought to 414 kPa air pressure, and concrete was poured in the forms, vibrated, finished, and cured following standard practice.

In the approaches, distribution and collection PVC pipes had to be installed and connected to the manifolds before the concrete slab was poured. PVC pipes, flexible expansion loops, valves, and PVC pipe insulation were installed under the elevated structure at the convenience of the contractor.

4. MONITORING AND EVALUATION

The monitoring and evaluation plan was prepared by Kevin Cole, Ph.D., Professor in the University of Nebraska at Lincoln Mechanical Engineering Department. The plan included installing monitoring equipment, collecting data, removing monitoring apparatus from the site after 12 months of data collection, and preparing a summary report.

Monitoring equipment included 18 temperature sensors and one fluid-flow sensor. Sensors were installed in five clusters of three. Each cluster included a sensor at the top surface, center, and bottom of the concrete. Clusters were installed on the centerline in the elevated structure 3 m and 6 m from the north abutment, on the centerline in the north approach 9 m and 12 m from the abutment, and in an unheated sidewalk adjacent to the boiler building. A sensor was installed in the supply pipe and return pipe to monitor fluid temperature and a sensor was positioned to monitor ambient air temperature. Finally, a volume-flow sensor was installed in the return pipe near the boiler. Sensors were wired to a data-acquisition board in a computer located inside a cabinet with temperature controlled by a thermostat.

5. SYSTEM OPERATION

The heating system was charged and operable in November 1994 and operated on December 6, 8, 20, and 31, 1994. The December 31 event, which consisted of a 76-mm snowfall, is described in detail below.

Ambient temperature was 275°K at mid-day on December 30 and dropped to 269°K during the following night. Temperatures remained around 269°K through most of the day on December 31, dropping to 265°K by 1800 hours, and to 257°K by 0700 on January 1, 1995. The temperature then rose to 268°K by 1600 hours. Temperature then began dropping, reaching 258°K at 0700 hours on January 2. The temperature reached a high of 271°K at 1600 hours and dropped to 260°K by 0800 hours on January 3.

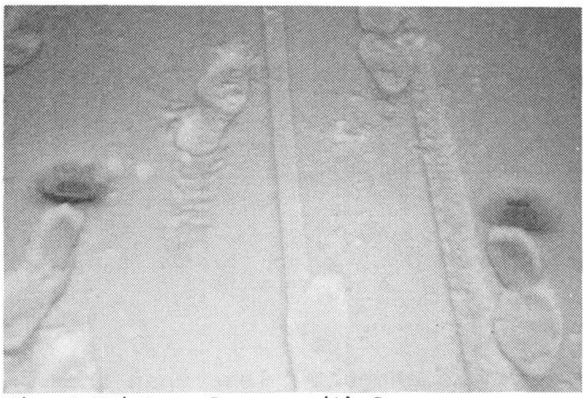


Fig. 9 Moisture Sensors with Snow

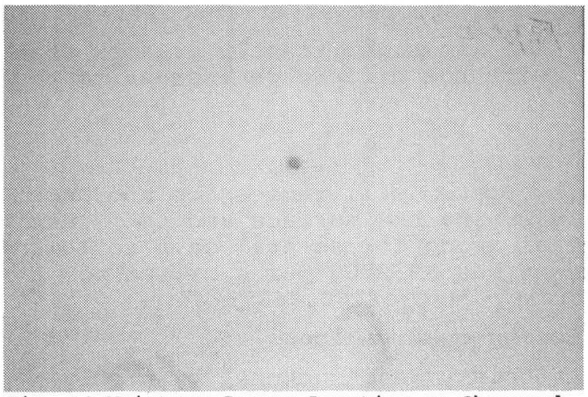


Fig. 10 Moisture Sensor Location as Observed

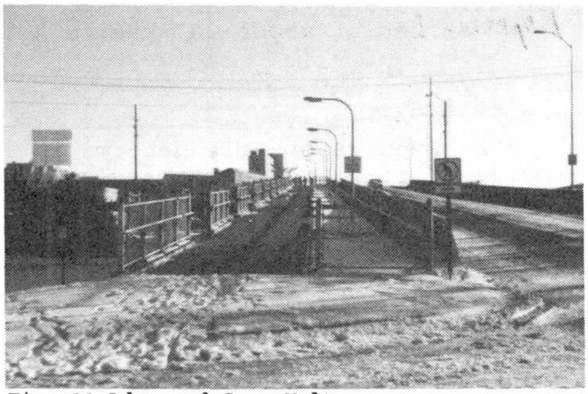
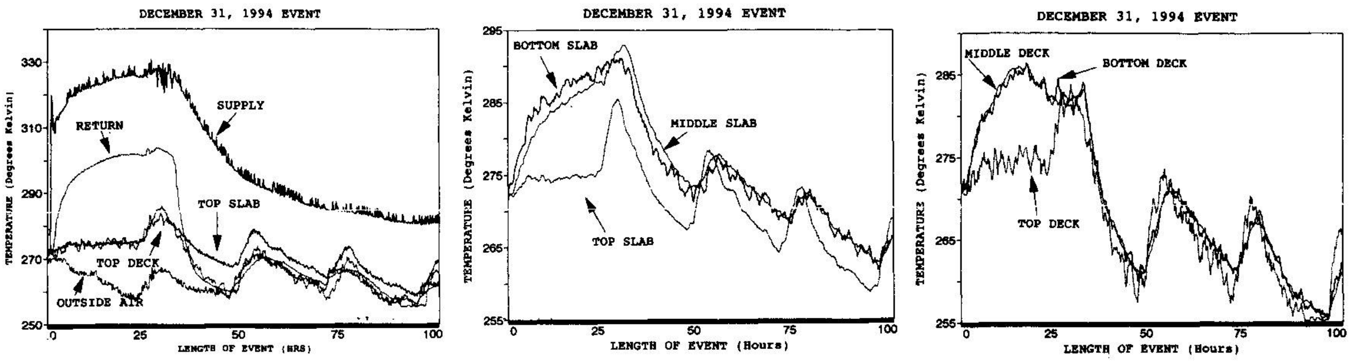


Fig. 11 Advanced Snow Melt

Light drizzle with very light snow flakes began early in the morning on December 30, 1994. This continued through most of the day. At 1200 hours the deck was wet, except at the control moisture sensors. Each sensor and about a 50-mm region around each sensor remained dry. Heat from sensors was evaporating moisture. At 1630 hours sensors had some ice accumulation that bridged the sensing elements. At 2330 hours snowfall was very light and about 20 mm of snow had accumulated on the deck. Sensors had no ice and were dry with adjacent snow accumulation (Fig. 9). At 0800 hours on December 31, about 32 mm of snow had accumulated on the deck and sensor location was slightly marked by dark spots on the snow (Fig. 10). Snow accumulation had formed a cap over each sensor and each sensor remained dry. The system did not start automatically because of this "igloo" effect. During investigation of the sensors, snow fell on the sensors, was melted, and the system started at 0955 hours on December 31. Gas and electric meter readings were 8 393 m^3 and 2 276 kWh, respectively. At 1840 hours, gas and electric meter readings were 8 996 m^3 and 2 320 kWh, respectively. Snow had been melted on about 40 percent of the deck and some spots on the deck were dry. At 1200 hours on January 1, 1995, about 38 mm of snow had accumulated on unheated streets and sidewalks. Gas and electric meter readings were 10 191 m^3 and 2 402 kWh, respectively. The deck was about 95 percent cleared with significant dry areas. The boiler was cycling on and off. At 1600 hours the gas and electric meter readings were 10 432 m^3 and 2 420 kWh, respectively. The deck was 99 percent clear and the boiler was cycling on and off (Fig. 11). At 1830 hours gas and electric meter readings were 10 516 m^3 and 2 421 kWh, respectively. Pump motors were running and the boiler was not operating. The system was manually turned off at 2330 hours and motors stopped. Subsequent investigation showed that system fluid was low and the siphon had broken.

Data collected during this event are displayed in Figs. 12 (a), (b) and (c). The flow meter was not functioning during this event.

The boiler shut off at 1418 hours on January 1, 1995. About 1 798 m^3 of gas was burned by the boiler by 1200 hours on January 1 during the first 26 hours of operation, and about 241 m^3 were burned between 1200 hours and 1600 hours on January 1. Most of the gas was burned before 1418 hours when the boiler first began to shut off. Based on the gas used and 80 percent boiler efficiency, 372 W/m^2 of heat flux was delivered to the deck during the first 26 hours of operation. Temperature drop between supply and return pipes was about 26°K during snow melting. Temperature of the concrete surface on both the elevated deck and approach slab remained at 273°K during snow melting, and then increased to 286°K after snow was melted and the system approached shutoff.



(a) Supply, Return, Outside Air, and Concrete Surface

(b) Top, Middle, and Bottom of Approach Slab

(c) Top, Middle, and Bottom of Elevated Deck

Fig. 12 Temperature Data

Temperature of the bottom of the elevated deck was about 2°K less than the middle of the deck during snow melting. The elevated deck temperature increased to slightly over 288°K during snow melting, then dropped after shutoff.

Temperature of the bottom of the approach slab was significantly greater than the temperature of the middle of the slab, with the difference increasing to about 5°K as the system approached shutoff.

6. CONCLUSIONS AND RECOMMENDATIONS

Our experience demonstrates that the heating system will remove ice and snow from the slab and deck surfaces--thoroughly drying the surface and eliminating the possibility for frosting and preferential icing for several days following a storm event. Cost of operation for this event was $9.25US per hour, using natural gas cost of $0.134US/m^3 and electricity cost of $0.04US/kWh.

Based on our experience, we offer the following observations:

- Expansion of PVC must be accommodated at joints in structures by highly flexible hose. Nipples or other appendages protruding from pipes in the sand approaches should be covered with material to allow slight movement. Also, joints of PVC should be wrapped with tape that can resist about 207 kPa pressure.

- Propylene glycol fluid should be colored with a dye.

- Valves and bridge pipes should be installed between reasonably determined large regions, such as the bridge and the abutment areas, to permit isolation when the system is charged with fluid. This enables isolation of leaks in the system.

- Standpipe devices should be installed for visual verification of fluid level in the distribution and collection pipes on the bridge and approaches, as well as in the expansion tanks. Valves should be installed at high points in all supply and return pipes to allow bleed-off of air during charging of the system with fluid. Valves should be installed at low points of the distribution and collection pipes to permit complete discharge of fluid from the system.

- The moisture- and temperature-sensing control system should include a device that senses when snow has been cleared from a significant portion of the deck surface. This would enable earlier automatic shutoff of the system, with potential savings of 10 to 30 percent per event.

- Finally, manual controls should be provided in the boiler building, wired to override the automatic control device operation. Wireless or landline control of system operation would be very advantageous.

REFERENCE

1. National Climatic Center, NOAA. *Climatological Data*. Asheville, N.C., USA