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# AIRFIELD PAVEMENT DEICING WITH CONDUCTIVE CONCRETE OVERLAY

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## ABSTRACT

Conductive concrete is a cementitious admixture containing a certain volumetric ratio of electrically conductive materials to attain high and stable electrical conductivity. Due to its electrical resistance, a thin overlay of conductive concrete can generate enough heat to prevent ice formation when energized by AC power. Under a research sponsored by Nebraska Department of Roads, Yehia and Tuan developed a mix specifically for concrete bridge deck deicing while meeting the ASTM and AASHTO strength specifications for overlay construction. An average thermal power of 591 W/m$^2$ (55 W/ft$^2$) with a heating rate of 0.56$^o$C/min (1$^o$F/min) was generated by a 1.2 m by 3.6 m (4 ft by 12 ft) and 8.9 cm (3.5 in.) thick conductive concrete test slab in snow storms. The average energy cost was about \$0.8/m$^2$ (\$0.074/ft$^2$) per snow storm. This technology is readily available for airfield pavement deicing application.

The Phase I findings of this research have shown that conductive concrete overlay has the potential to become the most cost-effective concrete pavement deicing method. A Phase II project is underway, in which a 45.7 m (150 ft) long and 11 m (36 ft) wide bridge deck at Roca, Nebraska, will have conductive concrete overlay implemented. The construction is scheduled for summer 2002.

In this paper, evaluations of conductive concrete mixes with steel shaving, carbon and graphite products, in addition to steel fibers, are discussed in detail. Also, the implementation of two conductive concrete sidewalks in Shelby, Ohio is presented.

## INTRODUCTION

Conductive concrete is a cementitious admixture containing electrically conductive components to attain stable and high electrical conductivity. Due to its electrical resistance, a thin conductive concrete overlay can generate enough heat to prevent ice formation on a bridge deck when connected to a power source. Conductive concrete has been used for anti-static flooring, electromagnetic shielding, and cathodic protection of steel reinforcement in concrete structures. However, previously developed conductive concrete have limited applications because the material did not have adequate strength requirements and it was not cost-effective.

The main objectives of this research are:

(1) Design a conductive concrete mix specifically for bridge deck overlay for deicing and anti-icing application;
(2) Evaluate properties of the new conductive concrete mix to ensure that the mechanical and physical properties meet the ASTM and AASHTO specification for overlay;
(3) Conduct deicing and anti-icing experiments using conductive concrete overlay in a natural environment to determine factors affecting the deicing and anti-icing performance; and
(4) Provide a feasibility study for using the new material as a heating system for bridge deck deicing.

After three years of extensive research on conductive concrete by the University of Nebraska and Nebraska Department of Roads, the researchers have developed an optimized mixture with excellent workability and surface finishability. The mechanical strength of the conductive concrete mixture has met the AASHTO Specifications for bridge deck overlay design. Two concrete slabs have been constructed with a 9-cm (3.5-in.) conductive concrete overlay for conducting deicing experiments in the natural environment. Deicing experiments were conducted during the winter of 1998, 1999, and 2000 under two scenarios: deicing and anti-icing. Average power of about 591 $W/m^2$ (55 $W/ft^2$) was generated by the conductive concrete to prevent snow accumulation and ice formation. In this paper, a summary of the project achievement is presented as follows.

## PART I: CONDUCTIVE CONCRETE MIXES WITH STEEL SHAVING AND STEEL FIBERS

## MIX DESIGN, OPTIMIZATION AND PROPERTIES

Conventional concrete is not electrically conductive. The electric resistivity of normal weight concrete ranges between 6.54 – 11 kΩ•m. (1,2). Most common aggregates (e.g., lime stone) used in concrete, with electric resistivity ranging between $3\times10^2$ and $1.5\times10^3$ Ω•m, are non-conductive. Conduction of electricity through concrete may take place in two ways: electronic and electrolytic. Electronic conduction occurs through the motion of free electrons in the conductive media, while electrolytic conduction takes place by the motion of ions in the pore solution. Approaches to improving the electrical conductivity of a concrete mix include: (1) use of conductive aggregates such as iron ore, slag, etc.; and (2) increasing the conductivity of the cement paste by adding conductive materials such as steel shaving, coke breeze, steel or carbon fibers, etc.

In 1998, Yehia and Tuan (3,4) at the University of Nebraska developed a conductive concrete mix specifically for bridge deck deicing. In this application, a conductive concrete overlay is cast on the top of a bridge deck for deicing and anti-icing. In this mix, steel shaving with particle size ranged between 0.15 and 4.75 mm (0.007 to 0.19 in.) and steel fibers with four different aspect ratios between 18 to 53 were added to the concrete as conductive materials.

Over 150 trial mixes were prepared to optimize the volumetric ratios of the steel shaving and fibers in the mix proportioning. The evaluation criteria were mechanical properties (compressive and flexural strength), slab heating performance, power source (DC vs. AC), size effect, electric resistivity, and electrode configuration. Detailed discussion of the optimization results is presented elsewhere (4). The following conclusions were drawn from the optimization process:

1. The required electrical conductivity and mechanical strength of a bridge deck overlay for deicing can be achieved by using 15-20 percent of steel shaving and 1.5 percent of steel fibers per volume of conductive concrete.
2. The workability and surface finishability of the conductive concrete mix developed by Yehia and Tuan at the University of Nebraska-Lincoln are excellent and comparable to those of regular concrete.
3. The heating rate of the slabs using AC and DC power was similar. However, AC power is preferred since the heating is more uniform than using DC power.
4. Using a thermal insulation layer underneath a conductive concrete overlay will reduce the energy consumption in deicing and anti-icing operations.
5. Once the electric resistivity of a mix is determined, the optimum electrode spacing can be determined for a bridge deck overlay for minimum power consumption.
6. Perforated steel plates should be used for electrodes to provide good conductive bond with conductive concrete.

## SLAB HEATING TESTS

Slab heating tests were conducted under two different initial slab temperatures at 23°C (74°F) and –1.1°C (30°F). The slabs were 305mm×305mm×51mm (1 ft × 1 ft × 2 in.). Average power of 516 $W/m^2$ ($48W/ft^2$) was generated by the conductive concrete to raise the slab temperature from -1.1°C (30°F) to 15.6°C (60°F) in 30 minutes. This power level is consistent with the successful deicing applications using electrical heating cited in the literature (5,6).

## MATERIAL EVALUATION

### Mechanical and physical properties

The mechanical and physical properties of the conductive concrete mix were evaluated (4) in accordance with the ASTM (7) and AASHTO (8) specifications. The compressive strength, flexural strength, modulus of elasticity and rapid freeze and thaw resistance of the conductive concrete mix after 28 days have met the AASHTO requirements for bridge deck overlay. These mechanical and physical properties are summarized in Table 1.

Table 1. Mechanical and physical properties of the conductive concrete

| Tests | Results |
|---|---|
| Compressive strength | 31-41 MPa (4500-6000 psi) |
| Flexural strength | 4.6-5.5 MPa (670-800 psi) |
| Rapid freeze and thaw resistance | None of the 17 specimens failed after 312 cycles |
| Modulus of elasticity | 3634 MPa ($5.27 \times 10^5$ psi) |

### Durability test

A conductive concrete patch was constructed on December 3, 1999 on an interstate bridge near the Nebraska-Iowa border for durability evaluation. The patch was 6.4m × 3.65m × 9 cm (21ft × 12 ft × 3.5 in.) and the optimized mix design was used. The overlay was visually inspected every 6 months. As shown in Figure 1, there was no fiber exposure but with reflective cracking developed in the overlay.

## DEICING AND ANTI-ICING EXPERIMENTS

Two 15-cm (6-in.) thick concrete slabs, one 2m by 2m (7 ft by 7 ft) and the other 1.2m by 3.6m (4 ft by 12 ft), were constructed to simulate bridge decks. A 9-cm (3.5-in.) thick conductive concrete overlay from the same mix used for the material evaluation was cast on the top of each slab. Perforated steel plates were embedded along the length of each slab for electrodes. The objectives of the experiments are to utilize the conductive concrete mix in overlay application and to conduct deicing experiment for temperature monitoring and power consumption evaluation.

Figure 1. Conductive concrete patch after 12 months

## Instrumentation

Thermocouples were installed in the conductive overlay for temperature monitoring. An electronic weather station was used to record the ambient air temperature, relative humidity, and wind speed/direction during each testing. The temperature, humidity, and wind sensors were mounted at 1.8m (6 ft) above the overlay surface. A 220V, 60 Hz, AC power was used for powering the overlays. A VARIAC was used to regulate the applied voltage. A transformer was used to elevate the applied voltage to a maximum of 420 volts. The overlays were connected to the AC power in parallel. An amp-meter was used to record the electrical current going through each overlay. The total current going through both overlays was limited to the maximum capacity of the power source. In 1998 experiments, the current was limited to 10 Amps, while in the 1999 and 2000 experiments the limit was 15 Amps.

## ELECTRIC HEATING CHARACTERISTICS

Several tests were conducted using AC and DC power to study the conduction of electricity through the conductive concrete mix. A model, as shown in Figure 2, (9,10) commonly used to describe the behavior of a semi-conductor or a diode is also applicable to conductive concrete. The movement of electrons is presumed to flow through a resistor in parallel with a variable resistor and a capacitor. The resistor represents the electrical resistance of the steel shaving in the cement paste and steel fibers that are directly connected, the variable resistor represents the electrical resistance of steel fibers and steel shaving not directly connected, and the variable capacitor represents gaps among the steel fibers and shaving with the cement paste as the dielectric. Three main zones, Figure 3, can describe the conduction of electricity through conductive concrete. In the linear zone, the relation between the applied voltage and the current going through the mix is linear. The electric charges accumulate in the capacitor, and the heating rate is minimal. In the operational zone, a nonlinear relation exists between the applied voltage and the associated current. There is more current flow through the conductive concrete and the heating rate increases. In the saturation zone, the applied voltage is high enough to break down the capacitor. The current going through the conductive concrete rapidly increases.

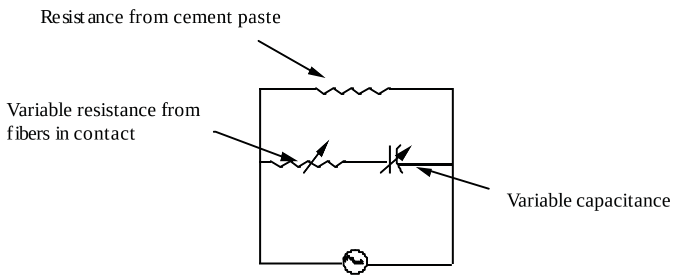
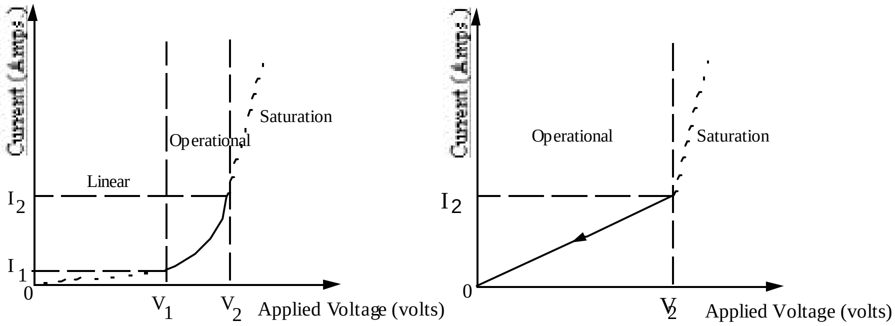


Figure 2. A model for conduction of electricity through conductive concrete



(a) Starting from zero to saturation

(b) Starting from saturation - Voltage can be reduced to control heating rate

*$V_1$ and $I_1$ values are temperature dependent

| Slab | Electrode spacing (in) | Steel* Shaving % | $V_2$ | $I_2$ |
|---|---|---|---|---|
| 30cm x 30cm x 5cm (1ft x 1ft x 2 in.) | 12 | 15 | 110 | >10 |
| | | 20 | 98 | >10 |
| 91cm x 61cm x 9cm (2ft x 3ft x 3.5 in.) | 24 | 20 | 196 | >10 |

* 1.5% steel fibers were used in all mixes

Figure 3 Conduction of electricity through conductive concrete - model parameters

For efficient heating of a conductive concrete overlay, the break down point of the capacitor must be reached first, and the voltage may be reduced to the operational zone afterwards. The heating rate in the conductive concrete depends upon the current going through, which can be controlled by maintaining the applied voltage in the operational range and by limiting the current. The “break down” voltage is in the range of 450-480 volts for the 1.2m x 3.6m (4 ft x 12 ft) overlay, and 780-840 volts for the 2m x 2m (7 ft x 7 ft) overlay. The following operation sequence was carried out during the experiments of 1998: (1) a 420-volt voltage was applied first, and the current was recorded; and (2) once the total current going through the overlays reached the 10-Amp limit, the voltage was reduced to keep the current below 10 Amps. In the experiments during the winter of 1999 and 2000, another operation sequence was followed: (1) a 420-volt voltage was applied, and remained constant during the experiments; and (2) once the total current going through the overlays reached the 15-Amp limit, the power was turned off for at least 30 min to control the current by reducing the slab temperature; therefore increasing the slab resistance. For an electrode spacing of 1.2m (4 ft), an applied voltage of 420 V was in the operational zone. However, for an electrode spacing of 2m (7 ft), an applied voltage of 420 V was in the linear zone and the heating rate was minimal.

## High Voltage and Safety Concerns

Initially safety was a major concern due to applying high voltage (i.e., 420 V) to heat the overlay. Since conductive concrete behaves as a semiconductor, 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 "step potential" measurements. Several measurements were taken at different locations on the overlay surface during heating experiments, and the voltage readings were in the range of 10 to 20 volts. The current readings were in the range of 20 to 30 mA. This voltage and current level poses no hazard to the human body. However, the use of a thin coating of polymer on the conductive concrete overlay to serve as an electric insulator is under evaluation.

## EXPERIMENTAL RESULTS

Four anti-icing experiments were conducted during the winter of 1998 and 2000. In the anti-icing experiments, the overlays were preheated 2 to 10 hours (depend on the initial temperature of the overlay) before and heated during the storms. In addition, deicing experiments, in which the overlays were heated only during the storms, 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. Table 2 summarizes the essential data of these events. Figure 4 shows the 1.2m x 3.6m (4ft x 12ft) slab during anti-icing experiment. In the winter of 2000 (December 2000 through March 2001) most of the experiments were conducted with initial overlay temperature –26°C (-15°F). Under this temperature most deicing chemicals will become ineffective. However, the heating rate of the test slab was consistent with the winter 1998 (December1998 to March 1999) experiments at about 0.56°C/min. (1°F/min.)

Table 2 Anti-Icing experiments during winter 1998 and 2000

| **Date** | **Snow accum. mm (in.)** | **Air Temp. °C (°F)** | **Preheating (hours)** | **Test Duration (hours)** | **Power (Kw-hr)** |
|---|---|---|---|---|---|
| Feb. 11, 1999 | 75 (3) | -5 to –3<br>(22 to 26) | 6 | 16 | 32.48 |
| Feb. 17, 1999 | 200 (8) | 0.6 to 2<br>(33 to 28) | 4 | 18 | 42.64 |
| Feb. 22, 1999 | 275 (11) | -3 (26) | 2 | 25 | 33.76 |
| Dec. 18, 2000 | 142 (5.6) | -8.9 (16) | 10 | 26 | 48 |

*Data are for the 1.2m x 3.6m (4ft x 12ft) slab

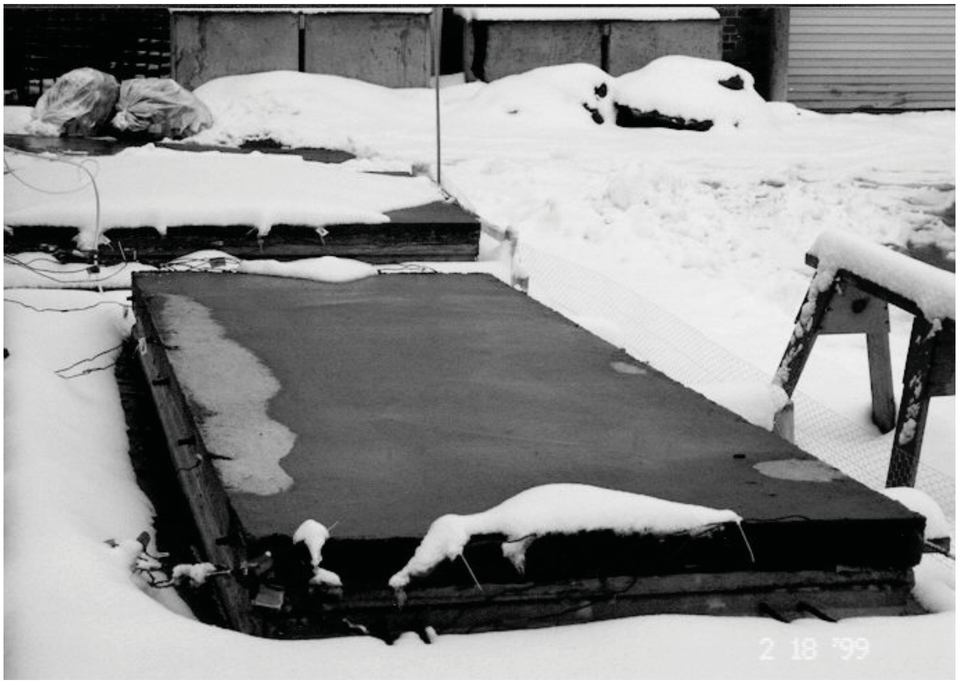


Figure 4. The 1.2m x 3.6m (4ft x 12ft) slab during anti-icing experiment – winter 1998.

### Energy Cost

Table 3 shows energy cost/m$^2$ during each storm, with one kW-hr costs 8 cents in Omaha, Nebraska. This energy cost is consistent with the successful deicing applications using electrical heating cited in the literature (5,6,12,13,14).

Table 3 Energy cost/m$^2$ using Conductive Concrete

| **Date** | **Power consumption (kW-hr)** | **Energy Cost $** | **Cost $/m$^2$ ($/ft$^2$)** |
|---|---|---|---|
| Feb. 11, 1999 | 32.48 | 3.25 | 0.7 (0.065) |
| Feb. 17, 1999 | 42.64 | 4.3 | 0.9 (0.086) |
| Feb. 22, 1999 | 33.76 | 3.4 | 0.7 (0.068) |
| Dec. 18, 2000 | 48 | 4.8 | 0.98 (0.096) |

## DEMONSTRATION PROJECT

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. Nebraska Department of Roads has approved a phase II demonstration project at Roca, located about 20 miles south of Lincoln, Nebraska, to implement a conductive concrete overlay on a highway bridge. The Roca Spur Bridge has a 45.72m (150 ft) long and 10.97m (36 ft) wide concrete deck. 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 with construction starting in the summer of 2002. The overlay will be instrumented with temperature sensors to provide data for heating performance monitoring.

## PART II: CONDUCTIVE CONCRETE MIXES WITH CARBON PRODUCTS AND STEEL FIBERS

During the research and development of the conductive concrete, several drawbacks about using steel shaving in the mix have been noticed. First, there is no wide availability of supplies of steel shaving. Second, steel shavings acquired from metal fabricators are usually contaminated with oil, which requires cleaning. And third, steel shaving poses a safety hazard for handling and requires a specialized mixing procedure to ensure uniform distribution. The researchers at the University of Nebraska considered several alternatives to replace the steel shaving in the conductive concrete mix.

In the spring of 2001, Yehia and Tuan developed a conductive concrete mix utilizing graphite and carbon products to replace steel shaving. Ten trial mixes with seven carbon and graphite products were included in the preliminary experimental evaluation. The evaluation criteria used for each trial batch were workability and finishability, compressive strength, heating rate, and electric resistivity. Two of the mixes showed superior heating performance. The results are summarized in Table 4.

Table 4. Summary of the test results

| **Criteria of evaluation** | **Slag+25%EL** | **EC-all** |
|---|---|---|
| Workability and finishability | Good | Good |
| Compressive strength at 28 days( psi) | 6750 | 4997 |
| Heating rate at 25°F (°F/min.) | 5.88 | 2.80 |
| Electrical resistivity (Ohm.cm) for temperature 25° - 120° | 808 - 207 | 435 - 208 |

## HEATED CONDUCTIVE CONCRETE SIDEWALKS – SHELBY, OHIO

Two sidewalks, one 15m × 3m (50ft × 10ft) in front of the City Hall, and the other 12m × 6m (40ft × 20ft) in front of the Utility Building, were selected as the test sites. The Slag+25%EL mix was poured for the City Hall sidewalk and the EC-all mix was poured for the Utility Building sidewalk on September 29, 2001. Figures 5 and 6 show the construction of the sidewalks.

The prototype sidewalks will be monitored and tested over the years on their heating performance and power consumption.

Figure 5. Layout of electrodes

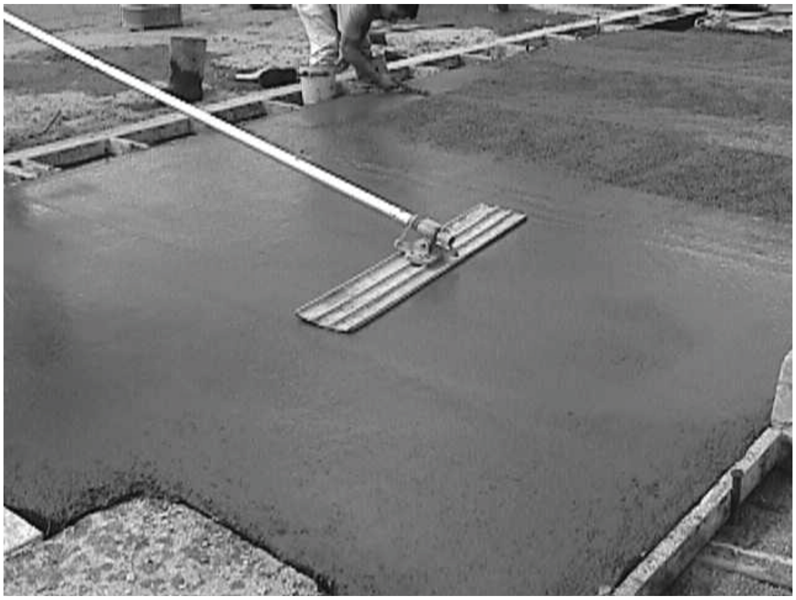


Figure 6. Finishing sidewalk surface

## CONCLUSIONS

The optimized mix developed at the University of Nebraska for a bridge deck overlay showed excellent workability and surface finishability. The mechanical strength of the conductive concrete mix has met the ASTM and AASHTO Specifications for bridge deck overlay construction. Stable and uniform temperature distribution with gradual heating was achieved during the deicing experiments. Anti-icing operation is more cost effective and energy efficient than deicing and it is the preferred heating operation. The heating rate was consistent during three consecutive years of testing and the results showed no sign of loosing electrical conductivity with time. Average power of about 590 W/m$^2$ (55 W/ft$^2$) was generated by the conductive concrete overlay to prevent snow and ice accumulation. Energy cost is in the range of \$0.6 to \$0.8/m$^2$ (\$0.056 to 0.074/ft$^2$) per storm. The use of steel shaving is expected to be replaced with carbon and graphite products.

Ice accumulation on paved surfaces is not merely a concern for motorists; ice accumulation on pedestrian walkways accounts for numerous personal injuries, due to slipping and falling. The results from the Phase I study have indicated that the payoff potential for this project is tremendous: it would eliminate icy pavements for wintry travel safety and save lives for accident-prone areas such as bridge overpass, exit ramps, airport runways, sidewalks and driveways, which are prime candidates for conductive concrete deicing.

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