Implementation of Conductive Concrete Deicing Technology

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What is Conductive Concrete?

"A concrete mixture containing a certain amount of electrically conductive materials, designed to enable conduction of electricity."

Steel fibers

Carbon particles

Applications

* Pavement deicing
* Radiant heating
* Cathodic rebar protection
* Anti-static flooring/grounding
* Structural health monitoring
* Electromagnetic wave shielding

Previous and Current Projects

Naval Air Station
VEMP Grounding Plane
Pax River, MD

Existing deicing methods

* **Salt and Deicing Chemicals**

Spray system

Resistive Heating Cable System

Electric Cables in the Bridge Approach Roadway, Newark, New Jersey, 1961

Heated Fluid Hydronic System

Approaches of 10th Street Pedestrian Overpass in Lincoln, NE, 1993

Heated Fluid Hydronic System

Heated Fluid Pipe System in the Buffalo River Bridge Deck, Amherst, Virginia, 1996

Advantages of Conductive Concrete Deicing Technology

Comparison of Various Deicing Systems

Deicing system	Initial cost*	Annual operating cost*	Power consumption
Automated Spray System	$600,000	$12,000	Not applicable
Electric heating cable, 1961	$54/m^2	$4.8/m^2	323 to 430 W/m^2
Hot water, 1993	$161/m^2	$250/storm [76 mm snow]	473 W/m^2
Heated gas, 1996	$378/m^2	$2.1/m^2	Not available
Conductive Concrete, 2003	$635/m^2	$0.81/m^2/storm	350 W/m^2

*Cost figures are quoted directly from the literature; conversion to present worth was not attempted.

*Conductive concrete requires very little to no maintenance.

Comparison of Energy Efficiency

Electric Heating Wires

Conductive Concrete Slab

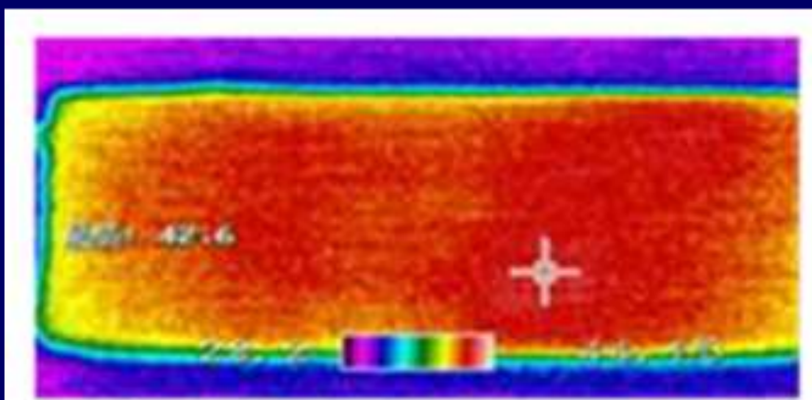
	Sidewalk	Bridge deck
	kWh/m^2	kWh/m^2
London, UK	~100	~250
Copenhagen, DK	~300	~600
Oslo, NO	~450	~850
Kiev, UA	~400	~700
Munich, DE	~600	~650

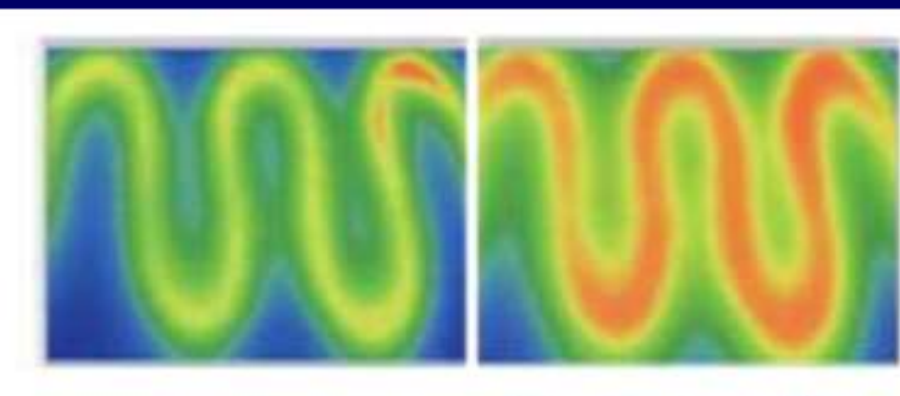
Roca Spur Bridge: **9.27** kWh/m^2

Omaha driveway: **2.05** kWh/m^2

10'x20' test pad: **3.69** kWh/m^2

Surface Temperature Distribution

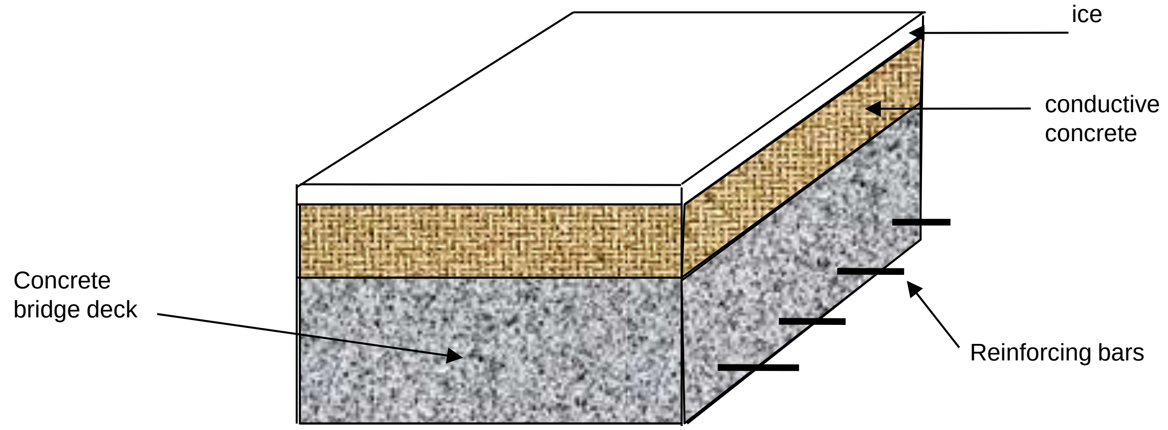




Conductive Concrete

Hydronic System

Electric Heating Analysis of Conductive Concrete



Conductive concrete deicing concept

Coupled-field governing differential equations:

- Electric field equations
- Transient heat conduction equations

Electrical conductivity is a function of temperature and internal heat generation is function of electric potential.

Electric field equation:

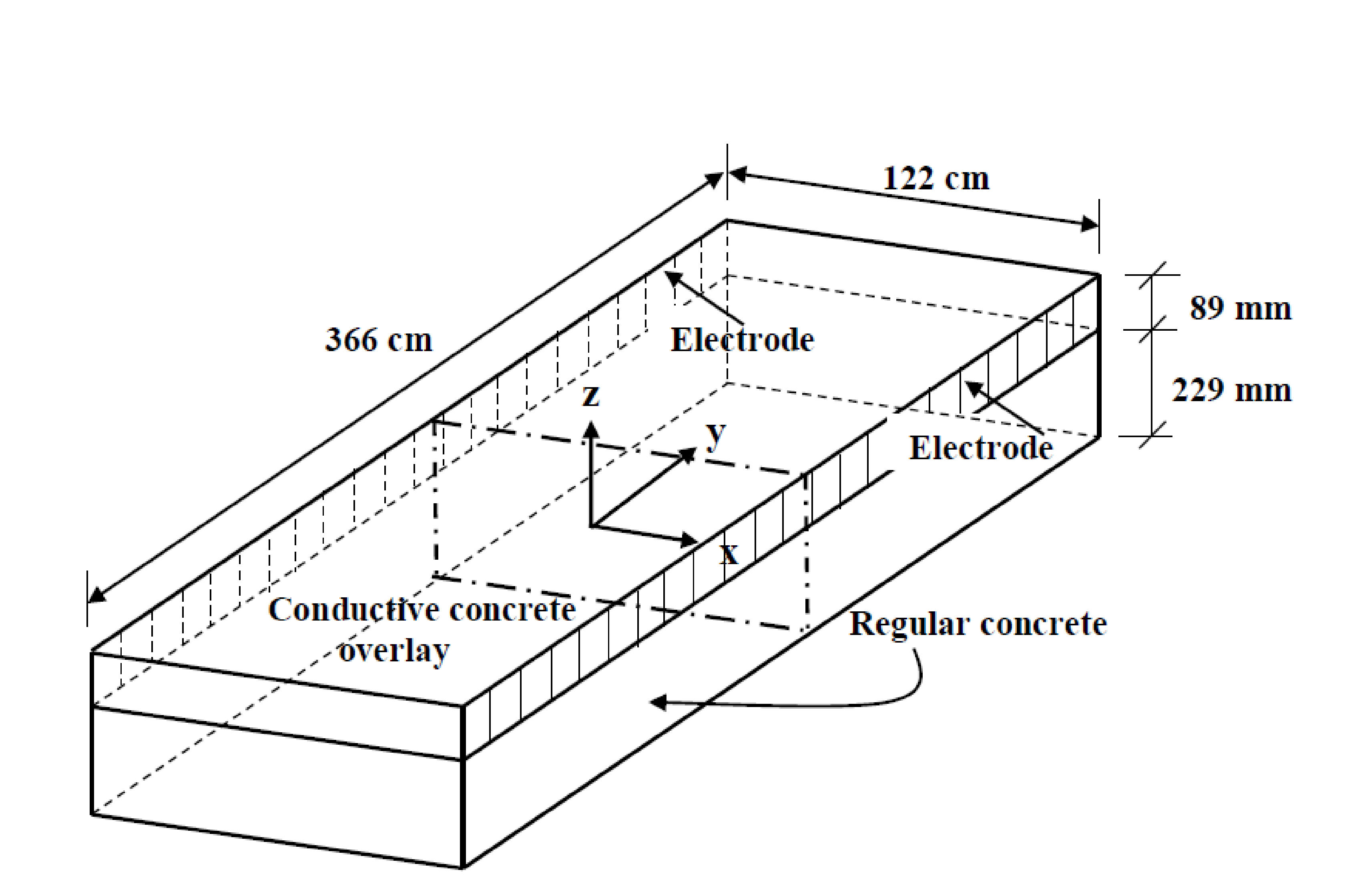
$$\frac{\partial}{\partial x}\left(\kappa_\phi \frac{\partial \varphi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\kappa_\phi \frac{\partial \varphi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\kappa_\phi \frac{\partial \varphi}{\partial z}\right)=0$$

where $\varphi(x,y,z)$ is the electric potential, and κ_ϕ is the electrical conductivity of the conductive concrete.

Transient heat conduction equation:

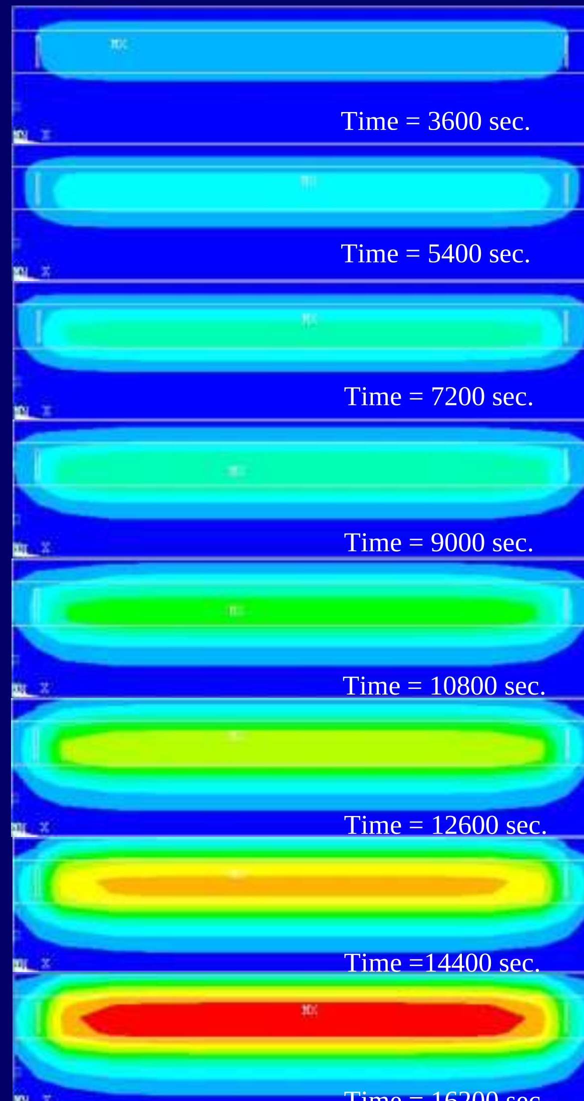
$$\rho C_p \frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(\kappa_T \frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\kappa_T \frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\kappa_T \frac{\partial T}{\partial z}\right)+Q$$

where ρ, C_p , and κ_T are the mass density, heat capacity, and thermal conductivity of the conductive concrete, respectively. Q is the rate of internal heat generation per volume. $T(x,y,z,t)$ is the temperature field, and t is time. Assume κ_T is constant within the temperature range -25 to 10 C.

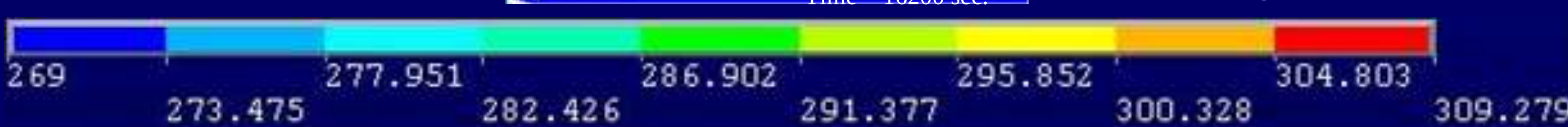


3D Finite Element Modeling

Electrical Heating FE Simulation



Temperature (ºK)



Steel Fibers
1.5~2% by volume

Steel shavings
15~20% by volume

Anti-icing 1998

Deicing 1999

Deicing 2000

Conductive Concrete with Steel Fibers and Shavings

Date	Snow accumulation (in.)	Experiment type	Hours of preheating	**Power consumption** (kW-hr)	**Energy Cost** ($/ft^2)
Feb. 11, 1999	3	Anti-icing	6	32.48	0.052
Feb. 17, 1999	8	Anti-icing	4	42.64	0.068
Feb. 20, 1999	2	Deicing	---	9.84	0.016
Feb. 22, 1999	11	Anti-icing	2	33.76	0.054
March 8, 1999	10	Deicing	---	46.16	0.074

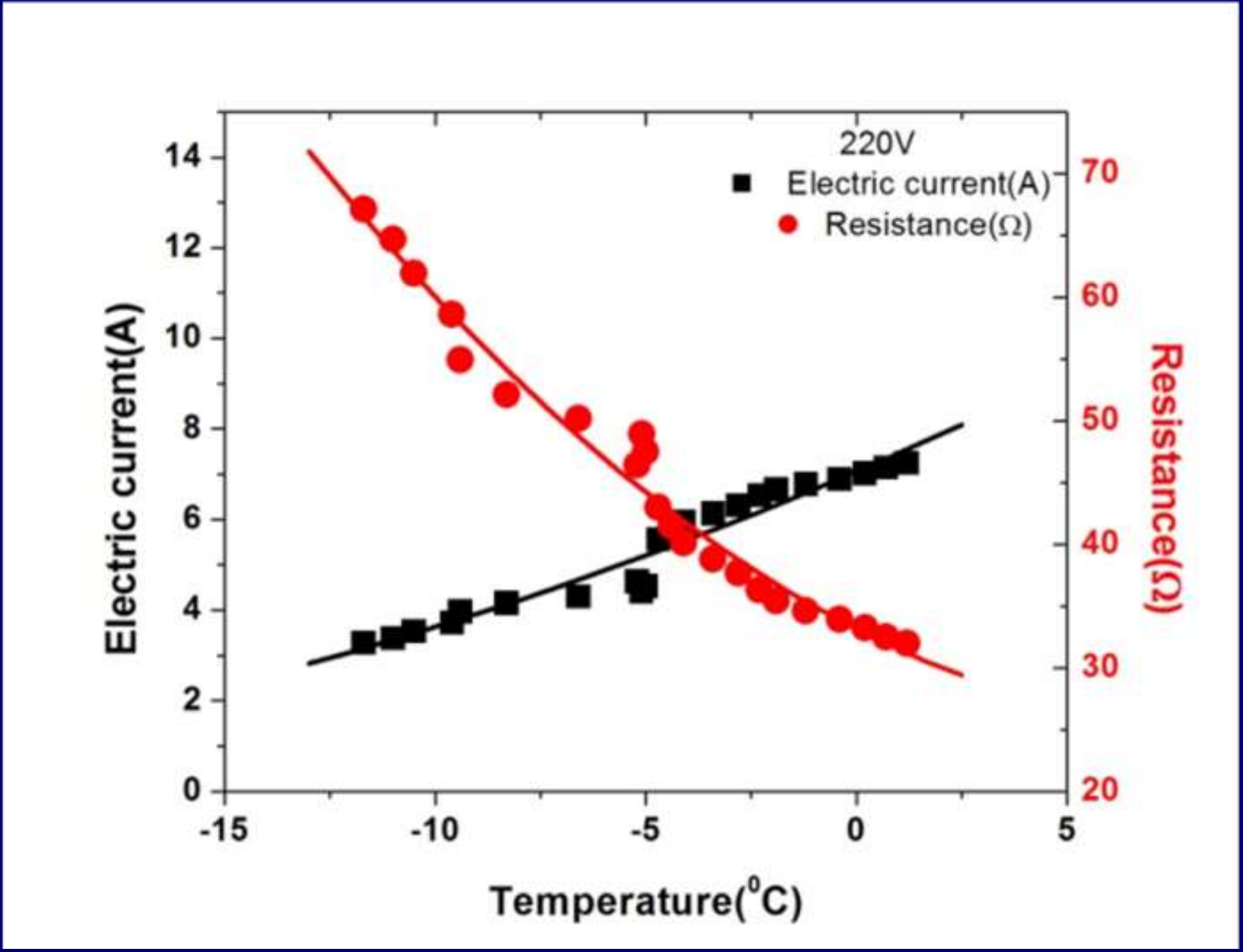
Material Testing - ASTM and AASHTO Specifications

- Compressive strength: 45 MPa (6500 psi)
- Flexural strength: 4.6 MPa (670 psi)
- Modulus of Elasticity: 3634 MPa (527 ksi)
- Freeze-thaw Resistance: 312 cycles, no failure
- Shrinkage: less than ACI-209 by 20~30%
- Permeability: 0.004~0.007 cm^3/sec.
- Thermal Conductivity: 7.8 W/m-^{o}K
- Electrical Resistivity: 500~1000 Ω-cm

Conductive Concrete with Carbon & Graphite Products and Steel Fibers

2nd generation conductive concrete mix utilizing graphite and carbon particles to replace steel shavings.

Current, Resistance and Temperature Relationships (at -15°C, 220 V AC)



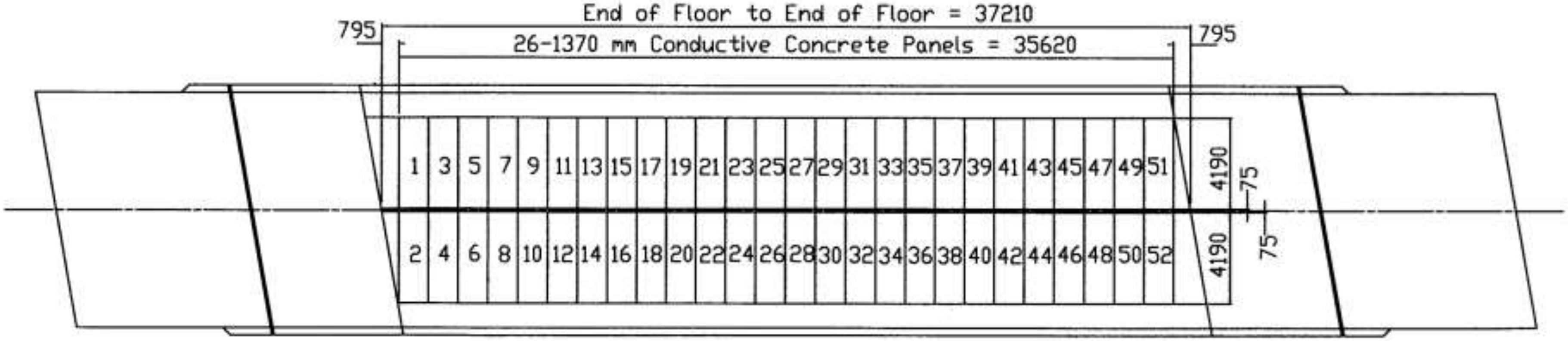
Roca Spur Bridge

built in 2002

- Located about 15 miles south of Lincoln, Nebraska, on Highway 77 South.
- Roca Spur Bridge is a three-span slab bridge with a 45.7m (150 ft) long and 11m (36 ft) wide concrete deck.
- The bridge has a 36 m (117 ft) long and 8.5 m (28 ft) wide conductive concrete inlay.
- The inlay consists of 52 individual 1.2m x 4.1m (4 ft x 14 ft) conductive concrete slabs.

52 Individual Heated Deck Panels

Nebraska Department of Roads



CONDUCTIVE CONCRETE PANEL LAYOUT

(Dimensions in mm)

Bridge Deck Construction


55

Consistent Deicing Performance

Feb 5, 2004

March 21, 2006

Feb 13, 2007

Feb 6, 2008

Monitoring Bridge Performance in Real Time

Computer screen display

Bridge Status

Temp	40.2	38.5	39.1	38.4	39.3	37.7	38	37.5	34.9	34.8	34.7	33.9	34.1	33.9	34.6	35.3	34.8	36.7	35.3	36.1	36.1	37.1	37.1	37.4	35.6	34.9
Amps	3.4	2.8	2.8	2.9	3	2.9	2.7	2.6	2.6	2.4	2.4	2.3	0	3.1	2.7	2.9	3.5	4	5.1	4.4	4.2	3.7	3.1	3.2	3.3	3.4
Slab#	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
Temp	39	40.1	37.9	39.1	38	39.6	39.5	40	37	35.9	35.2	35.1	35	34.7	31.2	34	35.1	35.8	36.6	35.8	37.2	36.5	37.4	38	35.1	35.6
Amps	3.1	3.5	3.3	3.2	3.2	3.3	3.2	3.6	3.5	3.6	3.5	3.7	0	3	2.9	3.3	3.2	3.1	3.4	3.8	4.2	3.7	3.2	3.4	3.5	4
Slab#	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52

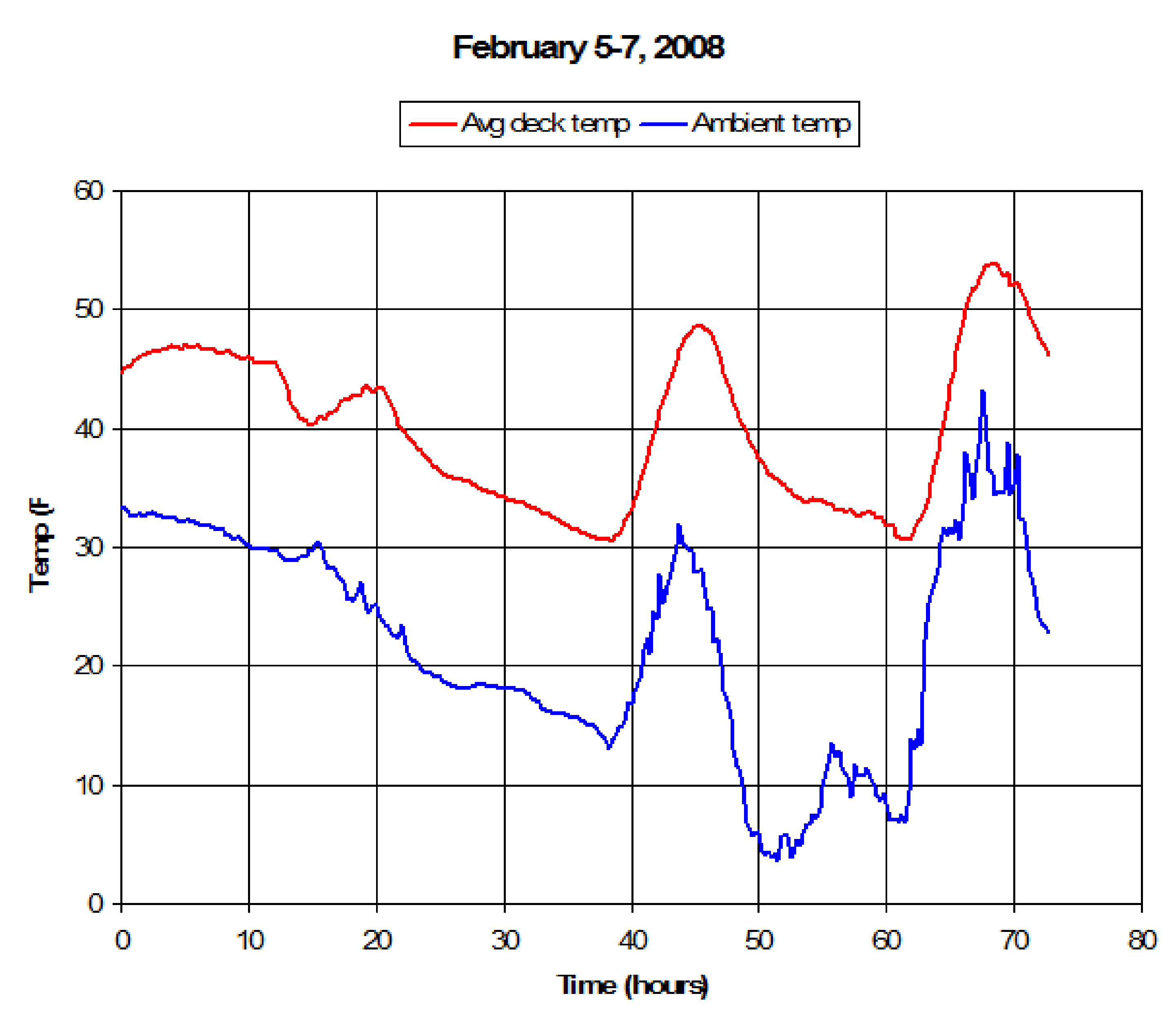
Ambient Temp 31.2

Legend

On Off Fault

Nov 30, 2007

Heating Performance



Deicing Performance Data

Storm Date	Snow depth (in.)	Air temp. (ºF)	Wind (mph)	Energy (kW-hr)	Unit Cost ($/ft^2)	Peak Power Density (W/ft^2)
Dec 8-9, ‘03	6.5	20.7	16.2	2,023	0.050	40.04
Jan 25-26, ‘04	10.1	14.9	14.4	2,885	0.070	30.74
Feb 1-2, ‘04	5.7	14.4	11.1	2,700	0.066	26.57
Feb 4-6, ‘04	7.8	19.2	11.5	3,797	0.093	35.94
Jan 2-5, ‘05	8.5	15.6	14.3	3,128	0.076	33.01
Feb 6-8, ‘05	4.6	17.3	12.7	3,327	0.081	32.25
Mar 18-21, ‘06	9.9	32.5	16.2	2,786	0.068	29.97
Jan 13-14, ‘07	3.3	10.9	21.7	2,366	0.058	18.86
Jan 20-21, ‘07	6.0	19.4	17.4	2,573	0.063	30.19
Feb 12-13, ‘07	3.8	17.6	16.2	2,653	0.065	33.54
Mar 1-3, ‘07	7.1	29.8	19.9	2,893	0.071	36.79

Deicing Performance Data (cont.)

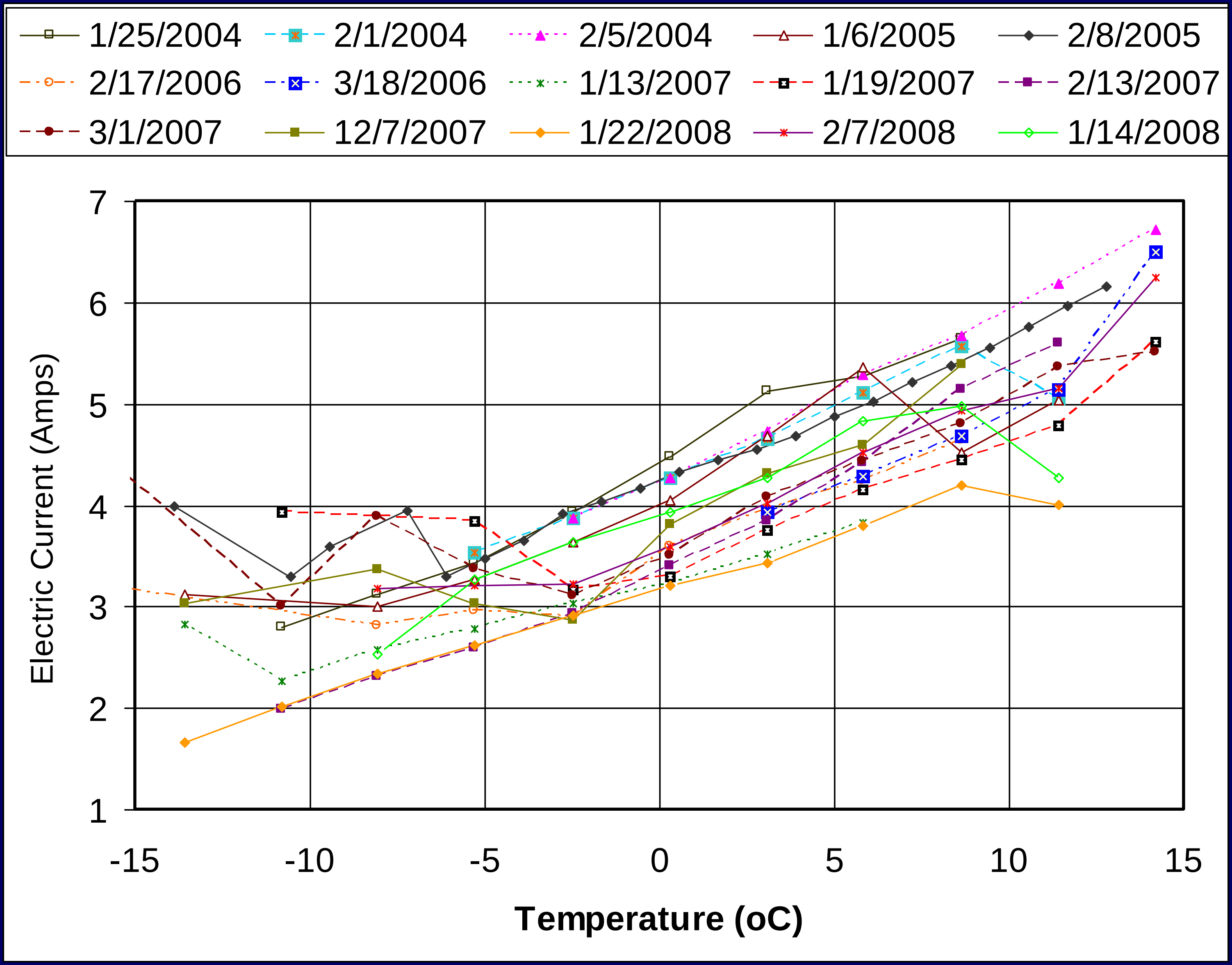
Storm Date	Snow depth (in.)	Average Air temp. (°F)	Wind (mph)	Energy (kW-hr)	Unit Cost ($/ft^2)	Peak Power Density (W/ft^2)
Dec 5-7, '07	3.5	22.5	20.5	2,866	0.070	35.02
Jan 15-18, '08	3.8	18.1	24.8	2,445	0.059	34.56
Feb 4-7, '08	4.6	21.9	22.4	3,046	0.074	36.98

Operating cost

Energy consumption during a major storm (3 days):
Average = 1,000 kW-hr/day
Total Cost = $250/storm

Utility cost = $0.08 per sq. ft. of deck surface

Stability of Electrical Conductivity



Award-winning Bridge Project

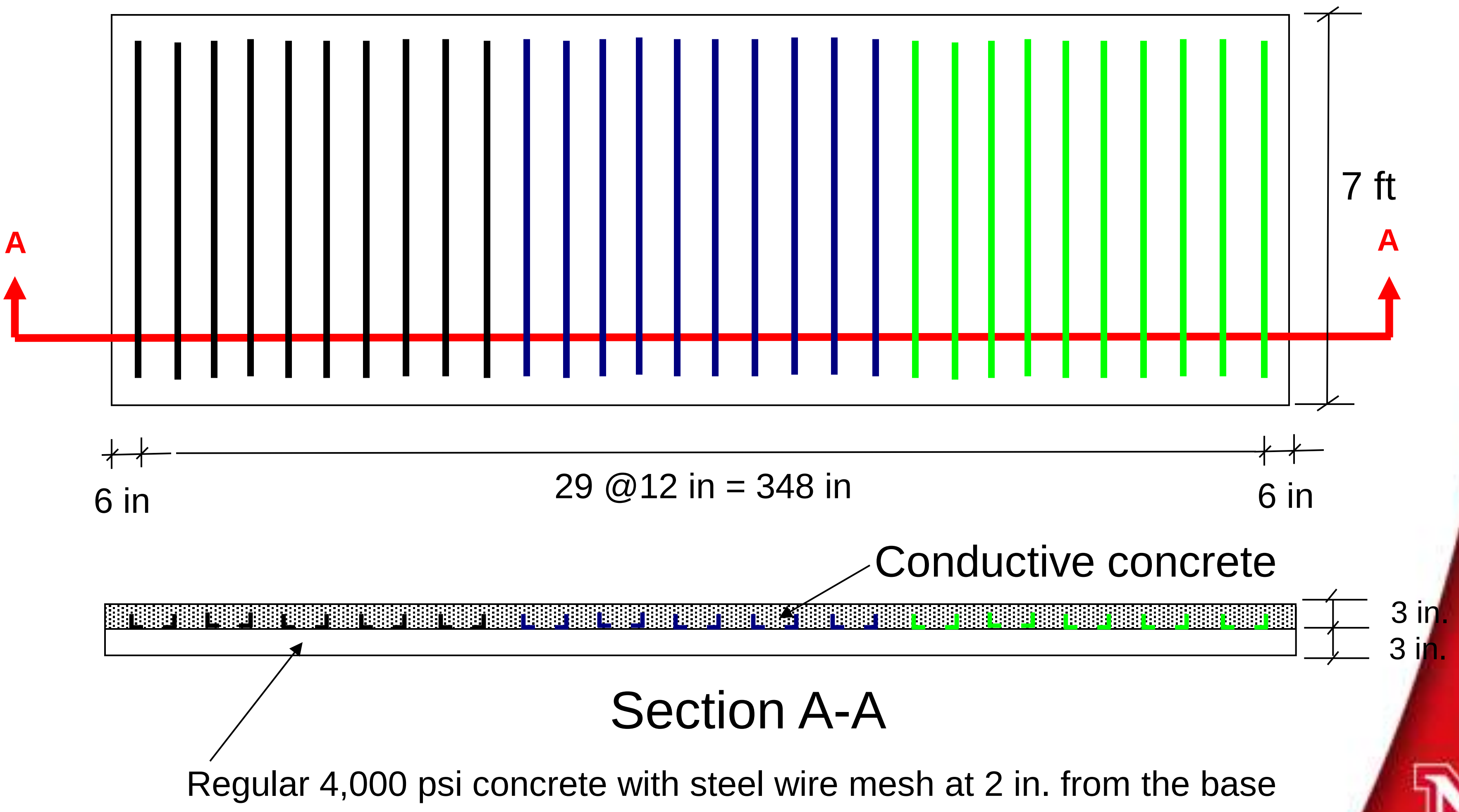
American Concrete Institute
Award of Excellence, 2004

- The Economist, 9/29/06

- Discovery Channel Magazine
August 2010

Heated Driveway Entrance

Electrodes Layout



Heated Driveway – under 48 V AC

June 2010

Dec 2010

Deicing performance

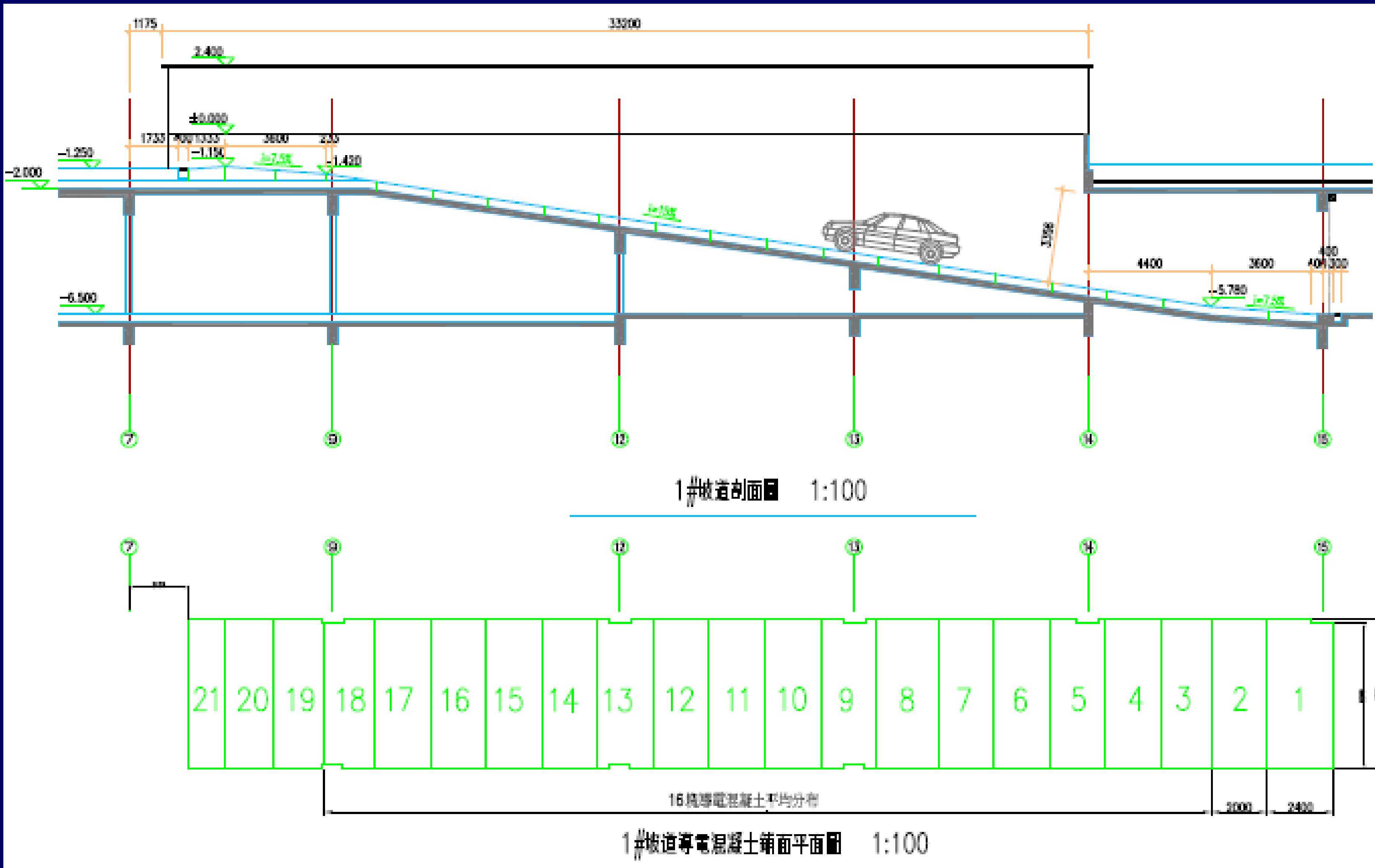
December 8, 2011

- **Ambient temp = 22 F, the total current = 36 Amps under 48 V AC. The slab temp was about 38 F.**
- **The heated pad is 7 ft wide and 30 ft long. Output power density = (36x48)/(7x30) = 8.2 W/ft^2.**
- **Energy consumption per day = 40 kW-hr. $0.075/kW-hr x 40 kW-hr = $3/day.**
- **Powered by a 3 kVA transformer.**

Parking Ramps – Harbin Institute of Technology built in 2012

- The East and North Ramps of the parking garage at the Architectural Design and Research Institute, Harbin, China.
- Both ramps were overlaid 3.5-in. conductive concrete for deicing.
- The East Ramp is 135 feet long and 18.5 feet wide, and the North Ramp is 135 feet long and 25 feet wide.
- Both ramps have a steep slope of 15%.
- Powered by 48 V AC via transformers connected to a 220 V AC source.

North Parking Ramp – Harbin Institute of Technology, China



Construction Sequence

Acceptance Heating Tests

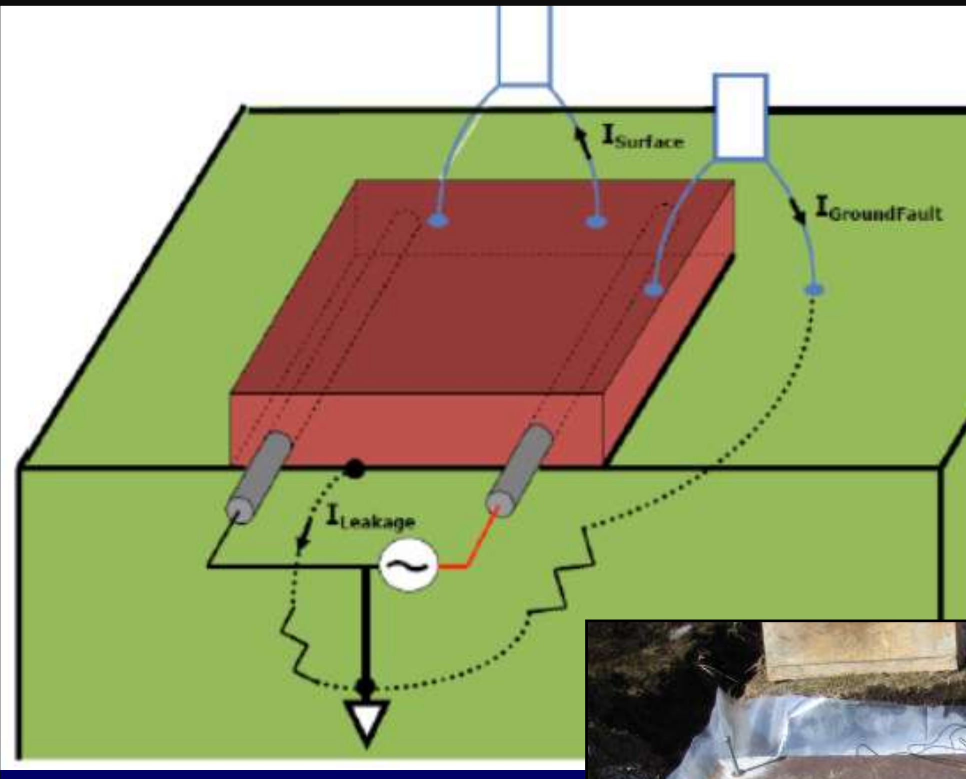


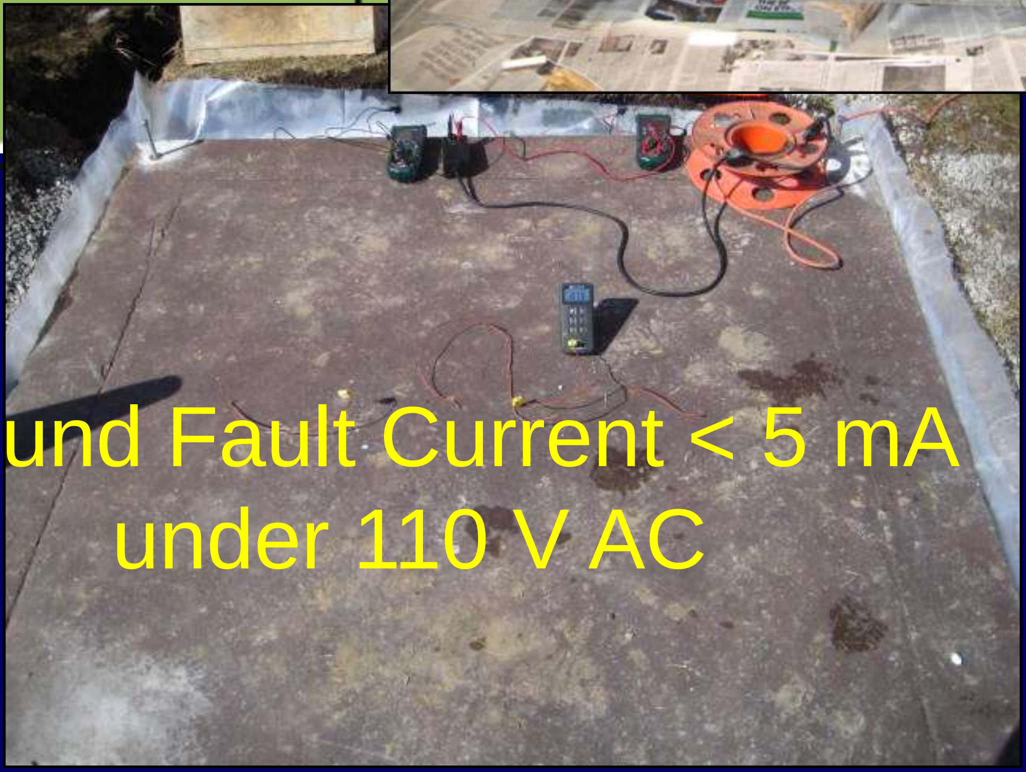



September 2013

East Ramp Heating Performance

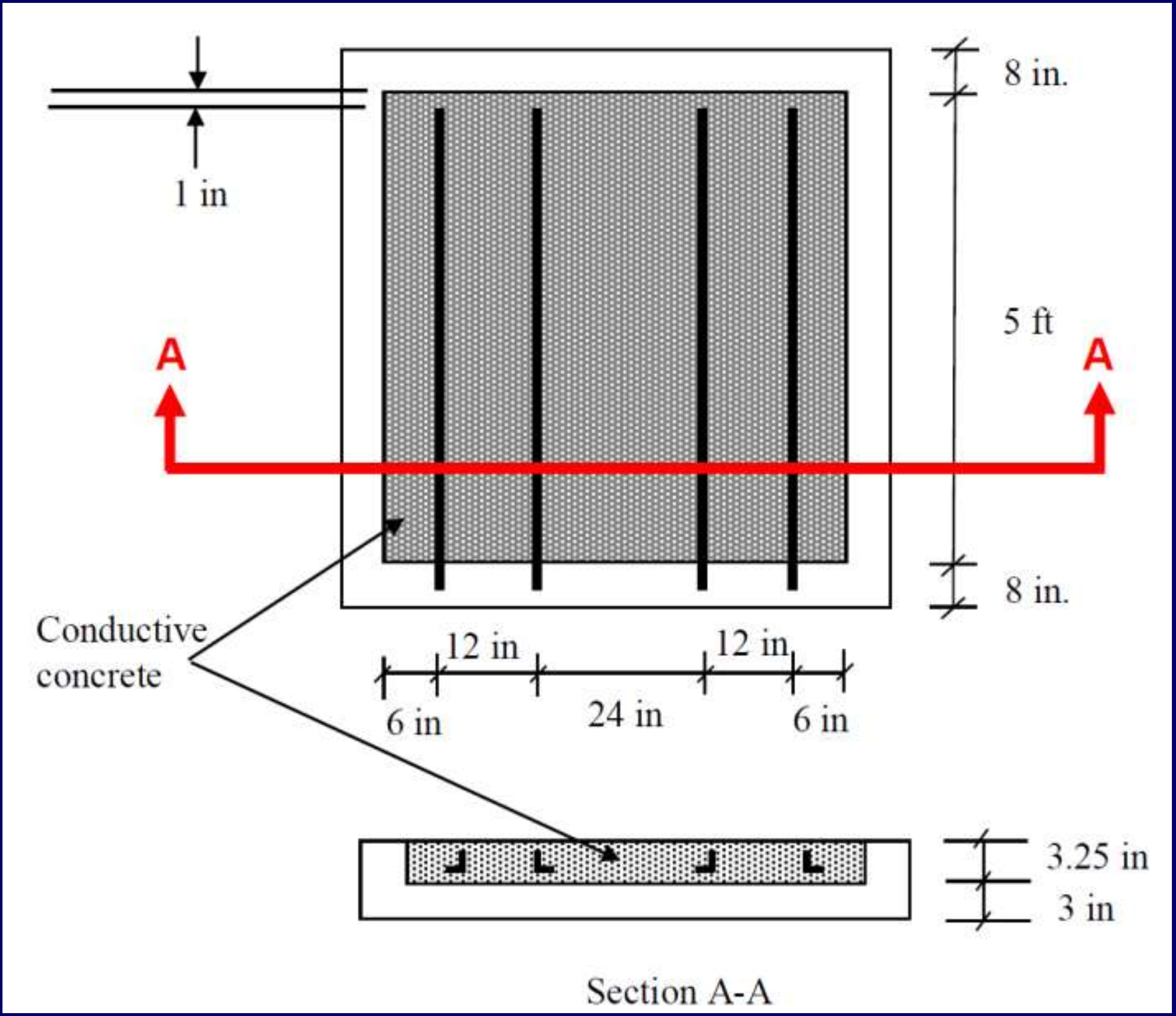
North Ramp Heating Performance

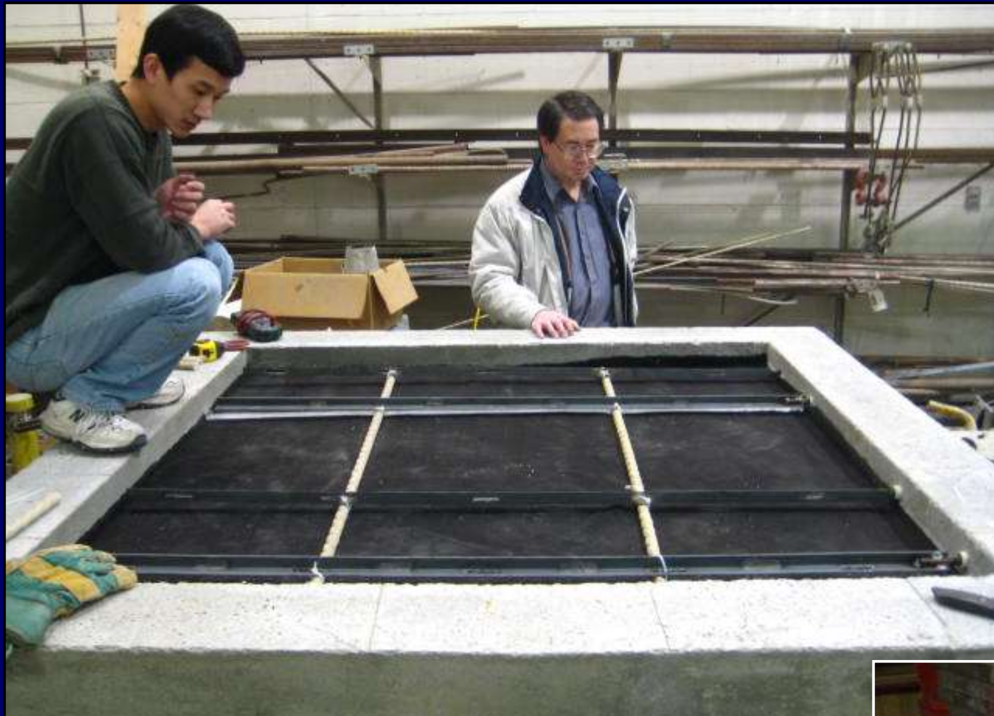




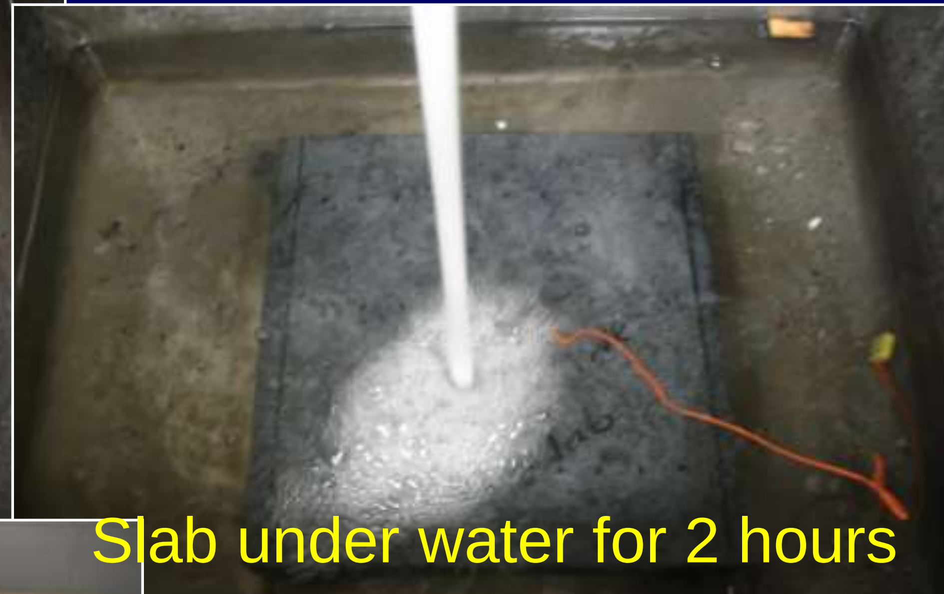
Ground Fault Current < 5 mA
under 110 V AC

Precast Heated Concrete Panels



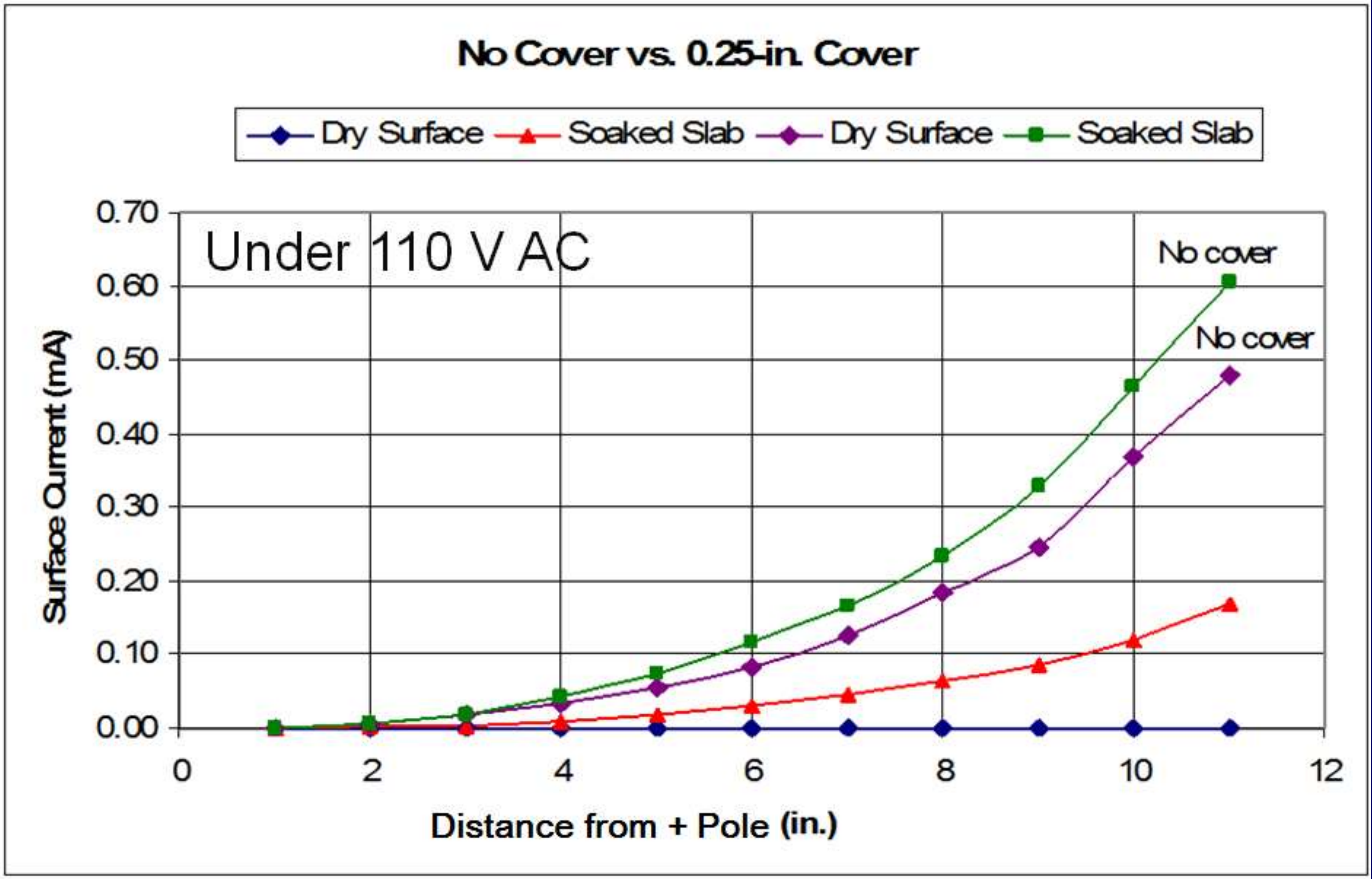



Surface Current Measurement



Slab under water for 2 hours

Effects due to 0.25 in. Concrete Cover



Schemes to Mitigate Surface Current

(1) use thin polymer concrete overlay

(2) use a 1/8-in. coating with low-viscosity, low-modulus epoxy (Unitex DOT III)

(3) use steel wire mesh on top for grounding

(4) use precast conductive concrete panels

"The following material is based upon work supported by the Federal Aviation Administration under Grant Number. (14-G-017)."

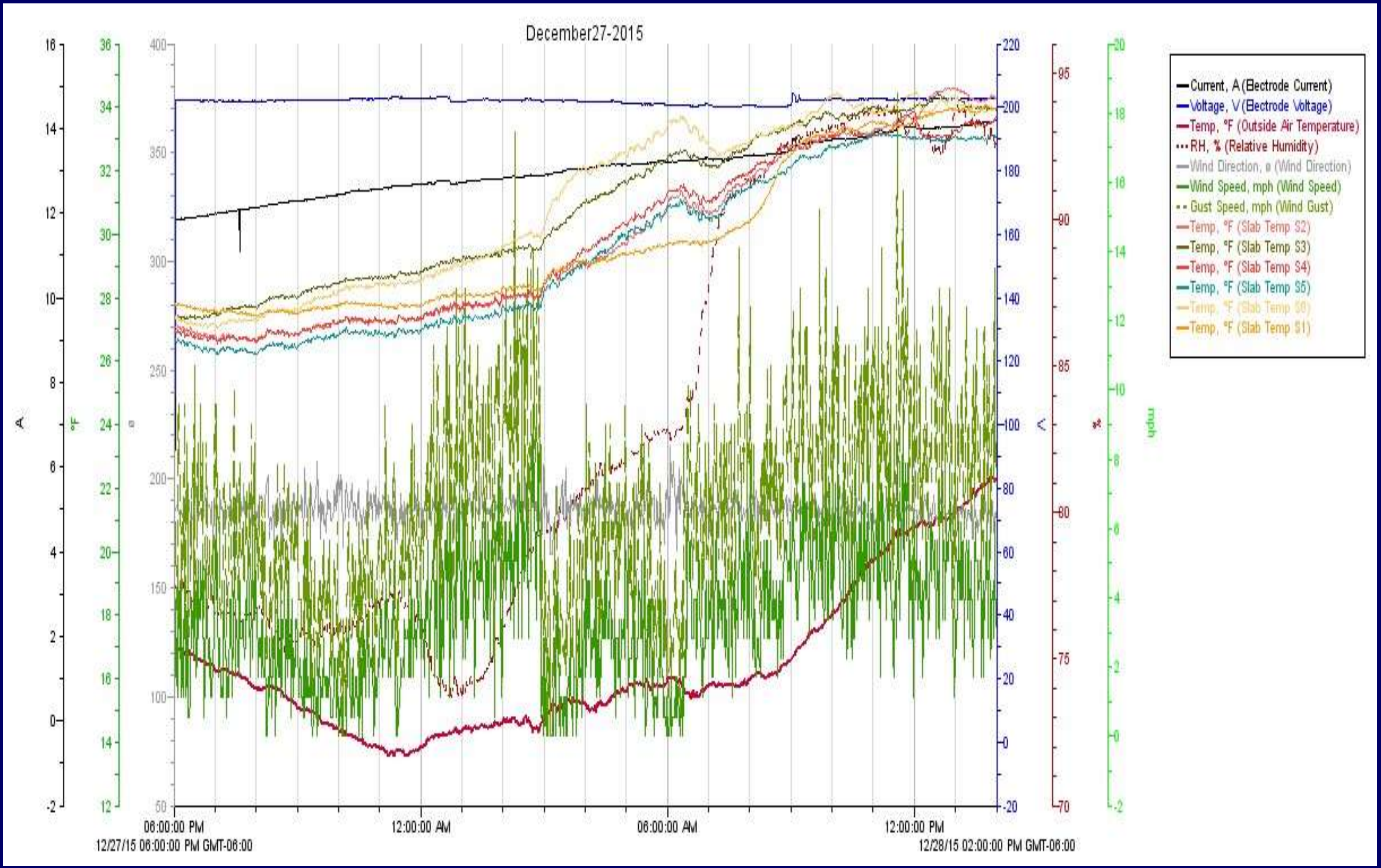
"Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Federal Aviation Administration."

10 ft x 20 ft Test Pad – Research funded by FAA

Dec 28, 2015

Layout Electrodes and Power Chords

Weather and Sensor Data



10 ft x 20 ft Test Pad Deicing Data

Storm Date	Snow depth (in.)	Air temp. (°F)	Wind (mph)	Energy (kW-hr)	Unit Cost ($/ft^2)	Peak Power Density (W/ft^2)
Dec 24-25, '15	7.0	23.4	8.5	45.9	0.021	15.5
Dec 27-28, '15	4.2	13.6	18.6	69.8	0.031	14.4
Jan 25, 2016	4.0	25.2	16.5	73.4	0.032	13.0
Feb 2-3, '16	4.9	12.9	12.4	84.9	0.037	11.8

Power source: 3-phase, 208 V AC, 30 A capacity

Snowstorm – Dec 28, 2015

Snowstorm – Feb 2, 2016

THANK YOU