Investigation of Popout and Scaling in Concrete Driveways

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Several homeowners of the Eagle Ridge subdivision in the Village of Oak Lawn, Illinois encountered concrete deterioration problems with their driveways. An investigation was conducted to determine the cause of this deterioration. Upon site inspection of the various driveways, five locations appeared to have the most severe concrete deterioration, scaling, and popout of parts of the finished surfaces. As a result, these driveways were selected for the field and laboratory investigation.

Scaling is a breakdown of a concrete surface (Fig. 1). This scaling begins as a flaking off in several areas of the top 3 to 9 mm of the concrete surface. The possible factors that lead to scaling are:

- inadequate air entrainment,
- application of calcium and sodium chloride deicing salts,
- performing finishing operations while bleeding water is still on the surface, and
- insufficient curing before exposure of concrete to frost action in the presence of moisture and deicing salts.[?]

According to city officials, the scaling started in September 1992, three to four months after placement of the concrete, during which no deicing materials were applied to the concrete surface. To identify the factors that may have caused the problem, the following field and laboratory investigations were carried out at the University of Illinois at Chicago:

- determination of the air-void system parameters by using petrographic analysis of the hardened concrete samples with both linear-traverse and modified point-count methods (ASTM C 457),
- determination of the acid-soluble amounts of chloride as a percentage of hardened concrete at different depths using the RCT method (comparable to ASTM C 114), and
- determination of the compressive strength of the cored concrete samples (ASTM C 42).

Field investigation and experimental program

A field investigation of the five sites was necessary to identify the main factors that caused the driveways to deteriorate. The field investigation included visual inspection as well as sampling of 100 mm diameter cylindrical concrete cores. The cores from the selected sites were taken to the University of Illinois at Chicago for analysis. The analysis involved:

- a petrographic analysis of the hardened concrete,
- the determination of chloride ion concentration as a function of depth, and
- the determination of the concrete compressive strength.

Petrographic examination

Quantitative determination of constituents of concrete was carried out via an automated concrete analysis system (CAS 2000). ASTM C 457 describes two procedures for the microscopical quantification: the linear-traverse method and the modified point-count method. Both methods are incorporated into the CAS 2000.

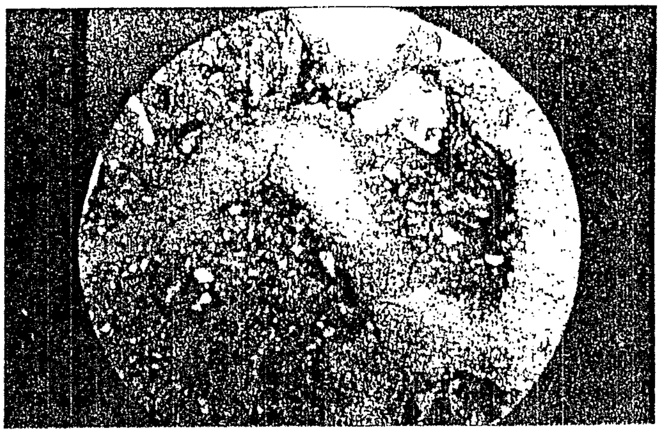

Fig. 1 — Scaling of the concrete surface.

The samples had to be prepared according to ASTM standards before the test procedures were applied. First, the samples had to be cut perpendicular to the top surface layer, and to an area slightly larger than that recommended for the maximum aggregate size. The samples obtained from the designated site had a maximum aggregate size of 19 mm, therefore, at least 6875 mm^2 had to be secured for the linear-traverse and point-count methods. After sawing the samples with a diamond saw, all scratches and unwanted debris had to be polished off by the use of a lapping machine. Each sample was lapped and washed according to ASTM standards. A magnification of 50x was used in both methods. These test methods are summarized in References 1 and 10.

Rapid Chloride Test (RCT)

The Rapid Chloride Test (RCT) provides a reliable and fast method of measuring the acid-soluble amount of chlorides of hardened concrete. The test has a precision similar to a standard laboratory titration (ASTM C 114). The RCT procedure is described in References 1 and 12. To obtain the chloride profile, the five selected sites were investigated. Dust was collected at depths of 5, 10, 20, 30, 40, 50, 70, and 90 mm.

Compressive strength

Concrete samples that were drilled out at the five different locations were tested according to ASTM C 42. This standard test method is used for obtaining and testing drilled cores of concrete. A 100 mm cylindrical core was taken perpendicular to the horizontal finished surface. One end of the cores had to be sawn so as to have a smooth surface. The cores were left in a curing room at 73 F (23 C) and 100 percent relative humidity. Prior to testing, the cores were capped with a sulfur-capping compound (CYLCAP). The lengths of the capped specimens were measured to the near-

Table 1 — Linear traverse method

Address	Void content (%)			Spacing content (mm)			Paste-to-air ratio			Specific surface (1/mm)			Voids per mm		
	Avg.	σ*	Allow.†	Avg.	σ*	Allow.†	Avg.	σ*	Allow.†	Avg.	σ*	Allow.†	Avg.	σ*	Allow.†
10701	5.30	0.2094	6	0.163	0.003	0.1-0.2	4.16	0.164	4-10	25.5	0.64	24-44	0.34	0.010	0.32
10728	5.00	0.2474	6	0.200	0.003	0.1-0.2	4.42	0.223	4-10	21.7	0.95	24-44	0.27	0.006	0.30
10745	6.44	0.2690	6	0.125	0.003	0.1-0.2	3.42	0.148	4-10	27.6	1.46	24-44	044	0.015	0.38
10812	5.44	0.4060	6	0.185	0.005	0.1-0.2	4.07	0.303	4-10	21.9	1.16	24-44	0.30	0.011	0.33
10840	5.58	0.2975	6	0.140	0.003	0.1-0.2	3.96	0.211	4-10	28.2	1.49	24-44	0.39	0.010	0.33

*Standard deviation, †ASTM C 457

est 2.5 mm, then used to compute the length-to-diameter ratio (*l/d*). The average diameter was determined by averaging two measurements taken at right angles to each other at about the midheight of the specimen. The specimens were then tested using a compression testing machine with a capacity of 1779 kN, in accordance with the applicable provisions of ASTM C 39. The compressive strength was calculated for each specimen using the computed cross-sectional area based on the average diameter of the specimen. Strength correction factors were applied to the compressive strength values to account for the length-to-diameter ratio, *l/d*.

Results, analysis, and discussion

Air-void system parameters

The voids must be spaced close enough to reduce the pressure below which would exceed the tensile strength of concrete. For air-entrained concrete designed in accordance with ACI 201.2R and ACI 211.1, the allowable values for the paste-to-air ratio (*P/A*), the specific surface, and the spacing factor usually range from 4 to 10, 24 to 44 mm^2/mm^3, and 0.1 to 0.2 mm, respectively.[4,6,7,10] According to the *ACI Manual of Concrete Practice*, Part 1,[5] the total air content ranges from 5 to 6 percent for moderate-to-severe frost-resistant concrete with a maximum aggregate size of 19 mm.[5] Furthermore, the number of voids per linear inch of traverse should be at least 1½ to 2 times greater than the numerical value of air in the concrete.

The results of the air-void system parameters as well as the volumetric composition of the concrete samples obtained by the linear-traverse and modified point-count methods are summarized in Tables 1 and 2, respectively. Values reported in Table 1 are the averages and standard deviations of four trials on each section. The values in Table 2 are averages of two trials on each section. Typical output from the linear-traverse method is presented in Fig. 2. All values of the spacing factor were within the allowable limits (0.1 to 0.2 mm). The number of voids per linear inch of traverse (*n*) were within the allowable values, except for two, which had slightly lower values.

The paste-to-air ratio (*P/A*) obtained ranged between 3.5 and 4.41. These values were within the allowable limits (4 to 10), except for one driveway where the value 3.5 was slightly less.

Table 2 — Modified point count method

Address	Hardened air (%)		Paste volume (%)	Fine aggregate volume (%)	Coarse aggregate volume (%)	Paste-to-air ratio, *P/A*	
	Avg.	Allow.*	Avg.	Avg.	Avg.	Avg.	Allow.*
10701	5.40	6	22.65	30.65	41.20	4.19	4-10
10728	5.00	6	23.85	32.80	38.35	4.77	4-10
10745	6.16	6	24.30	32.65	36.55	3.95	4-10
10812	5.60	6	24.05	31.75	38.05	4.30	4-10
10840	5.54	6	23.65	32.05	38.40	4.27	4-10

*ASTM C 457

Table 3 — Strength test results

Address	Sample no.	Length (mm)	Diameter (mm)	*l/d*	Load (kN)	Strength (MPa)	Correction factor	Corrected strength (MPa)	Average strength (MPa)
10701	1	87.50	100.00	0.875	382.5	46.6	0.8432	39.3	40.2
	2	87.50	100.00	0.875	400.5	48.8	0.8432	41.2	
10728	1	87.50	100.00	0.875	387.0	47.2	0.8432	39.8	40.6
	2	93.75	100.00	0.938	396.0	48.3	0.8586	41.4	
10745	1	87.50	100.00	0.875	387.0	47.2	0.8432	39.8	36.7
	2	87.50	100.00	0.875	326.2	39.8	0.8432	33.5	
10812	1	90.63	100.00	0.906	378.0	46.1	0.8510	39.2	38.8
	2	90.63	100.00	0.906	369.0	45.0	0.8510	38.3	
10840	1	90.63	100.00	0.906	360.0	43.9	0.8510	37.3	37.8
	2	90.63	100.00	0.906	369.0	45.0	0.8510	38.3	

Table 4 — Rapid chloride test

Address	Chloride content Cl⁻, percentage of mass concrete						
	Depth (mm)						
	5	10	20	30	50	70	90
10701	0.0958	0.198	0.2392	0.1905	0.163	0.1506	0.1447
10728	0.0432	0.1506	0.2304	0.2304	0.2057	0.1567	0.1335
10745	0.0519	0.2348	0.2219	0.163	0.163	0.1506	0.1282
10812	0.0496	0.1133	0.139	0.1335	0.1133	0.123	0.1042
10840	0.0412	0.1308	0.2057	0.198	0.1181	0.0958	0.111

ACCUMULATED LINEAR TRAVERSE DATA -- SURFACE PLOT

```
Originator- UIC
Operator--- EDWARD YOUSIF                    Sample ID- 10701-A
Date------- 10/20/93                         Project #- 1
File------- 10701-1.
Assumed Paste Content = 22.0%
10701 LINDER STREET, OAK LAWN, ILLINOIS

Simulated 3D Surface Plot of Average Void Size per Sector.
Sample is divided into a 15 x 15 sector matrix. Peaks show relative average void
size in any one sector.
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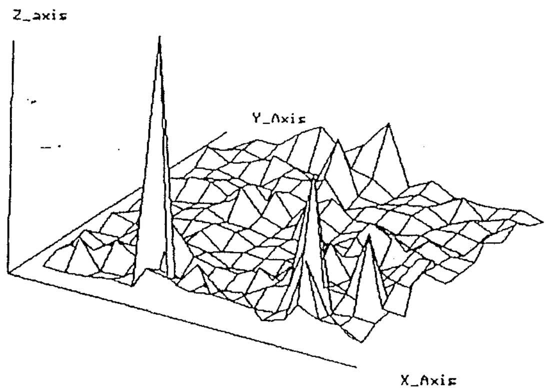


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Max/Min for any
single sector:
Max Avg Void=  2.315 mm
Min Avg Void=  0.022 mm
Max Number Voids=   7
Min Number Voids=   1

Sector width (x-axis)=   5.249 mm    Sector depth (y-axis)=   6.011 mm

Total Travel Executed------------------ 228.6    cm
Total Area Covered--------------------- 68.6     Sq. cm
Total Void Length---------------------- 11.4     cm
Total Number of Voids------------------ 738
Average Chord Intercept---------------- 0.1547   mm
Voids per mm--------------------------- 0.32
Specific Surface (1/mm)---------------- 25.9
Paste to Air Ratio--------------------- 4.41
Air Content---------------------------- 4.99     %
Spacing Factor------------------------- 0.1690   mm
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Fig. 2 — Typical output from petrographic analysis.

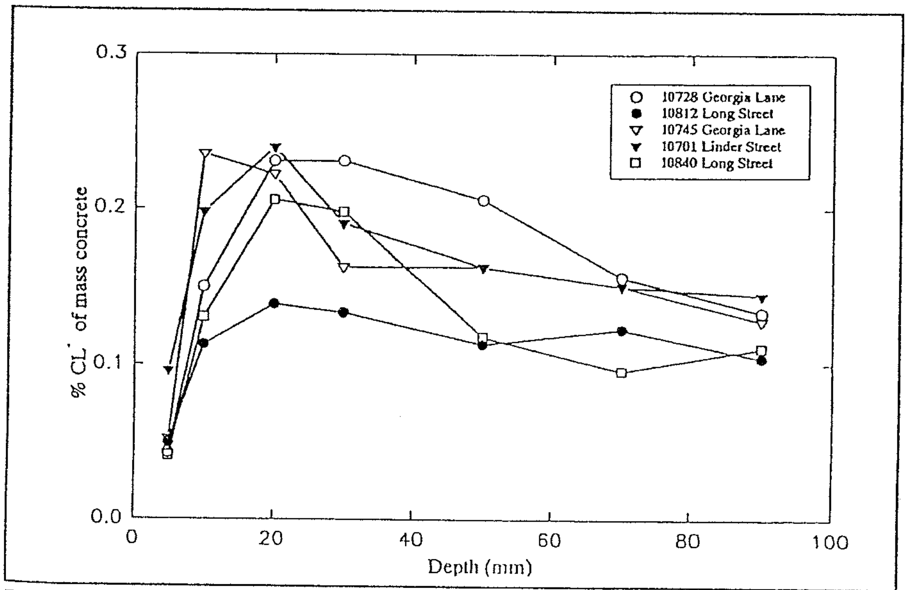

Fig. 3 — Chloride content as a function of depth.

This discrepancy may be attributed to the assumed paste content of 22 percent used in the calculations, whereas a paste content of 24.7 percent was obtained by using the modified point-count method, yielding a paste-to-air ratio of 3.98.

The values of the air content for all samples ranged from 5.00 to 6.28 percent; these values are within the allowable limits specified by ACI,[5] and are also within the limits specified by the Village of Oak Lawn Engineering, Planning, and Traffic Department (6 ± 1%). We concluded that since the air-void system parameters were within the allowable limits, other factors must have caused the scaling problem.

Strength

According to ASTM C 42 standards, a core having a maximum height of less than 95 percent of its diameter before capping or a height less than its diameter after capping should not be tested. All the cores drilled from the site were 100 mm in diameter, and the heights, after sawing the bottom part touching the underlying gravel layer, ranged from 88 to 94 mm. In this case, all the ratios for height over diameter (l/d) were less than 1. As a result, it was impossible to interpolate the correction factors by using the data provided in Section 6.7.2 of ASTM C 42. Therefore, in order to acquire a rough estimate of the compressive strengths, the data of Section 6.7.2 of ASTM C 42 were plotted, and the correction factors were estimated by extrapolation.

As shown in Table 3, all values for the compressive strength were greater than 36.6 MPa. These values were much higher than the allowable minimum limit value of 26.2 MPa specified in ASTM C 457. This large difference between the corrected and the minimum allowable values eliminates all doubts of the validity in extrapolating the correction factors. As a result, we can state that the compressive strength is acceptable, and the scaling is not due to a deficiency in the strength.

Chloride content

The results of the chloride content in the concrete samples collected at different levels for the five locations are summarized in Table 4. A plot of chloride content by concrete weight versus depth is shown in Fig. 3. All these values were much greater than the maximum allowable value of 0.02 percent acid-soluble chloride by weight of concrete as specified in ASTM C 114. In this case we suggest that the high levels of chloride contents occurred due to one or both of the following factors:

- $CaCl_2$ added as an accelerating admixture, and/or
- application of deicing materials on a poorly finished surface.

According to the information supplied by city officials, the surface popout due to scaling started three to four months after placing the concrete. In this period the concrete was not susceptible to freeze-and-thaw action; therefore, no application of deicing materials was encountered. If an adequate quantity (below allowable limits) of $CaCl_2$ was added as an accelerating admixture, then the high levels of chloride content are due to the application of deicing materials. Deicing salts are generally mixtures of NaCl and $CaCl_2$. Much of the salt will penetrate into the pores of the concrete and will slowly diffuse downward. Little chloride is lost once it enters the concrete, so there is a steady build up of chloride ions leading to salt scaling.[3] Having high levels of chloride at the different levels in a concrete slab less than two years old indicates that the concrete surface is porous and not durable due to inadequate finishing.

Conclusions

A field and laboratory investigation was carried out to investigate the concrete deterioration and popout of parts of the finished surfaces due to scaling on the selected driveways. Based on the laboratory investigation, the following conclusions are drawn:

- The air-void parameters are within the allowable limits as shown in Tables 1 and 2.
- The compressive strength for all the specimens (in the range 36.7 to 40.6 MPa) are much higher than the strength required by the standards of the Village of Oak Lawn (26.2 MPa) as shown in Table 3.
- The chloride content at various depths (Table 4) is much higher than the maximum allowable value of 0.02 percent acid-soluble chloride by weight of concrete (ASTM C 114). The high levels of chloride ions were caused by the ease of intrusion of deicing materials through the weak and porous concrete surface. This holds true if an adequate quantity of $CaCl_2$ (below allowable limits) was added as an admixture.

It is suggested that the problem may have been caused by inadequate finishing of the concrete surface. Floating tends to bring the cement and water to the surface; therefore, floating too early or for too long brings an excess of fines to the surface. This damages and weakens the bond between the surface and the concrete below by forming a high water-cement ratio layer of paste of 3 to 9 mm in thickness.[2,3] The paste layer at the surface is not condensed enough and has a high permeability coefficient. Also, deicing materials can intrude through it easily. This leads to weakness, porosity, and a lack of durability, consequently resulting in concrete scaling or flaking of the finished surface.

This deterioration problem was detected in other locations where scaling problems of this nature were experienced. As a result of this study, the homeowners and the contractor settled their dispute. The contractor agreed to pay 50 percent of the costs of materials and labor for replacing the driveways. The repairs are already underway.

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Selected for reader interest by the editors.

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