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Evaluation of Electrically Conductive Concrete Containing Carbon Products for Deicing

by Christopher Y. Tuan and Sherif Yehia

Using electrically conductive concrete for deicing is an emerging material technology. Due to its electrical resistance, a thin layer of conductive concrete can generate enough heat to prevent ice formation on concrete pavement when energized by a power source. Under research sponsored by the Nebraska Department of Roads, a concrete mixture containing steel fibers and steel shavings was developed specifically for concrete bridge deck deicing. The mixture has a compressive strength of 31 MPa (4500 psi) and provides average thermal power density of 590 W/m^2 (55 W/ft^2) with a heating rate of 0.14 °C/min (0.25 °F/min) in a winter environment. The average energy cost was about \$0.8/m^2 (\$0.074/ft^2) per snowstorm.

During development of the conductive concrete, several drawbacks about using steel shavings in the mixture were noticed. As a follow-up effort, carbon and graphite products were used to replace steel shavings in the conductive concrete design. The electrical conductivity and the associated heating rate were improved with the carbon products. A conductive concrete deck has been implemented for deicing on a highway bridge at Roca, located approximately 24 km (15 mi) south of Lincoln, Nebr. The Roca Spur Bridge has a 36 m (117 ft) long and 8.5 m (28 ft) wide conductive concrete inlay, which has been instrumented with temperature and current sensors for heating performance monitoring during winter storms. Experimental data and operating costs are presented in this paper.

Keywords: bridge deck; concrete; deicer; fiber; test.

INTRODUCTION

Conductive concrete may be defined as a cementitious composite that contains a certain number of electrically conductive components in regular concrete matrix to attain stable and relatively high electrical conductivity. Conductive concrete has many applications including bridge deck deicing, radiant heating, electrical grounding, and electromagnetic pulse (EMP) shielding.

In 1998, Yehia and Tuan,[1] Yehia et al.,[2] and Yehia and Tuan[3] at the University of Nebraska developed a conductive concrete mixture specifically for bridge deck deicing. The mixture design contained 1.5% of steel fibers and 20% steel shavings per volume of concrete. A 1.2 x 3.6 m (4 x 12 ft) and 150 mm-thick (6 in.) conventional concrete slab was constructed to simulate a concrete bridge deck. A 90 mm-thick (3.5 in.) conductive concrete overlay with two steel strips embedded for electrodes was cast on top of the concrete slab for conducting a deicing experiment in a natural environment. The mixture had an average compressive strength of 31 MPa (4500 psi) and provided an average thermal power density of 590 W/m^2 (55 W/ft^2) with a heating rate of approximately 0.14 °C/min (0.25 °F/min) in a winter environment. The average energy cost was approximately \$0.8/m^2 (\$0.074/ft^2) per snowstorm.

Steel shavings are waste materials produced by steel fabricators in the form of small particles of random shapes. The drawbacks noticed when using steel shavings during development of the conductive concrete are as follows: a lack of consistency in size and composition from various sources of steel shavings; the steel shavings were usually contaminated with oil and required cleaning; and the steel shavings required a specialized mixing procedure to ensure uniform dispersal in the concrete.

Xie and Beaudoin[4] summarized several research efforts in investigating the compositions of conductive concrete and patented[5] a mixture design using metallic and carbon fibers and particles. The volumetric ratios of the conductive materials and the corresponding electrical resistivity, however, were not explicitly specified in the patent for deicing applications. As a follow-up effort to eliminate the drawbacks, carbon and graphite products were used to replace steel shavings in several trial conductive concrete mixture designs. Test data showed that the electrical conductivity and the heating rates could be significantly improved with the carbon products. The Nebraska Department of Roads has sponsored a demonstration project at Roca, located on Nebraska Highway 77 South approximately 24 km (15 mi) south of Lincoln, to implement a conductive concrete deck on a highway bridge for deicing. The Roca Spur Bridge has been instrumented with temperature and current sensors to monitor heating performance during winter storms. Experimental data and operating costs are presented in this paper.

RESEARCH SIGNIFICANCE

The heated bridge deck of Roca Spur Bridge is the first implementation in the world to use conductive concrete for highway bridge deicing. The new mixture design containing carbon powder and particles is found superior to that containing steel shavings because the electrical conductivity and the heating rate are improved without the drawbacks mentioned previously. The construction costs and deicing performance of the heated bridge deck would demonstrate its cost-effectiveness as opposed to other existing deicing technologies. The conductive concrete deicing technology can be readily implemented at accident-prone areas such as bridge overpasses, exit ramps, airport runways, street intersections, sidewalks, and driveways.

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Table 1—Preliminary test results

Trial mixture	Workability	Finishability	28-day compressive strength, MPa (psi)	Remarks
1) 20% BD[*] (3/8× 0)	Good	Good	24.0 (3483)	Gas release during hydration causing volume expansion
2) 25% EL[†]	Good	Good	39.8 (5770)	—
3) 41% EL[†]	Good	Good	32.7 (4735)	Required more high-range water-reducing admixture
4) 25% EC-98C (10 × 0)	Good	Good	47.0 (6811)	—
5) 25% EC-100 (10 × 0)	Good	Good	40.5 (5870)	—
6) 25% EC-97 (3/8× 0)	Good	Good	41.8 (6061)	—
7) 25% EC-100 (3/8× 0)	Good	Good	37.4 (5416)	—
8) 25% FP-428 (100 × 0)	Good	Good	26.3 (3817)	Required more high-range water-reducing admixture
9) 25% EC-All	Good	Good	34.5 (4997)	—
10) 25% EL + slag aggregate	Good	Good	46.6 (6750)	—

[*] BD = Black Diamond.
[†] EL = Earth Link.

Table 2—Comparison of heating rate, operating voltage, and peak current

Specimen	Initial temperature	Maximum heating rate, °C/min	Operating voltage, V	Peak current, amp
EC-100 (3/8× 0)	–4 °C	0.25	140	0.93
EC-100 (3/8× 0)	2 °C	0.27	140	1.13
EC-100 (10 × 0)	–4 °C	0.26	140	0.67
EC-100 (10 × 0)	2 °C	0.38	140	0.95
EC-98C (10 × 0)	–4 °C	0.09	140	0.48
EC-98C (10 × 0)	2 °C	0.11	140	0.61
EC-97 (3/8 × 0)	–4 °C	0.38	140	0.89
EC-97 (3/8 × 0)	2 °C	0.38	140	1.00
FP-428 (100 × 0)	–4 °C	0.14	140	0.43
FP-428 (100 × 0)	2 °C	0.07	140	0.47
EC-All	–4 °C	**1.56**	140	**4.26**
EC-All	2 °C	**1.71**	140	**4.82**
41% EL[*]	–4 °C	0.36	84	0.62
41% EL	2 °C	0.31	84	0.69
BD 20%[†]	–4 °C	0.01	140	0.11
BD 20%	2 °C	0.09	140	0.17
Slag + 25% EL	–4 °C	**3.27**	140	**2.39**
Slag + 25% EL	2 °C	**2.28**	140	**1.97**
25% EL	–4 °C	0.38	140	0.80
25% EL	2 °C	0.37	140	1.13

[*] EL = Earth Link.
[†] BD = Black Diamond.

CONDUCTIVE CONCRETE USING CARBON AND GRAPHITE PRODUCTS

During the spring of 2001, carbon products were used to replace steel shavings in the conductive concrete mixture designs. Seven commercial carbon and graphite products were used in trial batches in an experimental program. Ten trial mixtures were prepared for evaluation. The criteria used for the trial mixtures were workability, finishability, compressive strength, heating rate, and electric resistivity. All mixtures contained steel fibers and carbon products for conductive materials. The steel fibers of variable lengths amounted to 1.5% and the carbon products amounted to 25% per volume of the conductive concrete mixtures. These trial mixtures are described as follows:

1. 20% Black Diamond (3/8 × 0);
2. 25% Earth Link;
3. 41% Earth Link;
4. 25% EC-98C (10 × 0);
5. 25% EC-100 (10 × 0);
6. 25% EC-97 (3/8 × 0);
7. 25% EC-100 (3/8 × 0);
8. 25% FP-428 (100 × 0);
9. 25% ALL—All graphite products were used in this mixture except the Black Diamond; and
10. 25% Earth Link + slag aggregate.

Black Diamond (BD) is the trade name of a natural graphite crystalline in the form of pellets. Earth Link (EL) is the trade name of graphite cement, which contains approximately 70% portland cement and 30% graphite powder. The EC designations are used to distinguish carbon products of different particle sizes. FP-428 is a product composed of small carbon particles. Crushed limestone, 13 mm (0.5 in.) maximum size, was used in the trial mixtures. However, 13 mm (0.5 in.) blast-furnace slag was used in one trial mixture to replace the limestone with an intent to improve the electrical conductivity. Coarse blast furnace slag is the coproduct of molten iron production in a blast furnace. When molten, slags float on the metal. Separating the two is not exact and there is some iron residue in the slags. Six 152 x 305 mm (6 x 12 in.) cylinders and one 457 x 330 x 63.5 mm (18 x 13 x 2.5 in.) slab were prepared from each trial mixture.

TEST RESULTS

Workability, finishability, and compressive strength

Workability and finishability were the two primary criteria used in the preliminary evaluation of the trial mixtures. In addition, three cylinders from each trial mixture were tested for compressive strength at 28 days. The test results are summarized in Table 1.

Heating rate

Heating tests with the slabs, 457 x 330 x 63.5 mm (18 x 13 x 2.5 in.), were conducted under two initial temperatures: –4 and 2 °C (25 and 35 °F). Two steel plates spaced at 305 mm (12 in.) were used for electrodes. The steel plates had perforations greater than or equal to the 13 mm (0.5 in.) maximum aggregate size to allow concrete to flow through to provide good anchorage. A Type TX thermocouple was embedded in the middle of each test slab to monitor the temperature. Alternate current (AC) power with a constant voltage of 140 V was applied, and the resulting current and

Table 3—Electrical resistivities of carbon concrete trial mixtures

Specimen	Initial temperature, C°	Temperature range, °C	Electrical resistivity, Ω.cm
EC-100 (3/8 × 0)	–4	–4 to 4.5	564 to 381
EC-100 (3/8 × 0)	2	2 to 10	451 to 323
EC-100 (10× 0)	–4	–4 to 4.5	721 to 576
EC-100 (10× 0)	2	2 to 15.5	519 to 392
EC-98C (10 × 0)	–4	–4 to –1	939 to 853
EC-98C (10 × 0)	2	2 to 4.5	733 to 669
EC-97 (3/8 × 0)	–4	–4 to 10	564 to 403
EC-97 (3/8 × 0)	2	2 to 15.5	518 to 357
FP-428 (100 × 0)	–4	–4 to 2	1048 to 958
FP-428 (100 × 0)	2	2 to 4.5	902 to 900
EC-All	**–4**	**–4 to 38**	**435 to 108**
EC-All	**2**	**2 to 49**	**395 to 101**
41% EL*	–4	–4 to 7	1006 to 762
41% EL	2	2 to 13	846 to 702
BD 20%†	–4	–4 to –3	8077 to 7404
BD 20%	2	2 to 7	7500 to 5226
Slag + 25% EL	**–4**	**–4 to 40**	**808 to 208**
Slag + 25% EL	**2**	**2 to 35**	**705 to 219**
25% EL	–4	–4 to 4.5	1813 to 728
25% EL	2	2 to 4.5	830 to 759

*EL = Earth Link.

†BD = Black Diamond.

slab temperature from each slab were recorded for 30 min. The slabs were kept inside a freezer during heating tests to maintain constant ambient temperature. The results are summarized in Table 2. High power densities of 3000 to 7000 W/m^2 (280 to 650 W/ft^2) were applied to the test slabs for comparison of accelerated heating performance. Power densities used in industry for deicing, however, typically range between 300 to 600 W/m^2 (28 to 56 W/ft^2),[6-8] as will be illustrated by the deicing data from the Roca Spur Bridge demonstration project. The readers are cautioned about the danger of using high power densities for any trials they might undertake themselves.

Electric resistivity

Conventional concrete is not electrically conductive. The electric resistivity of normalweight concrete ranges between 6.54 – 11 kΩ.m.[9,10] A hydrating concrete consists of pore solution and solids, including aggregates, hydrates, and unhydrated cement. The electric resistivity of the pore solution in the cement paste is approximately 0.25 to 0.35 kΩ.m.[10] Most common aggregates (for example, limestone) used in concrete, with electric resistivity ranging between 3×10^2 and 1.5×10^3 kΩ.m,[10] are considered nonconductive.

Based on the heating test data, approximate values of the impedance and the electric resistivity were calculated for each trial mixture using the following equations

$$Z = \frac{V}{I} \tag{1}$$

and

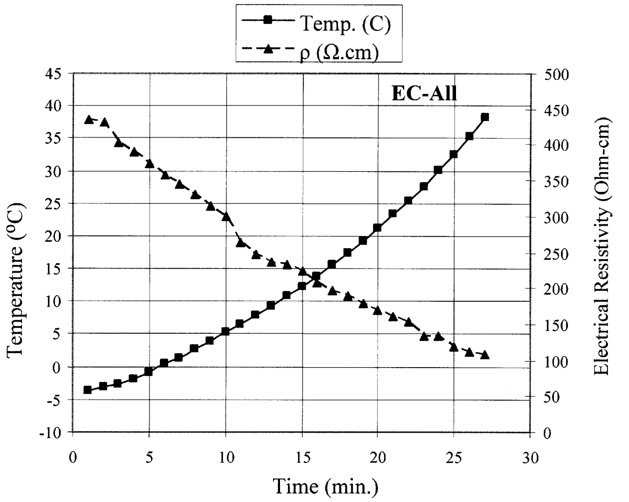

Fig. 1—Electric resistivity versus temperature—EC-All mixture.

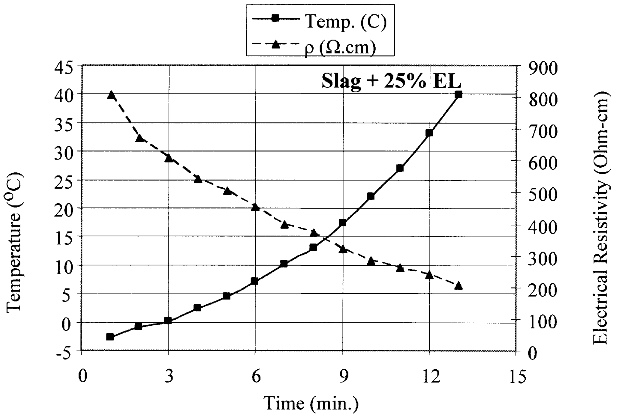

Fig. 2—Electric resistivity versus temperature—Slag + 25% EL mixture.

$$Z = \frac{\rho L}{A} \tag{2}$$

where Z is the impedance; V is the applied AC voltage; I is the AC current; ρ is the average electric resistivity of the specimen; L is the spacing between the electrodes or 305 mm (12 in.); and A is the cross-sectional area of the test slab parallel to the electrodes or 19,355 mm^2 (30 in.^{2}). A range of the electrical resistivity with respect to the initial temperatures is given for each trial mixture in Table 3.

Two trial mixtures, EC-All and Slag + 25% EL showed high electrical conductivity and heating rates. Experimental data from the heating tests of these two mixtures are presented in Fig. 1 and 2, respectively. The electric resistivity of these materials is a function of temperature. As temperature increases, the materials become more electrically conductive. The higher electrical conductivity is probably due to the good gradation of carbon particles in the EC-All and the added slag in the Slag + 25% EL mixtures. EC-All and Slag + 25% EL showed superior heating performance, as shown in Fig. 3.

ELECTRIC CONDUCTION MECHANISM IN CONDUCTIVE CONCRETE

Conduction of electricity through concrete may take place in two ways: electronic and electrolytic. Electronic conduction

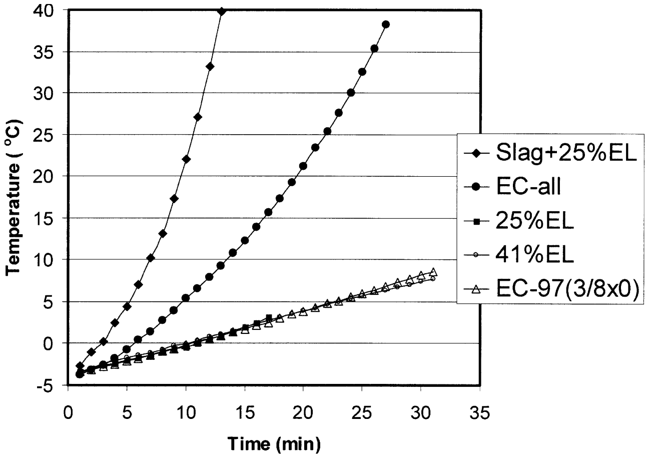

Fig. 3—Comparison of heating rates of trial mixtures.

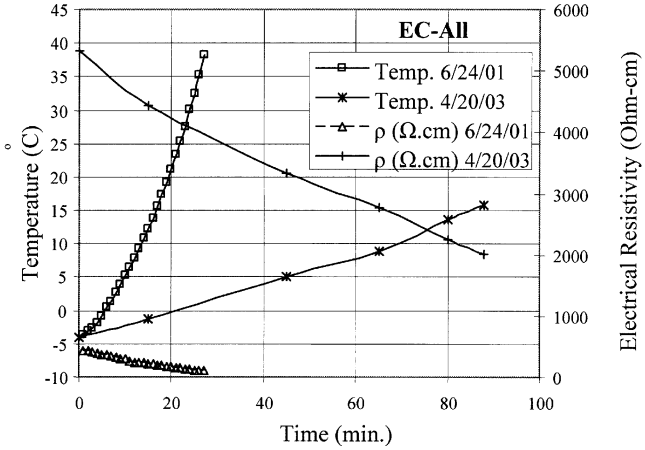

Fig. 4—Time effect on electric resistivity.

occurs through the motion of free electrons in the conductive media, whereas electrolytic conduction takes place by the motion of ions in the pore solution. Whittington, McCarter, and Forde[10] investigated conduction of electricity through conventional concrete using cement paste and concrete specimens. The electric resistivity was found to increase with time for both specimens because conduction in these specimens depended on the ions' motion in the pore solution. In addition, the electric resistivity of the concrete specimens was higher than that of the cement paste specimens due to the restricted ion movement from nonconductive aggregates used in the concrete specimens. Farrar[11] in 1978 used "marconite," a carbon by-product from oil refining, to replace sand in a conductive concrete mixture. The electric resistivity of the conductive concrete using marconite ranges between 0.5 to 15 $\Omega \cdot$ cm. The use of marconite was limited to small-scale applications such as electromagnetic shielding and antistatic flooring because it was expensive. Conduction of electricity in this case was through the movement of electrons, and the particles must be in continuous contact within the concrete. This phenomenon is called electrical percolation in concrete.[11,12]

Heating tests have been conducted using both AC and DC power to study the conduction of electricity through the conductive concrete mixture developed at the University of Nebraska. The conductive concrete behaved like a semiconductor or a capacitor. As electrical current flows through the conductive concrete, its temperature rises and the heating rate increases. The electrical conductivity of the conductive concrete will increase as its temperature rises. The increase in electrical conductivity will cause more current to flow through under a constant voltage. Hence, the applied voltage must be controlled to maintain a gradual heating rate to avoid thermal shock to the conductive concrete.

Because the conductive components added only amounted to 25% by volume of the total materials, there are probably not enough conductive fibers and particles to form a fully interconnected electronic circuit within the concrete. Instead, these dispersed conductive materials would act as capacitors when a voltage is applied across the material. Electrical current will flow through the material if the applied voltage is high enough to cause dielectric breakdown of the material. There is a critical threshold of voltage, above which large current will go through the material like a short circuit. If the applied voltage is kept below this "breakdown" voltage, a controllable amount of current proportional to the voltage will go through the material. This behavior is similar to that of a surge protector used in computers, which has been described by Yehia et al.[2]

Long-term stability of electric resistivity

The electric resistivity of the conductive concrete is relatively low during hydration due to the ionic conduction in the pore solution. The breakdown voltage would thus depend upon the moisture content in the material. Yehia et al.[2] showed that there exists a stable but higher breakdown voltage after the moisture in the conductive concrete has completely dried out. For instance, no degradation in the heating performance has been observed after a 5-year deicing experiment with the 1.2 x 3.6 m (4 x 12 ft) conductive concrete test slab using steel fibers and steel shavings. To prove the same is true with the carbon concrete, a heating test was conducted on the EC-All test slab two years later. The data from the two tests are compared in Fig. 4. The lower electric resistivity and higher heating rate are probably due to the higher moisture content in the specimen during the earlier test.

IMPLEMENTATION PROJECT—ROCA SPUR BRIDGE

Roca Spur Bridge is a 46 m-long (150 ft) and 11 m-wide (36 ft), three-span highway bridge over the Salt Creek at Roca, located on Nebraska Highway 77 South approximately 24 km (15 miles) south of Lincoln. A railroad crossing is located immediately following the end of the bridge, making it a prime candidate for deicing application. The Roca Bridge project was let in December 2001 and construction was completed in November 2002. The bridge deck has a 36 x 8.5 m (117 x 28 ft) by 102 mm (4 in.) conductive concrete inlay, which is instrumented with thermocouples for deicing monitoring during winter storms.

Construction sequence

A 102 mm- thick (4 in.) inlay of conductive concrete using the EC-All mixture was cast on top of a 256 mm-thick (10.5 in.) regular reinforced concrete deck. As shown in Fig. 5, the inlay consists of 52 individual 1.2 x 4.1 m (4 x 14 ft) conductive concrete slabs. In each slab, two 89 x 89 x 6 mm (3.5 x 3.5 x 1/4 in.) angle irons spaced 1067 mm (3.5 ft) apart were embedded for electrodes. Thread sleeves were welded to one end of the angle irons for making electrical connection. A Type TX thermocouple was installed at the center of each slab

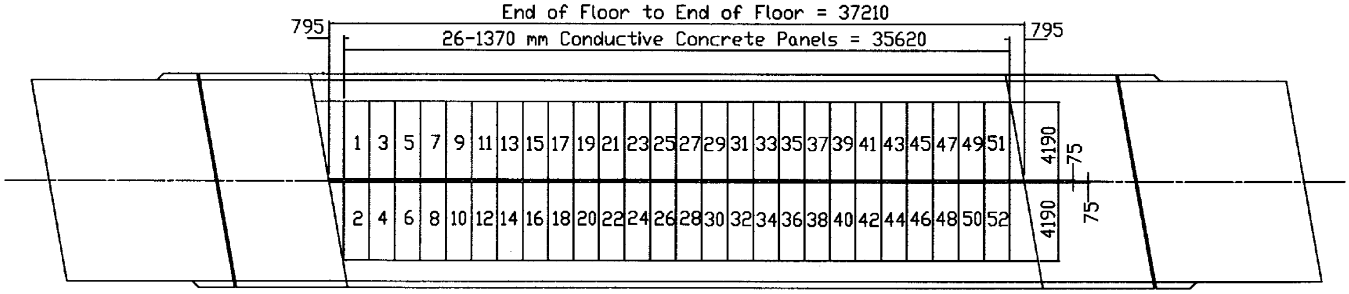

Fig. 5—Conductive concrete panel layout (dimensions in mm).

at approximately 13 mm (0.5 in.) below the surface to measure the slab temperature. The power cords and thermocouple wiring for each slab were secured in two polyvinyl chloride (PVC) conduits and are accessible from junction boxes along the centerline of the bridge deck.

The conductive concrete inlay was cast after the regular bridge deck had been cured for 30 days. After hardening, the conductive concrete inlay was saw cut to a 102 mm (4 in.) depth along the perimeters of the individual slabs and the gaps were filled with polyurethane sealant. There was a 152 mm (6 in.) gap along the centerline of the bridge to allow power cord connections with the thread sleeves on the angle irons, as shown in Fig. 6. The gap was then filled with a non-shrink, high-strength grout.

Integration of power supply, sensors, and control circuit

A three-phase, 600 A and 208 V AC power supply was provided by a power line nearby. A microprocessor-based controller system was installed in a control room to monitor and control the deicing operation of the 52 slabs. The system included four main elements: 1) a temperature-sensing unit; 2) a power-switching unit; 3) a current-monitoring unit; and 4) an operator-interface unit. The temperature-sensing unit took and recorded the thermocouple readings of the slabs every 15 min. A slab's power was turned on by the controller if the temperature of the slab was below 1.7 °C (35 °F) and turned off if the temperature was above 12.8 °C (55 °F). The power-switching unit controlled power relays to perform the desired on/off function. To ensure safety, a current-monitoring unit limited the current going through a slab to a user-specified amount. The operator-interface unit allowed a user to connect to the controller with a PC or laptop by a phone modem. The operator interface displayed all the temperature and electrical current readings of every slab in real time. A user also had the option of using a PC or laptop to download the controller-stored data into a spreadsheet.

Safety concerns

The use of high voltage and high current causes a safety concern, even though the conductive concrete behaves as a semi-conductor. A model commonly used to describe the behavior of a diode[2] as a resistor in parallel with a variable resistor and a capacitor may be used to describe the electrical conduction behavior of the conductive concrete. The isolated conductive particles within the concrete act as capacitors when a voltage is applied across the material. The current flows through the material due to dielectric breakdown. The summation of the potential drops of all the viable current paths between the two electrodes is equal to the applied voltage. Likewise, the total current going through all the viable paths is equal to the current corresponding to the applied voltage. This behavior has been confirmed by field measurements. Several measurements were taken at different locations on the inlay surface under 208 V during heating experiments, and "step potential" readings were in the range of 10 to 20 V. The current readings were in the range of 15 to 30 mA. These voltage and current levels pose no hazard to the human body. On another occasion, the authors touched the surface of the 1.2 x 3.6 m (4 x 12 ft) conductive concrete slab containing steel fibers and shavings during deicing experiment without feeling any electric shock while the slab was energized with 410 V of AC power and had approximately 10 amps of current going through it.

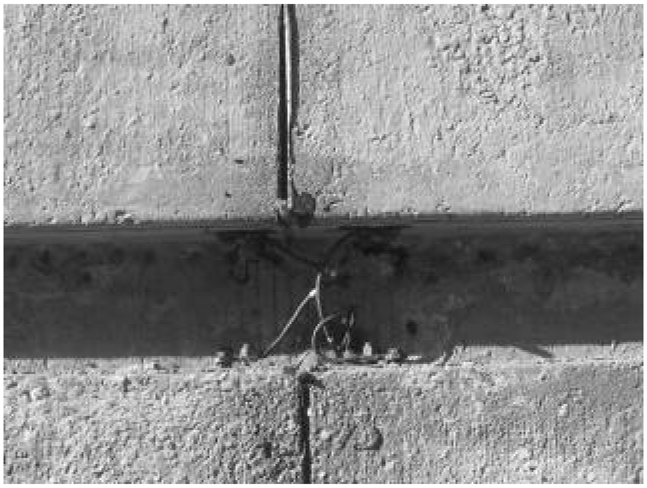

Fig. 6—Power cord and angle iron connection.

A potential safety hazard exists, however, if some steel fibers were in direct contact with electrodes and exposed on the surface. An effective measure to eliminate potential stray current on the surface is to apply 1.6 to 3.2 mm (1/16 to 1/8 in.) coating of a low-modulus and low-viscosity epoxy on the conductive concrete surface. Fine aggregate will then be spread on before the epoxy sets to form a skid-resistant surface. Although the power will be turned on only when snow/ice storms are anticipated, it may be prudent to monitor the step potential and stray current to ascertain that there is no electric shock hazard to the public.

Deicing operation

The deicing controller system was completed in March 2003. Although major snow storms of 2002 were missed, the system was tested successfully under freezing temperatures. The 52 conductive concrete slabs were activated for deicing during four major snow storms in the winter of 2003. The climatic data of these storms were obtained from the

Table 4—Deicing performance of Roca Spur Bridge

Storm date	Snow depth, mm	Air temperature*, °C	Wind speed, km/h	Energy, kW-h	Unit cost†, \$/m^2	Power scheme
December 8-9, 2003	165	–6.3	36	2023	0.54	Alternating
January 25-26, 2004	257	–11.1	23	2885	0.75	Simultaneous
February 1-2, 2004	145	–10.0	18	2700	0.71	Simultaneous
February 4-6, 2004	198	–7.2	19	3797	1.00	Simultaneous

*Average ambient temperature readings during deicing at bridge site.

†Energy cost per unit surface area of conductive concrete inlay.

Fig. 7—Roca Bridge deck deicing—February 5, 2004.

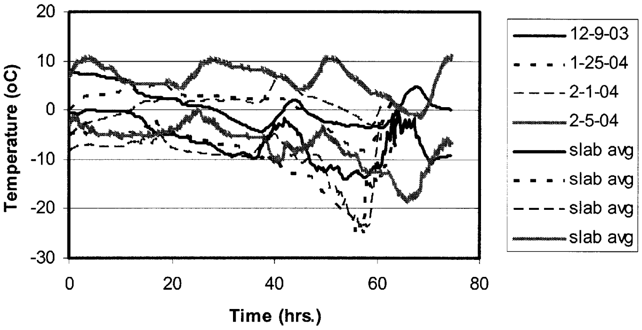

Fig. 8—Ambient versus average slab temperature.

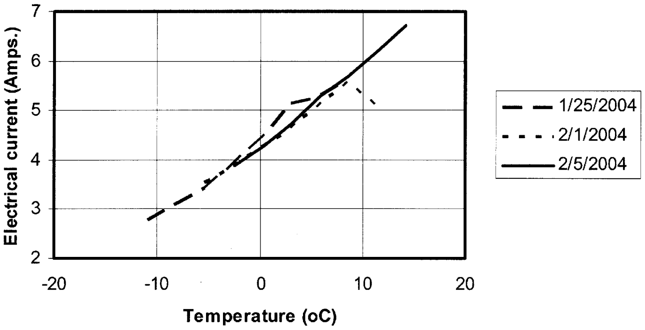

Fig. 9—Average current/temperature relationship.

National Climatic Data Center,[13] a weather station in Lincoln, Nebr., and are summarized in Table 4. The power was turned on 6 to 8 h before the snowstorms to preheat the slabs. The 52 slabs were divided into 26 groups with each group containing two consecutive slabs. Thus, Group 1 contains Slabs 1 and 2, Group 2 contains Slabs 3 and 4, and so on. During the December 8 storm, the odd-numbered groups were energized for 30 min and off for 30 min when the even-numbered groups were powered. This alternating form of energizing the slabs could not keep up with the low temperature, high wind, and a snow rate of about 25 mm/h (1 in./h). As a result, the deck was partially covered with snow. The scheme was revised to energize all the slabs when the ambient temperature dropped below –1 °C (30 °F) and switched to alternating powering when the ambient temperature was above –1 °C (30 °F). The revised scheme seems to have worked well in the later storms. Figure 7 shows that the deck was free of snow cover during the February 5 storm.

The slab temperature distribution was very uniform across the deck during deicing operations, generally in the –4 to 10 °C (25 to 50 °F) range. As shown in Fig. 8, the average slab temperature was consistently approximately 10 °C (18 °F) higher than the ambient temperature. The maximum current recorded varied between 7 and 10 amps. Figure 9 shows that the electrical conductivity of the conductive concrete increased with higher average slab temperatures. The peak power density delivered to the slabs varied between 360 and 560 W/m^2 (33 to 52 W/ft^2) with an average of 452 W/m^2 (42 W/ft^2). The total energy consumed by the conductive concrete slabs during the storms is summarized in Table 4. The energy consumed by the slabs varied from 47 to 70 kW-h, with an average of 58 kW-h per slab. The average energy consumption under simultaneous powering was approximately 3200 kW-h, which would cost approximately \$260 for each major storm based on the rate of \$0.08/kW-h. The operating costs per unit area of deck surface are presented in Table 4. The Roca Spur Bridge project has demonstrated that using conductive concrete for deicing has the potential to become the most cost-effective roadway deicing method in the future.

Construction costs

The construction costs of the conductive concrete inlay are itemized as follows:

- Placing, finishing, curing, and saw cutting conductive concrete: \$50,020
- Procuring conductive concrete materials: \$80,620
- Building and installing control cabinet with sensors and power relays: \$43,685
- Integrating and programming the deicing operation controller: \$18,850

Therefore, the total construction cost of the Roca Spur Bridge deicing system was \$193,175. The cost per unit surface area of the conductive concrete inlay is \$635/m^2 (\$59/ft^2). The heated deck of Roca Spur Bridge is the first implementation in the world using conductive concrete for deicing. The initial construction cost was high compared with the \$377/m^2 (\$35/ft^2) cost of a propane-fired boiler heating system recently installed in the Buffalo River Bridge in Amherst, Va., in 1996.[14] Life-cycle costs including system maintenance costs, deck repair costs, and vehicle depreciation caused by deicing chemicals, however, should be used as the basis for cost-effectiveness comparisons of different deicing systems. In addition, the construction costs of conductive concrete overlay/inlay are expected to drop significantly when the technology becomes widely accepted.

CONCLUSIONS

During the conductive concrete research at the University of Nebraska, drawbacks about using steel shavings in the mixtures were noticed. As a follow-up effort, carbon products were used to replace the steel shavings in the conductive concrete mixture design. Workability, finishability, compressive strength, slab heating rate, and electric resistivity were used as the criteria for evaluating each trial mixture. The EC-All and Slag + 25% EL mixtures showed a superior heating rate. A conductive concrete deck using the EC-All mixture has been implemented for deicing on a highway bridge at Roca, located approximately 24 km (15 mi) south of Lincoln, Nebr. The Roca Spur Bridge has a 36 m-long (117 ft) and 8.5 m-wide (28 ft) conductive concrete inlay, which has been instrumented with temperature and current sensors for heating performance monitoring during winter storms. The deicing system has worked well in four major snowstorms in the winter of 2003 and delivered an average power density of 452 W/m^2 (42 W/ft^2) to melt snow and ice. The conductive concrete deck deicing system at Roca Spur Bridge will continue to be monitored for the next several winters to evaluate its cost-effectiveness against other deicing technologies.

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