

# Conductive- *Concrete Overlays*

An innovative solution for bridge-deck deicing

---

BY SHERIF A. YEHIA AND CHRISTOPHER Y. TUAN

**B**ridge decks are prone to ice accumulation, making winter travel treacherous. Road salts and some other deicing chemicals are cost effective, but may cause surface scaling, reinforcing-steel corrosion, or both. Another alternative is a thin, conductive-concrete overlay that, when connected to a power source, can generate enough heat through electrical resistance to prevent ice formation on the deck or melt ice after it forms.

Using a conductive-concrete overlay provides an environment-friendly deicing method that would prolong bridge service life by significantly reducing the use of road salt and deicing chemicals. When used on pedestrian bridges, sidewalks, and driveways, it would also reduce the risk of personal injuries due to slip-and-fall accidents.

The conductive concrete is a cementitious mixture containing electrically conductive components that give it a stable and high electrical conductivity. After 3 years of extensive joint research on conductive concrete by the University of Nebraska and Nebraska Department of Roads, we have developed an optimized mixture with excellent workability and surface finishability.

When connected to a power source, the conductive-concrete overlays produce about 590 W/m<sup>2</sup> of power to prevent snow and ice accumulation.

## Laboratory studies

Using steel shaving and steel fibers as conductive materials, we developed a conductive-concrete mixture specifically for bridge deck deicing or anti-icing.<sup>1,2</sup> When used for anti-icing, the overlay prevents ice formation, and for deicing it melts ice that has formed. We tested conductive concrete test specimens that contained steel fibers only, steel shaving only, and a mixture of steel shaving and steel fibers. Electric resistivity test results showed that using steel fibers or steel shaving alone couldn't provide an electric resistivity lower than the 10 Ω·m needed for deicing application. The test results also showed that 20% by volume of steel shaving and 1.5% by volume of steel fibers were upper bounds of the conductive material, beyond which, workability and surface finishability were poor. The conductive concrete containing 20% steel shaving and 1.5% steel fibers has been tested extensively to evaluate its mechanical and physical properties (Table 1). This concrete was also used in field studies.

TABLE 1: MECHANICAL AND PHYSICAL PROPERTIES OF THE CONDUCTIVE CONCRETE

Test	Result
Compressive strength	31 MPa (4500 psi)
Flexural strength	4.6 MPa (670 psi)
Rapid freeze and thaw resistance	None of the specimens failed after 312 cycles
Shrinkage	Less than that predicted by ACI 209 equation by 20 to 30%
Modulus of elasticity	3634 MPa ( $5.27 \times 10^5$ psi)
Permeability	Permeability rate ranges between 0.004 to 0.007 cm <sup>3</sup> /sec.
Thermal conductivity	7.8 W/m-K.

## Field studies

### Durability under traffic

To evaluate the durability of conductive concrete under traffic loads, a 6.4 m x 3.65 m x 90 mm (21 ft x 12 ft x 3.5 in.) conductive-concrete overlay patch was placed in the I-480 westbound lane of a bridge over the Missouri River near the Nebraska-Iowa border (Fig. 1). On December 3, 1999, workers ground off the old overlay and cleaned the surface of the underlying concrete. On the next day, a 3-mm-thick (1/8 in.) bonding layer of cement grout was spread on the concrete deck before the conductive concrete overlay was placed. The patch contained 2.6 m<sup>3</sup> (3.5 yd<sup>3</sup>) of conductive concrete with 20% steel shaving and 1.5% steel fibers by volume. Figure 2 shows that placing and finishing methods for conductive concrete are similar to those used for conventional concrete.



Fig. 1: Conductive concrete patch on an I-480 bridge deck

The lane was opened to traffic on December 6, 1999, after the concrete strength had reached 18 MPa (2600 psi). The compressive strength reached 52 MPa (7500 psi) after 28 days. We visually inspected the overlay every 6 months and, as shown in Fig. 3, there was no fiber exposure or any sign of corrosion, but some reflective cracking did develop.

### Deicing experiments

Two 150-mm-thick (6 in.) concrete slabs, one 2 x 2 m (7 x 7 ft) and the other 1.2 x 3.6 m (4 x 12 ft), were constructed to simulate bridge decks. A 90-mm-thick (3.5 in.) conductive concrete overlay was cast on the top of each slab. Two steel plates, 64 mm (2.5 in.) wide and 6 mm (0.25 in.) thick, were embedded along the length of each slab for use as electrodes. The steel plates had perforations greater or equal to the 13 mm (0.5 in.)



Fig. 2: The conductive concrete showed excellent workability and surface finishability



Fig. 3: The conductive-concrete patch after 12 months. There was no evidence of corrosion, but some reflective cracking



Fig. 4: Thermocouple layout before casting overlay

maximum aggregate size to allow concrete to flow through to provide good anchorage.

Thermocouples installed in the conductive overlays monitored temperature (Fig. 4). During each test, an electronic weather station recorded the ambient air temperature, relative humidity, and wind speed/direction with temperature, humidity, and wind sensors mounted 1.8 m (6 ft) above the overlay surfaces. Sixteen thermocouple readings were recorded simultaneously at one sample per second during the deicing experiments. The overlays were connected in parallel to 220V, 60 Hz, AC power, and a variable transformer elevated and regulated the applied voltage to a maximum of 420 volts. An amp-meter recorded the electrical current going through each overlay. The total current going through both overlays was limited to 10 amps.

During the winter of 1998 (December 1998 through March 1999), we conducted experiments on the overlays in five snowstorms under two scenarios: anti-icing and deicing.<sup>3</sup> In an anti-icing scenario, the overlays were preheated 2 to 6 hours before the storms and also heated during the storms. They were heated only during the storms in a deicing scenario. During the deicing scenario, the slab temperature rose above freezing after 4 to 6 hours, and the test continued until the slab surface was dry and free from snow. We found that anti-icing is more cost effective and energy efficient than deicing. However, deicing experiments were conducted to evaluate the heating rate of the conductive concrete. In each experiment, the applied voltage, current going through each overlay, temperature distribution within each overlay, along with the air temperature,

humidity, and wind speed/direction were recorded.

One deicing experiment was conducted during the winter of 1999 (December 1999 to March 2000). The experiment started with 150 mm (6 in.) of snow accumulation. Figure 5 shows the 1.2 x 3.6 m (4 x 12 ft) slab before and after this deicing experiment. The heating rate was consistent with that of the winter 1998 experiments at about 0.56 °C/min. (1 °F/min.). Table 2 summarizes the essential data of the winter 1998 and 1999 deicing experiments.

### Material and energy costs

The average energy cost per unit surface area is about \$0.8/m<sup>2</sup> (\$0.074/ft<sup>2</sup>) per storm, given that 1 kW-hr costs about 8 cents in Omaha, Nebr. Table 3 compares the material costs of conductive concrete with those of conventional concrete. Although the unit cost of conductive concrete is higher than that of



Fig. 5: The 1.2 x 3.6 m (4 x 12 ft) slab during experiments in the winter of 1999: (a) slab before testing; and (b) slab during testing

TABLE 2: POWER CONSUMPTION FOR DEICING EXPERIMENT

Date	Snow accumulation, mm (in.)	Air temp., °C (°F)	Exp. time, (hours)	Power, Kw-hr	Cost, \$
Feb. 11, 1999	75 (3)	-5 (22)	16	32.48	2.6
Feb. 17, 1999	200 (8)	0.6 (33)	18	42.64	3.25
Feb. 20, 1999	50 (2)	3 (37)	5	10	0.8
Feb. 22, 1999	275 (11)	-3 (26)	25	33.76	3.4
March 8, 1999	250 (10)	0 (32)	24	46	3.7
Feb. 18, 2000	150 (6)	-2.5 (27)	10	34	2.7

TABLE 3: MATERIAL COSTS OF CONDUCTIVE CONCRETE VS. CONVENTIONAL CONCRETE

Material	Cost/kg	Cost/m <sup>3</sup>	
		Conductive concrete	Conventional concrete
Steel fibers	\$0.88	\$105	0
Steel shaving	\$0.22	\$115	0
Sand	\$0.0053	\$2.0	\$3.1
1/2 in. limestone	\$0.0053	\$2.0	\$6.2
Cement	\$9.30/100 kg	\$46	\$42
Total		\$270.1	\$51.3

conventional concrete, conductive-concrete overlays should be considered as heating elements rather than as repair materials.

### Demonstration projects underway

The Phase I findings of this research showed that the conductive concrete overlay had the potential to become the most cost-effective bridge deck deicing method. The Nebraska Department of Roads has approved a Phase II demonstration project at Roca, located about 20 mi (32 km) south of Lincoln, Nebr., to implement a conductive-concrete overlay on a highway bridge. The Roca Spur Bridge has a 45.72 m (150 ft) long and a 10.97 m (36 ft) wide concrete deck. A railroad crossing is located

immediately at the end of the bridge, making it a prime candidate for deicing application. The Roca Bridge Project was let in December 2001 with construction starting in the spring of 2002. The overlay will be instrumented with temperature sensors to provide data for deicing monitoring.

In addition to the highway bridge deicing demonstration, the researchers are actively seeking sponsors for smaller demonstration projects, such as sidewalks and driveways in residential areas. For more information about such projects, contact Sherif Yehia, Department of Civil Engineering, University of Nebraska, Peter Kiewit Institute, 1110 South 67th Street, Omaha, NE 68182-0178; telephone: (402) 554-2034 or e-mail syehia@mail.unomaha.edu.

## Acknowledgments

We would like to thank Bing Chen and David Ferdon of the University of Nebraska-Lincoln, and Moe Jamshidi, Gale Barnhill, George Woolstrum, and Dylace Ronnau of the Nebraska Department of Roads for their valuable feedback which made this research project practical. Norman Nelson, Mark Deetz, and Ben Ricceri of Lyman-Richey Corp. in Omaha shared their field experience with fiber-reinforced concrete and provided assistance in the overlay construction. Financial support provided by the Nebraska Department of Roads and the Center for Infrastructure Research of the University of Nebraska-Lincoln is gratefully acknowledged.

## References

1. Yehia, S. A., and Tuan, C., "Conductive Concrete Overlay for Bridge Deck Deicing," *ACI Materials Journal*, V. 96 No. 3, 1999, pp. 382-390.
2. Yehia, S. A.; Tuan, C.; Ferdon, D.; and Chen, B., "Conductive Concrete Overlay for Bridge Deck Deicing: Mix Design, Optimization, and Properties," *ACI Materials Journal*, V. 97, No. 2, 2000, pp. 172-181.
3. Yehia, S. A., and Tuan, C., "Thin Conductive Concrete Overlay for Bridge Deck Deicing and Anti-icing," *Transportation Research Record*, No. 1698, 2000, pp. 45-53.

Received and reviewed under Institute publication policies.



**Sherif A. Yehia** is a research assistant professor of civil engineering at the University of Nebraska-Lincoln. His research interests include behavior of reinforced concrete and prestress concrete, composite structures, and special concrete.



**Christopher Y. Tuan** is an associate professor of civil engineering at the University of Nebraska-Lincoln. His research expertise includes innovative construction materials and techniques, structural dynamics, and finite element modeling. Tuan spent 8 years in industry before joining the university in 1996.

**Still the champ,  
fair...and square.**

Thanks to our patented Square Head™ design, Wyco Flex Shaft Vibrators deliver faster, more efficient concrete consolidation. And they finish every job they start because they're built tough for peak performance and long-term durability. Plus with double-insulated motors, they meet or exceed the most stringent UL and CSA standards. So they're the safest way to get the job done - rain or shine.

We also have the strongest distributor network in the industry, so you're assured prompt, local assistance. No wonder Wyco remains the undisputed world champ of concrete vibrators, fair and square. After all, it's all we do.

For the name of your authorized Wyco distributor, call 1-800-ADD-WYCO (1-800-233-9926).

The Wyco Tool Company, 2200 South St., Racine, WI 53404  
262-639-6770 toll-free 1-800-233-9926 www.wycotool.com E-mail: wycosales@wycotool.com

**WYCO**

0794-1108

See us at CONEXP-CON/AGG Booth #S-010170  
CIRCLE READER CARD # 15