Scaling of Air-Entrained and Non-Air-Entrained Concrete

EDWARD A. ABDUN-NUR, Consulting Engineer, Denver; and
RICHARD C. MIELENZ, Master Builders Division of Martin Marietta Corporation, Cleveland

•IN THE Great Lakes area, a residential alley paving 8 in. thick was laid directly on a clay subgrade. The paving was placed in two seasons, late June and early July, in each case. Surface scaling randomly distributed was observed at the time of the examination, which was made after the concrete placed the first season had gone through two winters and the concrete placed the second season had gone through one winter. Cars and delivery vehicles had been dripping chloride solution as they came in off the salted streets. At the time of examination, the appearance of the scaling was somewhat different for the two concretes. Deterioration of the concrete placed in 1957 and exposed for one winter was at a more advanced stage than that of the concrete placed in 1956 and exposed for two winters. Some pitting was evident in the concrete placed earlier, but surprisingly little cracking.

CASE HISTORIES

The records showed that the same concrete mixture possessing the same properties was requested from the ready-mixed concrete supplier for both seasons. The brand of cement was unknown. The same aggregate source was used, and it had had a fairly good record locally. Supposedly, the mix contained six 94-lb bags of portland cement, 6 fl oz of Darex air-entraining admixture, and 34 gal total water content per cu yd. Some water was added at the site to the 7-cu yd loads in the transit mixer, but the amount varied and there was no available record of it.

The foreman, who was talked to after the petrographic findings, claimed that for the most part he could not obtain water to sprinkle the surface in the finishing operation. The concrete had looked dry to him, it could be walked on in a couple of hours after finishing, and no attempt was made to cure it.

WEATHER DATA

Records of local weather during and immediately following the placing of the concrete during the summers of 1956 and 1957 and for the winters of 1956-57 and 1957-58 were obtained from the nearby station of the U.S. Weather Bureau.

The weather during the latter part of June and early July 1956, when the pavement of area 80 was placed, was hot and humid with day and night temperatures in the range of 100 to 59 F. The first freezing occurred on November 8 and during that month the minimum temperature was below freezing on 17 days, the minimum temperature being 15 F. During December, 21 days of freezing occurred, and January 1957 is reported to have been the coldest January in 17 years to that date; a minimum temperature of -3 F was recorded. The cold weather was accompanied by 2.10 in. of precipitation. February 1957 was relatively mild, with subfreezing temperatures occurring on 17 days. On only 3 days did the temperature not rise above the freezing point; thus, numerous cycles of freezing-thawing were experienced. Occasional freezing continued throughout March, and the last freeze of the winter was on April 14, 1957.

The period from June 25 to July 10, 1957, was warm to hot. Rainfall totaled 1.01 in. during this period. More than 7.5 in. of rain fell during July, and an additional 7.0 in. of rain were recorded during August. From July 2 to December 31, 1957, precipitation totaled 24.93 in. More than 9 in. of precipitation occurred during the last 3 months of

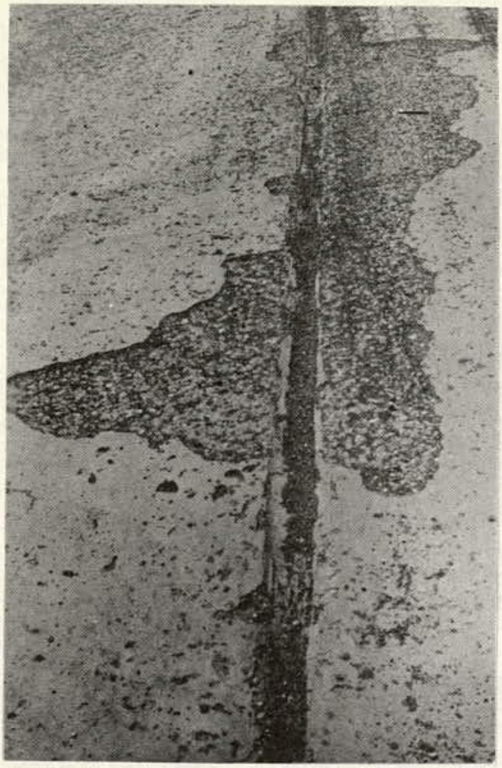

Figure 1. Typical scaling of concrete as it had occurred in areas 92, 93, and 98. Note localized pitting and spalling of the finished surface in advance of general scaling.

the year. The first freezing occurred on November 8, and there were 12 days during that month on which freezing temperatures were experienced; the minimum temperature was 15 F. Except for November 30, the maximum temperature exceeded 32 F. December 1957 was unusually warm, with 17 days in which freezing temperatures were encountered; the minimum temperature was 4 F. January and February 1958 included 52 days in which freezing temperatures occurred (minimum -5 F). In March 1958 there were 9 days in which the temperature fell below 32 F (minimum 28 F).

INVESTIGATION

Photographs of areas of the pavements at different stages of scaling were taken; Figure 1 shows several stages of deterioration, ranging from severe to lesser stages of symptoms. Four pairs of 4-in. diameter cores were taken at random in various areas. One core of each pair was tested for compressive strength (ASTM Designation C 42); the other was examined by petrographic methods and the air content was determined microscopically. The compressive strengths and visual impressions were as follows:

Area 80—Compressive strength of 5,150 psi; broken around aggregate particles; spongy-looking mortar; first season concrete.

Area 92—Compressive strength of 6,000 psi; good break through aggregate particles; good-appearing mortar except top 3 in. appeared less dense than did the concrete at greater depth; second season concrete.

Area 93—Compressive strength of 6,000 psi. Good break through aggregate; good mortar except top ½ to ¾ in.; second season concrete.

Area 98—Compressive strength of 6,600 psi. Good break through aggregate particles; good mortar except top ½ to ¾ in.; second season concrete.

PETROGRAPHIC EXAMINATION

The four cores extended through the thickness of the pavement. The top of the core from area 80 was partially scaled to a depth of $^1/_{16}$ to ⅛ in., whereas the tops of the cores from areas 92, 93, and 98 were almost completely scaled to a depth of ⅛ to $^5/_{16}$ in. In each instance, active progress of the scaling was indicated by roughly horizontal microfractures through the mortar matrix at depths of $^3/_{16}$ to ⅜ in.

The top 4 in. of each core were sawed parallel to the axis of drilling, and plane surfaces were prepared by lapping. Air content of the concrete was determined by the microscopical point-count procedure in accordance with ASTM Designation C 457, with the following results:

Pavement Area	Air Content, Percent by Volume of Concrete	Pavement Area	Air Content, Percent by Volume of Concrete
80	6.30	93	0.90
92	0.26	98	0.45

The air-void system in the core from area 80 was typical of air-entrained concrete prepared in accordance with American Concrete Institute Standard 613, except that the air content was slightly higher than the usual recommendation for pavement concrete. The air voids were small and well distributed throughout the upper 4 in. of the core. The air-void system in the cores from areas 92, 93, and 98 was typical of non-air-entrained concrete; the air voids were characteristically large and sparsely distributed.

The concrete was generally hard, compact, and apparently properly proportioned. Except for the topmost portion of the core from area 80 (see the following paragraph) and the fractured near-surface portion of the cores from areas 92, 93, and 98, the cement paste matrix was dense and firm. Portland cement had been used; no mineral admixture, such as fly ash, was present. The examination revealed no evidence of excessive bleeding, segregation, or poor finishing practices. No appreciable concentration of mortar or laitance materials was present at or near the top surface.

The cement paste matrix in the topmost ¼ to ⅜ in. of the core from area 80 was bleached almost white and was substantially weaker and more absorptive than the cement paste matrix in the concrete at greater depth. In the bleached zone, the cement paste matrix was very highly carbonated as a result of carbon dioxide penetration into the concrete at an early age. Such a bleached and highly absorptive zone was not present in the cores from areas 92, 93, and 98.

The aggregate was a combination of natural gravel, crushed gravel, and natural sand. The aggregate in the four cores was similar. The coarse aggregate and the coarse fractions of the sand included moderate proportions of chalcedonic and quartzose cherts and cherty dolomites. No contaminating substances or natural coating materials were detected. Secondary rims resulting from cement-aggregate reactions were observed on occasional particles of dolomite, on cherts, and on cherty zones in dolomite particles. Trace amounts of alkalic silica gel were detected in the core from area 92. In this core, occasional particles of chert in the coarse sand fractions were softened as a result of the alkali-silica reaction. No cracking or other evidences of distress were observed in association with the affected particles.

DISCUSSION OF RESULTS

The concrete of area 80 was subjected to daytime temperatures exceeding 90 F shortly after placing was completed; it was not cured. Explicit correlation of the concreting operations with the local weather conditions is not possible because of lack of information on exact dates during which the work was accomplished. However, it is evident that drying and carbonation of the near-surface region of the pavement relate to drying conditions immediately following the placement. The winter of 1956-57 was unusually severe (especially during January 1957), and severe freezing and thawing conditions were experienced a second time in the winter of 1957-58, especially in December, January, and February, when numerous cycles of freezing and thawing occurred.

The concrete of areas 92, 93, and 98 was subjected to high temperatures in the period during and immediately following placement. However, the placing operations were accompanied and followed by heavy precipitation that persisted through August and resumed in October. With the onset of freezing in early November, the concrete probably was in a nearly saturated condition. A high degree of saturation of the pavement would be promoted also by direct contact of the concrete with a clay subgrade. Hence, the non-air-entrained concrete would be especially susceptible to breakdown in freezing and thawing in spite of a relatively low water-cement ratio. The observed compressive strength of the three cores from these areas suggests a net water-cement ratio substantially less than 6 gal per 94-lb sack of cement (0.53 by weight).

CONCLUSIONS

1. Area 80 constituted well-air-entrained concrete, but the topmost ¼ to ⅜ in. of the pavement was susceptible to disruption by freezing and thawing because of high absorptivity, resulting from lack of adequate curing, and early drying and carbonation of the cement paste matrix. The action of freezing probably was aggravated by the presence of de-icing salts.

2. Areas 92, 93, and 98 comprised non-air-entrained concrete that was not resistant to freezing and thawing while wet, especially in the presence of de-icing salts. Examination of the local weather records indicates that, although they were not purposefully cured, these pavements could not experience any substantial drying following placing and were well saturated with water at the time of freezing and thawing because of heavy precipitation during the late summer and early fall of 1957. Thus, this concrete of low water-cement ratio was susceptible to rapid disintegration during repeated freezing.

3. Incipient cement-aggregate reactions involving dolomites, chalcedonic cherts, and cherty phases of dolomites had occurred, but no deleterious effects were indicated by the petrographic examination.

4. The experience illustrates the fact that air-entrainment will not ensure adequate durability of exposed concrete in the absence of good concreting practices. In this instance, the defect leading to failure of concrete in area 80 was the result of inattention to curing and protection of the concrete from early drying prior to development of a sound cement paste matrix of low absorptivity. The defect leading to failure of the pavement surface in the other areas was the absence of a proper entrained air void system in the concrete.