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Examining repairs in Staunton, Illinois

Evaluation of Bridge Deck Overlays

by Rachel J. Detwiler, Tony Kojundic, and Per Fidjestøl

The IL 4 bridge over Interstate 55 was originally built in 1973 on State Route 4 near Staunton, Ill., about 50 mi (80 km) northeast of St. Louis, Mo. It is approximately 300 ft (91 m) long with two traffic lanes separated by a median strip.

In October 1986 the southbound lane was repaired using a standard dense mix concrete; the northbound lane was repaired in March 1987 using a silica fume concrete, the first use by the Illinois Department of Transportation (IDOT) of a silica fume concrete bridge deck overlay. Both repairs were performed by the same contractor and in both cases consisted of partial- and full-depth repairs followed by a 2 - 4 in. (50 - 100 mm) overlay. The mix proportions are given in Table 1.

IDOT's construction records indicate that the dense concrete as placed contained 5.5 - 6.3 percent air. The 7-day compressive strength was 5660 psi (39 MPa), and the 14-day strength was 6370 psi (44 MPa). IDOT elected to take advantage of the greater ease with which strength is obtained using silica fume concrete to increase the air content for additional resistance to salt scaling. Thus the silica fume concrete as placed contained 6.0 - 8.4 percent air. The 7-day compressive strength was 5780 psi (40 MPa) and the 14-day strength was 6950 psi (48 MPa).

According to IDOT's records of the silica fume concrete overlay repair, the bridge deck was first prepared by hydrodemolition in order to remove the salt-contaminated concrete, after which the water and debris were blown off the deck. Bonding grout containing one part cement and one part sand plus 15 percent silica fume by mass of cement was broomed into place on the deck. The concrete was placed and finished. Texturing was accomplished using an Astroturf drag followed by tining. The overlay was covered with wet burlap and plastic and kept continuously wet for seven days. An inspection of the bridge three months after the placement of the silica fume concrete overlay revealed four short transverse cracks and a few shorter cracks near the drains. These were not considered significant.

IDOT's records of the three-month inspection indicate cracking at most of the supports, with a few transverse cracks found at other locations. Luther[1] reports that, at the time of the three-month inspection of the silica fume concrete overlay, the adjacent dense concrete overlay had seven transverse cracks at 6 - 8 ft (1.8 - 2.4 m) intervals.

According to IDOT,[2] the average snowfall in this part of the state is 20 in. (500 mm) per year. The application of salt in a given year depends on the snowfall — for the years 1993, 1994, and 1995, the application was 30, 32, and 20 tons (27, 29, and 19 metric tons) of salt per mile-lane of roadway, respectively. Because bridge decks freeze more readily than the adjacent pavement, they are subjected to heavier salt applications whenever there is a frost alert. Thus IDOT estimates that the IL 4 bridge receives 10 times the salt of the adjacent pavement, or in excess of 6.3 lbs/ft^2 (31 kg/m^2) annually.

Based on a report by Janssen et al.,[3] pavement in the St. Louis area experiences an average of 46 freeze/thaw cycles per year; the bridge experiences somewhat more cycles. IDOT estimates the average annual daily traffic on the bridge at 2600 vehicles in 1985, 2200 in 1987, 3200 in 1991, and 3600 in 1993. Traffic on the bridge was lighter in 1987 because of construction in the area.

Field survey

Conducted in July 1995, the field survey consisted of a visual examination, photo documentation, and delamination survey by means of the chain drag method. A total of 10 4-in. (100 mm) diameter cores were taken from the silica fume concrete overlay and two from the dense concrete overlay. After

Table 1 — Mix proportions and properties for overlay concretes

	Silica fume concrete (*w/cm* = 0.31)	Dense concrete (*w/cm* = 0.32)
Water	218 lb/yd^3 (129 kg/m^3)	264 lb/yd^3 (157 kg/m^3)
Cement	630 lb/yd^3 (374 kg/m^3)	823 lb/yd^3 (488 kg/m^3)
Silica fume	70 lb/yd^3 (42 kg/m^3)	0
Coarse aggregate	1590 lb/yd^3 (943 kg/m^3)	1389 lb/yd^3 (824 kg/m^3)
Fine aggregate	1358 lb/yd^3 (806 kg/m^3)	1410 lb/yd^3 (837 kg/m^3)
Strength, 7 days	5780 psi (40 MPa)	5660 psi (39 MPa)
14 days	6950 psi (48 MPa)	6370 psi (44 MPa)
Air content	6.0 - 8.4 percent	5.5 - 6.3 percent

review of the laboratory data, it was decided to remove and test an additional six cores of the dense concrete overlay; these cores were taken in January 1996.

Observations of the northbound lane that had been repaired with the silica fume overlay indicated good performance. The surface shows very little abrasion wear, with the tine marks clearly visible. There is no evidence of surface scaling, indicating good resistance to freezing and thawing and deicer scaling. Chain dragging indicated overall good bond to the concrete substrate, with delamination in 22 areas representing less than 2 percent of the total overlay. The cracking pattern is primarily transverse; spacings vary from 3 - 4 ft (1.0 - 1.2 m).

Observations of the southbound lane that had been repaired with the dense concrete overlay indicated a similar degree of cracking. The surface shows good resistance to abrasion and freezing and thawing and is well bonded to the concrete substrate. Chain dragging indicated delamination in 8 areas representing less than 1 percent of the total overlay.

Finishing work on IL 4 overlay.

Laboratory investigation

Petrographic examination

Ten cores of the silica fume concrete overlay were examined according to ASTM C 856-83 (reapproved 1988), "Standard Practice for Petrographic Examination of Hardened Concrete." In general, the overlay was tightly bonded to the substrate. The overlay concrete was well consolidated. In those cores containing reinforcing steel or the impression of reinforcing steel, minor amounts of corrosion products were detected. This corrosion appears to have taken place primarily within the substrate.

Two cores of the dense concrete were also examined. These showed the overlay to be well consolidated and tightly bonded to the substrate.

Overall, those properties of concrete that are important for durability were considered excellent in both silica fume and dense concretes: the paste was uniformly dense, the paste-aggregate bond was tight, and there was very little microcracking.

Table 2 — Total charge passed, coulombs, in six hours (ASTM C 1202)

Silica fume concrete	Dense concrete
240	1350
330	2200
250	2720
140	2380

Chloride ion penetration

Four cores of each concrete were tested according to ASTM C 1202-94, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration." Table 2 shows the total charge passed in six hours for each core. The values are not averaged because the cores were taken from widely separate locations on the deck; thus they do not necessarily represent the same batches of concrete. The values for the silica fume concrete indicate very low penetrability, while the values for the dense concrete indicate moderate or (in one case) low penetrability.

Similar tests were conducted of 42-day-old cylinders from a trial mix of the silica fume concrete. They had been moist cured for 28 days before shipment and placed in limewater on arrival at the laboratory. The average charge passed in six hours for these cylinders was 540 coulombs, also characterized as very low penetrability.

Chloride profiles

Four cores of each concrete were milled on a lathe in layers of approximately 1 mm (0.04 in) thickness. The dust from each layer was carefully collected and analyzed for acid-soluble chlorides. Fig. 1 shows chloride profiles for the silica fume and dense concrete mixes. The lower chloride concentrations near the surface most likely reflect the washing out of the salt with rain. Note that the chloride ion concentration never reaches zero because the local aggregates contain chlorides; it does not reflect the migration of salt from the surface.

Chloride ions migrate into a concrete bridge deck overlay by several mechanisms: diffusion, capillary action, and convection. Pettersson[4] reports that in laboratory tests of silica fume concretes subjected to cycles of wetting and drying, the transport of chloride ions is governed by diffusion at distances greater than about 30 mm (1.2 in.) below the surface. In the IL 4 bridge specimens studied the chlorides for the most part have not penetrated to this depth; therefore Fick's Second Law (which describes diffusion only) cannot be applied to the data. Instead we show the chloride concentrations at the depths of 10 mm (0.4 in.) and 25 mm (1.0 in.) from the surface for each core. Table 3 gives the results.

Conclusions and recommendations

From the field survey and the petrographic examination, it is clear that both the dense concrete and the silica fume concrete overlay repairs were originally of high quality. Both have

Table 3 — Chloride concentrations, percentage by mass of concrete

Silica fume concrete		Dense concrete	
Depth from sufrace of cores			
10 mm	25 mm	10 mm	25 mm
0.152 (0.839)	0.042 (0.232)	0.253 (1.19)	0.084 (0.397)
0.074 (0.409)	0.014 (0.077)	0.263 (1.24)	0.061 (0.288)
0.087 (0.480)	0.014 (0.077)	0.077 (0.364)	0.021 (0.099)
0.066 (0.365)	0.018 (0.099)	0.370 (1.75)	0.114 (0.538)

Percentage by mass of cementitious material in parenthesis.

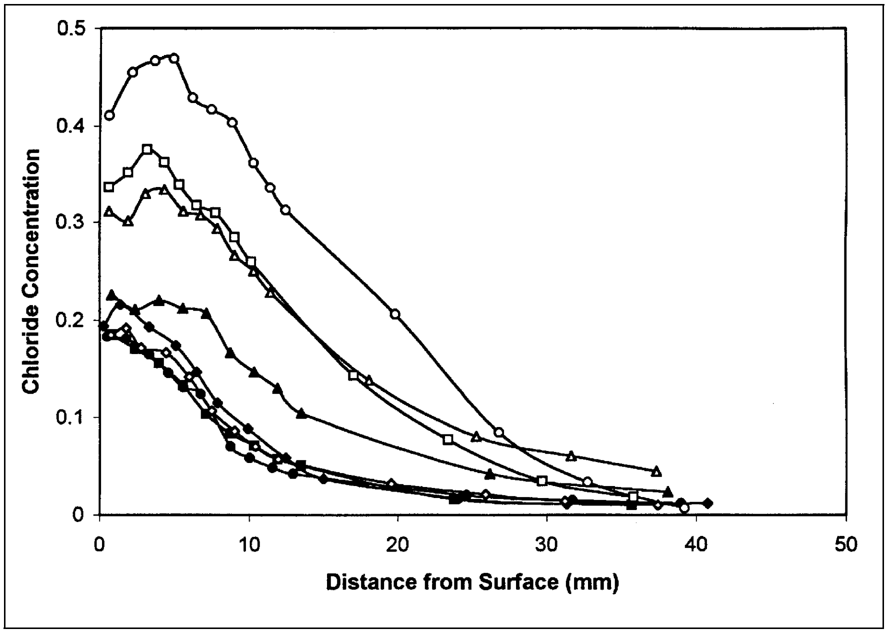

Fig. 1 — Acid soluble chloride content, percentage by mass of concrete, vs. distance from surface. The hollow symbols represent the dense concrete (without silica fume) and the filled symbols represent the silica fume concrete. Because the aggregates used contain chlorides, the concentration does not reach zero even at some distance from the surface; this does not reflect chloride ion migration from the surface.

performed well under exposure conditions of more than 46 freeze/thaw cycles and in excess of 6.3 lb/ft^2 (31 kg/m^2) of salt applied annually — 8 years in the case of the silica fume concrete and 9 years in the case of the dense concrete.

Taking into account the additional winter of exposure for the dense concrete, the silica fume concrete appears to provide better protection against the ingress of chloride ions. The results of the test of resistance to chloride ion penetration (ASTM C 1202) show the silica fume concrete to have very low chloride ion penetrability. These results are consistent with the chloride profiles, which generally show the chloride ion concentration of the silica fume concrete to be lower than for the dense concrete at a given distance from the surface. The dense concrete had moderate to low penetrability according to ASTM C 1202; these results are also consistent with the chloride profiles of the companion cores.

The IL 4 bridge over I-55 provides an unusual opportunity for the comparison of good quality field placements of dense concrete and silica fume concrete. The same contractor used the same bridge paving screed to place, level, and consolidate the concrete and essentially the same hand-finishing techniques for texturing before curing for both jobs. In addition, the exposure conditions were known to be particularly severe: the original bridge deck had to be replaced after 13 years. According to IDOT, bridges at that time were designed for a 50-year life, with initial deck maintenance (patching) anticipated after 15-20 years and replacement of the deck or patching followed by an overlay expected at 25 years.

Because it was the first use of silica fume concrete by IDOT for a bridge deck overlay, the repair procedures are particularly well documented. The fact that it was an overlay allowed us to investigate the bond strength and other aspects of the performance of bonded overlays. We recommend that a similar study be conducted in five to ten years to obtain further data on the field performance of the two types of concrete.

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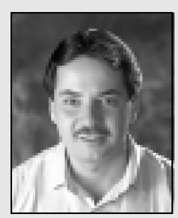
References

1. Luther, M.D., “Silica Fume (Microsilica) Concrete in Bridges in the USA,” *Paper* no. 870257, presented at the Transportation Research Board 67th Annual Meeting, January 11-14, 1988, Washington, D.C.
2. Hahn, R.W., Illinois Department of Transportation, personal communication to Terry J. Willems, October 25, 1995.
3. Janssen, D.J.; Dempsey, B.J.; DuBose, J.B.; and Patel, A.J., Predicting the Progression of D-Cracking, Transportation Engineering Series No. 44, Illinois Cooperative Highway and Transportation *Series* No. 211, University of Illinois, Urbana, Illinois, February 1986.
4. Pettersson, K., Olika Faktorers Inverkan på Kloriddiffusion i Betongkonstruktioner (The Effect of Different Factors on Chloride Diffusion in Concrete Structures), CBI *rapport* 4:94, 37 pp., Cement och Betong Institutet, 100 44 Stockholm, Sweden, 1994.

Selected for reader interest by the editors.

Rachel J. Detwiler received her PhD from the University of California at Berkeley. She is a senior engineer at CTL in Skokie, Ill. She is secretary of ACI Committee 234, Silica Fume in Concrete, and a member of ACI Committee 227, Radioactive and Hazardous Waste Management.



Tony Kojundic is business manager at Elkem Materials, Inc., in Pittsburgh, Pa., where he directs development of silica fume products. He was Elkem’s project manager for the IL 4 bridge project. He is a member of ACI Committees 234, Silica Fume in Concrete; 362, Parking Structures; and 363, High Strength Concrete.

ACI Fellow **Per Fidjestøl** is technical manager for Elkem A/S Materials in Norway. He is chairman of ACI’s International Activities Committee and a member of several ACI technical committees, among them TAC High-Performance Concrete; 234, Silica Fume Concrete; 201, Durability; and 213, Lightweight Concrete.