Schmitt
Technical Services INC

January 27, 2014

Mr. Chris Petykowski, P.E.,
Principal Engineer
City Of Madison - Engineering Division
City-County Building, Room 115
210 Martin Luther King, Jr. Blvd.
Madison, WI 53703

Re: Evaluation of Concrete Cores and Soils from Tree Openings between 329 and 528 State Street, Madison, Wisconsin (STS Job. No. 13068)

Dear Mr. Petykowski:

Schmitt Technical Services, Inc. (STS) has completed laboratory evaluation of concrete cores and soil from the above referenced tree opening along State Street Pedestrian Mall, in downtown Madison, WI.

PROJECT BACKGROUND

As part of the Phase II reconstruction of the State Street Pedestrian Mall, new tree planters were installed along the 300 to 500 blocks. Figure 1 shows the cross section of the new planter design. The design called for a 7 in. thick structural slab having an exposed (granite) aggregate finish.

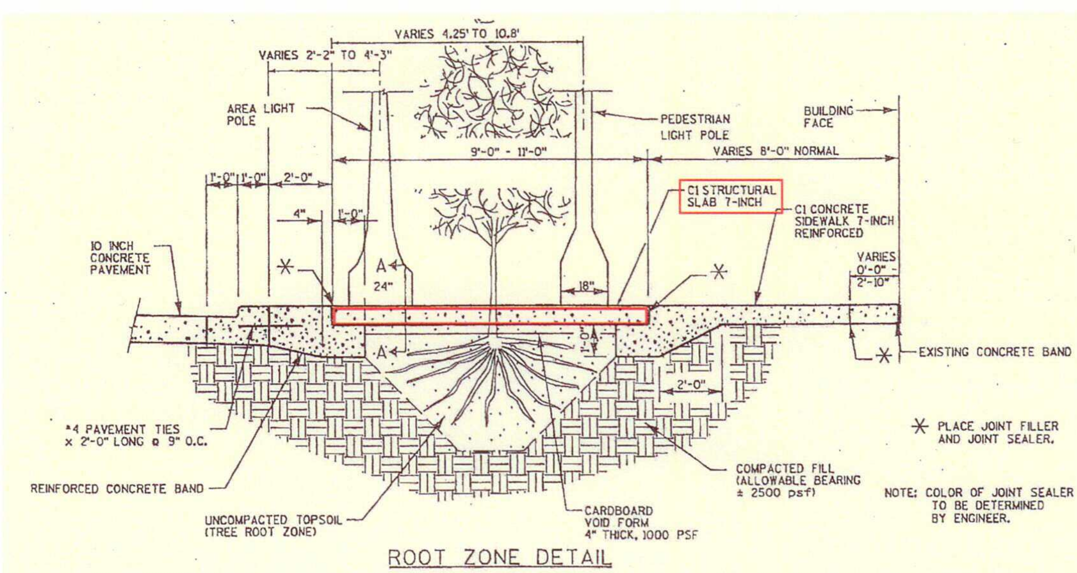

Figure 1. Cross-section of planter design showing the concrete slab in question.

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Sometime this past Fall, it was determined that along joints the slabs were deteriorating from the bottom upward (Figure 2). The deterioration is in the form of bottom of the slab cracking and spalling (Figure 2) and joint surface cracking and spalling (Figure 3). The City of Madison contracted CGC, Inc. to take cores of various slabs for testing to determine the cause(s) and extent of the deterioration.

Figure 2. Oblique view of the slab showing deterioration of the slab bottom (red arrows) and corrosion of a dowel bar (yellow arrow).

Figure 3. Cracking, spalling and raveling along joints

SAMPLES AND WORK SCOPE

Four (4) concrete cores and one (1) soil sample, identified in Table 1 were delivered to STS by CGC on November 21, 2013. The concrete samples did not exhibit the reported deterioration. Therefore, two (2) more cores exhibiting the deterioration were drilled (Figures 4 through 6) by CGC and delivered to STS (by CGC) on December 4, 2013. STS was requested to perform petrographic examination on one (1) of the cores exhibiting deterioration. STS selected Core 1 for petrographic analysis. STS was also requested to perform acid-soluble chloride analysis at the top, middle and bottom of Core 1 and on the soil sample. pH measurement of the soil sample was also requested.

Table 1 –Sample Identification, Location/Description and Tests Performed

Sample ID	Sample Location/Description	Test(s) Performed
Core 1	528 State St./Undeteriorated	Hold - Does not show the problem
Core 1A	528 State St./Undeteriorated	Hold - Does not show the problem
Core 2	409 State St./Undeteriorated	Hold - Does not show the problem
Core 3	329 State St./Undeteriorated	Hold - Does not show the problem
Hole 3	329 State St./Soil	Chloride, pH
Core 1	Deteriorated/Not Reported (Figs. 4 and 5)	Petro. Exam., Chloride
Core 2	Deteriorated/Not Reported (Figs. 4 and 6)	Hold

Figure 4. The location of cores showing the deterioration and which were subjected to laboratory testing.

FINDINGS AND CONCLUSIONS

Subject to the qualifications in the attached Appendix, results of the analyses are as follows:

1. Several, semi-parallel, fine (0.15 mm and narrower), cracks occur in the bottom 40 mm (1.5 in.) of the core (Figure 7). The cracks are oriented parallel to the wearing surface. This sort of crack orientation is quite typically seen as a result of freeze-thaw damage. Portions of the bottom of the slab have spalled away along these cracks. The cracks pass around and through granite aggregate particles, suggesting significant tensile force was applied to cause these cracks to form.

2. The aggregate does not exhibit any form of deterioration or evidence of poor service. Rather, the aggregate observed appears to be performing as intended. However, the crushed granite coarse aggregate is very angular and frequently particles are flat and elongated. Inclusion of this aggregate type is not common to the local marketplace. Therefore, use of this aggregate in concrete would produce, to some, a mix that could be considered "harsh" or hard to place and work.

3. Cement paste is carbonated to a depth of 1-to-2 mm (0.04-to-0.08 in.) below the wearing surface, suggesting the concrete was well-cured.

4. However, the cement paste properties are highly variable (Figures 8 and 9). Some areas of the cement paste contain virtually no residual cement particles, but very large calcium hydroxide masses and poor hydration (Figures 10 and 11). These areas are highly porous, very soft and chalky (Figure 8). In other areas, paste is slightly harder, denser (Figure 9) and residual cement particles and normal hydration products are present (Figure 12).

5. Based on paste properties observed, water-cement ratio is estimated to be moderately high and in the range of 0.55-to-0.65, except in the soft, porous areas devoid of normal hydration. In the soft areas, the water-to-cement ratio is high and estimated to be in excess of 0.65.

6. Air content varies. Air content is estimated to be 6-to-7%, by volume of concrete in the harder, denser sections of concrete, which is well within the range to provide resistance to freezing and thawing damage in concrete with a 3/8 in. maximum size. But, in the areas of very high water-to-cement ratio, there is a very high degree of clustering of air voids and a very high void content, estimated to be 15-to-20% (Figure 14). This high of an air content would also adversely affect the freeze-thaw durability of the concrete.

7. This variability in water-to-cement ratio and pockets of clustered air voids of high air content, particularly being present as inconsistent masses within the concrete, indicates addition of retempering water followed by incomplete mixing of the retempered water.

8. These areas of soft, high water-to-cement ratio and high air comprise over 50% of the core area and are not considered resistant to freezing and thawing service conditions.

9. Innocuous, secondary deposits composed of calcium carbonate and ettringite line some of the voids, and which, suggests moisture has migrated into the concrete, likely along the joint, which has a compromised seal (Figure 3). Thus, the joint sealant is not protecting the concrete along the joints against the effects caused by ingress of significant amounts of moisture.

10. Acid soluble chloride content results suggest the concrete has been subjected to application of deicer salts as the chloride content is highest at the wearing surface and decreases with depth in the core. The soil sample has a low chloride content and pH of the soil is 6.3, slightly acidic, which is likely due to tannins in the soil mixture. There is nothing in the results of the chemical analyses that suggests chemical attack as the cause of the concrete deterioration. Petrographic examination did not reveal any of the typical properties indicative of chemical attack.

Table 2 – Results of Acid Soluble Chloride Analysis

Sample ID	Sample Description	%Cl , by mass of sample
Core 1	Top (0.0-0.5”)	0.135
Core 1	Middle (3.4- 3.9”)	0.058
Core 1	Bottom (6.2-6.7”)	0.055
Hole 3	329 State St./Soil	0.007

11. Based on results of this evaluation, the deterioration is due to freeze-thaw damage of concrete that contains nondurable, very high air content and high water-to-cement ratio due to addition(s) of retempering water and inadequate remixing after water addition(s). Ingress of moisture along unsealed joints likely provided saturation conditions at least at and adjacent to the joint. It appears from the number of cores submitted that do not exhibit damage that this deterioration may not be a widespread condition.

Details of the petrographic examinations are provided in the following sections of this report.

METHODS OF TEST

Chemical Analysis

Chlorides in the concrete sample were analyzed in accordance with ASTM 1152-04 “Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete”. Chloride in the soil sample was analyzed in accordance with AASHTO Designation: T 291-94 (2008): “Standard Method of Test for Determining Water-Soluble Chloride Ion Content in Soil”. pH in the soil was evaluated on a 0.01% (w/v) using an Accumet AP110 pH meter.

Petrographic Examination

The concrete samples were examined using selected techniques and procedures outlined in ASTM C 856, “Standard Practice for Petrographic Examination of Hardened Concrete” and the Federal Highway Administration’s Publication No. FHWA-HRT-04-150, “Petrographic Methods of Examining Hardened Concrete: A Petrographic Manual.”

The examination included sawing each core longitudinally followed by lapping the sawed slice with successively finer lapping grits to produce a finely ground (and nearly polished) surface. The lapped surface of the concrete slice and freshly broken surfaces of the concrete were examined visually (with the unaided eye) and under a stereomicroscope at magnifications of 7 to 40X.

In addition, a thin section was made from each concrete sample, as were temporary, crushed fragment (i.e., “powder or immersion”) mounts of paste and aggregate. The thin section and immersion mounts were examined under plane and cross-polarized light at magnifications of 50 to 400X using a polarizing light microscope.

Estimates of water-to-cement ratio were done using techniques outlined in FHWA-HRT-04-150 and methods developed by Dr. Donald Campbell (“Application of the Microscope in the Concrete Industry,” Proceedings of the Third International Conference on Cement Microscopy, Houston, 1981).

PETROGRAPHIC EXAMINATION

Core 1

General Description

The sample consists of a concrete core labeled “1” (Figure 5). The core is 170 mm (6.7 in.) long and has a diameter of 94 mm (3.7 in.). The core was received intact.

The top (wearing) surface has an exposed (granite) aggregate finish that has been coated with a clear shiny substance, presumed to be a sealer or other similar protective treatment (Figure 5a).
The bottom surface is an irregular fractured surface. The fractured surface passes both around and through aggregate particles.

Several, semi-parallel, fine (0.15 mm and narrower), cracks occur in the bottom 40 mm (1.5 in.) of the core (Figure 7). The cracks are oriented parallel to the wearing surface. The cracks pass around and through granite aggregate particles, suggesting significant tensile force was applied to cause these cracks to form.

Two (2), epoxy coated reinforcing bars, oriented perpendicular to each other are present at depths of 64 mm (2.5 in.) and 80 mm (3-1/8 in.). Both bars are 12 mm (1/2 in.) in diameter. A horizontal piece of wire mesh, that is 6 mm (1/4 in.) diameter, is immediately below the lower reinforcing bar. An oval shaped piece of wire mesh of the same diameter is tack welded to the straight piece of mesh. This wire mesh configuration may be a stand for the reinforcing bars or some other related supporting item. The wires and bars are uncorroded.

Aggregate

Aggregate appears fairly well graded and uniformly dispersed. Measured maximum aggregate size is 9.5 mm (3/8 in.).

Coarse aggregate is composed of crushed, red granite with minor amounts of black, crushed gabbro. Coarse aggregate is hard; dense; angular; equant to more commonly elongated in shape and has a rough surface texture.

Fine aggregate is natural sand containing quartz, feldspar, dolomite and granite (some of which may be fines from the coarse aggregate). Fine aggregate particles are variously colored from brown, beige, red, gray and translucent; moderately hard to hard, dense; subangular-to-well rounded; generally spherical and have a smooth surface texture.

The aggregate does not exhibit any form of deterioration or evidence of poor service. Rather, the aggregate observed appears to be performing as intended.

Cement Paste

The cement paste is very light gray. Paste properties are highly variable (Figures 8 and 9). The paste has a subvitreous-to-dull luster and a microgranular-to-chalky texture. Cement paste is moderately soft-to-soft, fairly porous-to-highly porous and moderately bonded to aggregate particles, as laboratory induced fractures pass both around and through aggregate particles. The fractures are not sharp, but rather more muted and uneven. Cement paste is carbonated to a depth of 1-to-2 mm (0.04-to-0.08 in.) below the wearing surface, suggesting the concrete was well-cured.

Some areas of the cement paste contain virtually no residual cement particles but contain very large calcium hydroxide masses (Figures 10 and 11). These areas are highly porous, very soft and chalky (Figure 8). In other areas, paste is slightly harder, denser (Figure 9) and residual cement particles are present and are estimated to be 4-to-6 %, by volume of paste. Calcium hydroxide, a normal hydration product, is abundant as very fine crystalline masses and estimated as 12-to-17% of the paste, by volume; Figure 12). No evidence of supplementary cementitious materials was observed.

Properties of the paste previously described are evaluated to provide an estimate of the water-to-cement ratio (w/c). Based on paste properties observed, water-cement ratio is estimated to be moderately high and in the range of 0.55-to-0.65, except in the soft, porous areas devoid of normal hydration. In the soft areas, the water-to-cement ratio is high and estimated to be in excess of 0.65.

This variability in water-to-cement ratio, particularly being present as inconsistent masses within the concrete indicates the addition of retempering water followed by incomplete mixing of the retempered water. These soft areas comprise over 50% of the core area and are not considered resistant to freezing and thawing service conditions.

Air Voids

The concrete contains small-to-large and irregularly shaped voids, which are typical of entrapped air and numerous tiny, spherical voids typical of entrained air (Figure 13). Therefore, the concrete is air entrained. However, the air content varies and corresponds to the areas of very high water content. Air content is estimated to be 6-to-7%, by volume of concrete in the harder, denser sections of concrete. But, in the areas of very high water content, there is a very high degree of clustering of air voids and a very high void content, estimated to be 15-to-20% (Figure 14). This high of an air content would also adversely affect the freeze-thaw durability of the concrete.

Innocuous, secondary deposits composed of calcium carbonate and ettringite line some of the voids, and which, suggests moisture has migrated into the concrete.

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We appreciate the opportunity to assist you on this project. If you have any questions or need additional consultation, please contact us.

Sincerely,

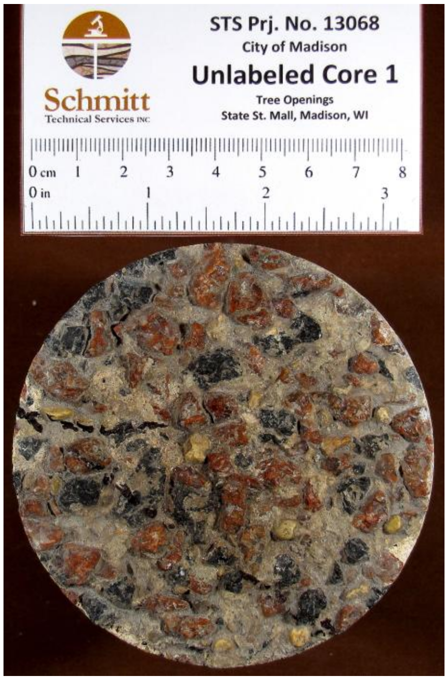
Schmitt Technical Services, Inc.

James W. Schmitt SMG

James W. Schmitt
Principal/President

JWS/jws

Attachments



(a) Exterior surface.

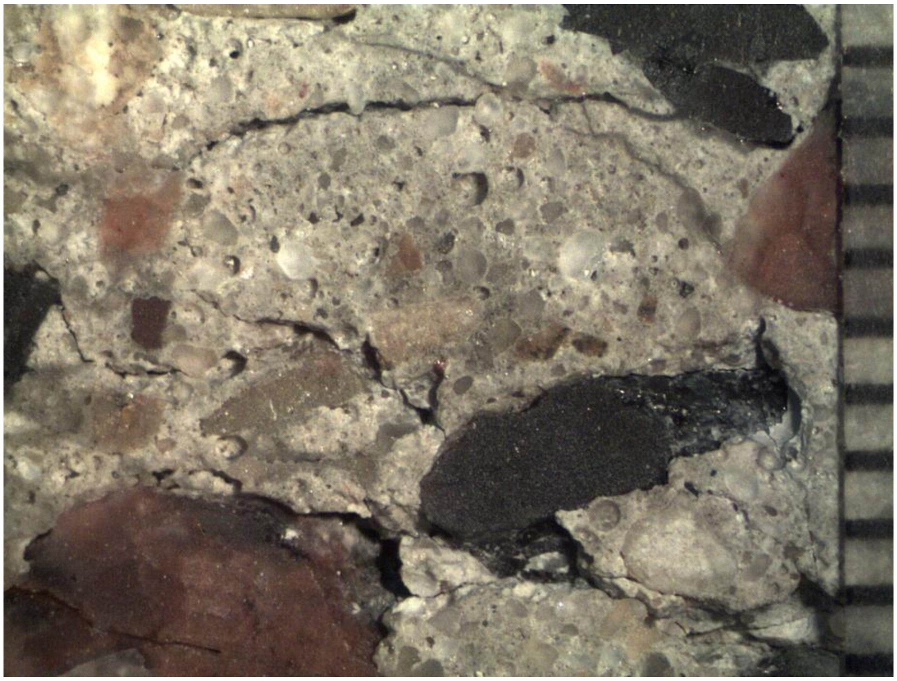
(b) Core side, exterior surface is to the left.

Figure 5. Core 1 as received for laboratory testing. Top scales are in centimeters. Bottom scales are in inches.

(a) Exterior surface.

(b) Core side, exterior surface is to the left in the left photograph and exterior surface is to the right in the right photograph.

Figure 6. Core 2 as received for laboratory testing. Top scales are in centimeters. Bottom scales are in inches.



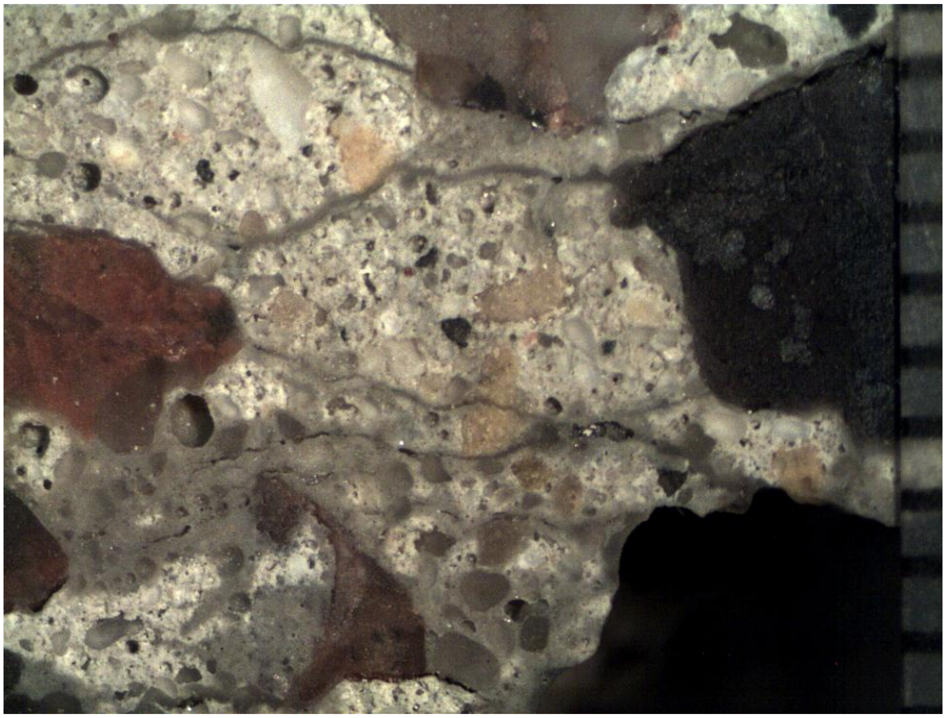


Figure 7. Photomicrographs illustrating semi-parallel, fine (0.15 mm and narrower) cracks occurring in the bottom 40 mm (1.5 in.) of the core. The cracks are oriented parallel to the wearing surface. The cracks pass around and through granite aggregate particles, suggesting significant tensile force was applied to cause these cracks to form. Scales are in millimeters.

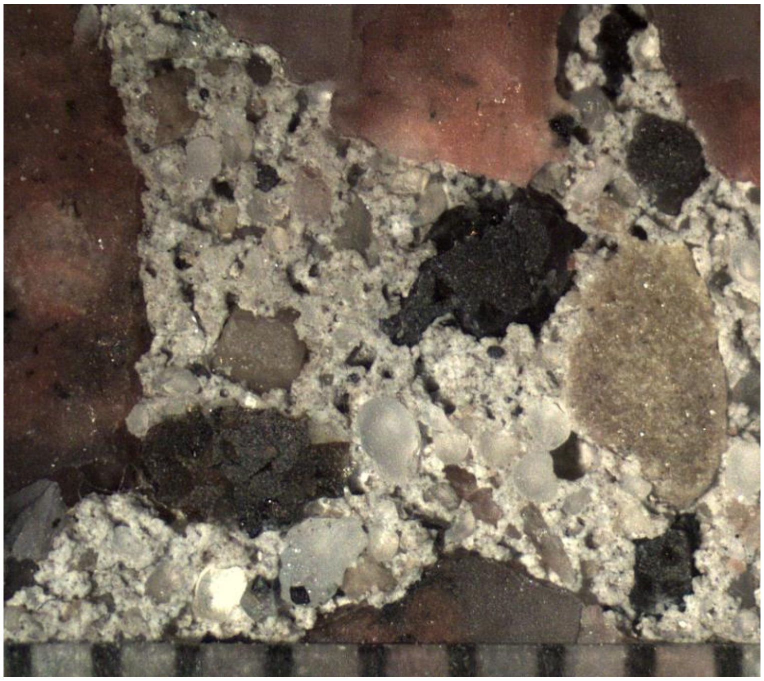


Figure 8. Photomicrograph showing an area of highly porous, very soft and chalky cement paste that has a high water-to-cement ratio (estimated to be in excess of 0.65). These soft areas comprise over 50% of the core area and are not considered resistant to freezing and thawing service conditions. Scale is in millimeters.

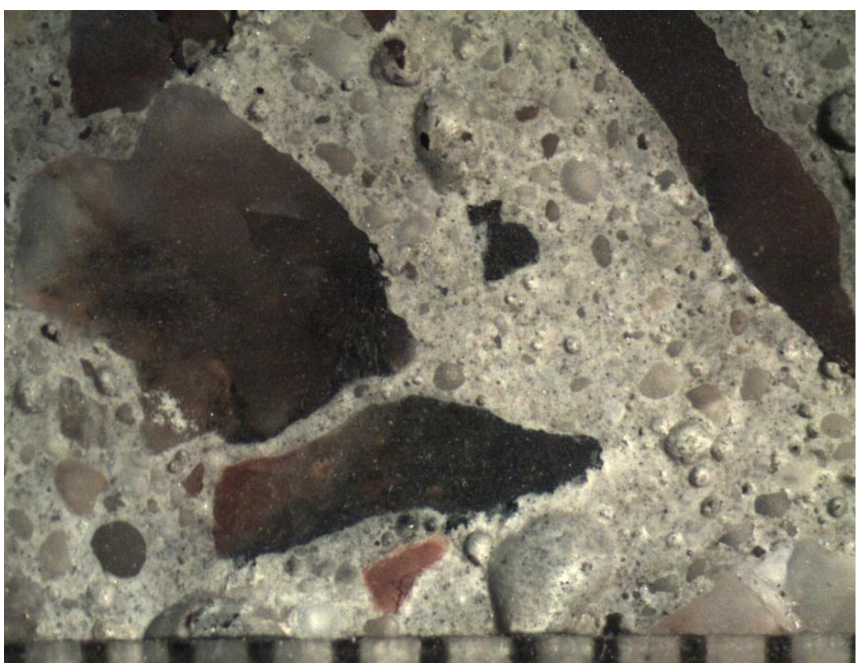


Figure 9. Photomicrograph along an area of lower water-to-cement ratio paste that is slightly harder, denser and with an estimated water-cement ratio in the range of 0.55-to-0.65. Scale is in millimeters.

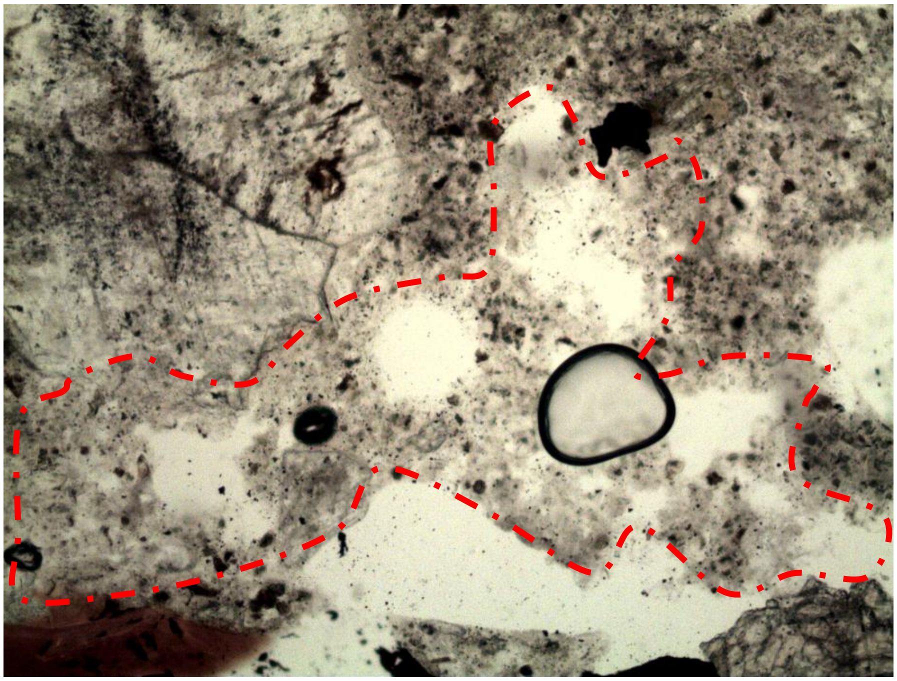


Figure 10. Thin section photomicrograph showing an area of highly porous, very soft and chalky cement paste that has a high water-to-cement ratio (estimated to be in excess of 0.65). The cement paste contains virtually no residual cement particles and is highly porous (within red dashed circle) compared to surrounding cement paste. 100x magnification. Plane-polarized light.

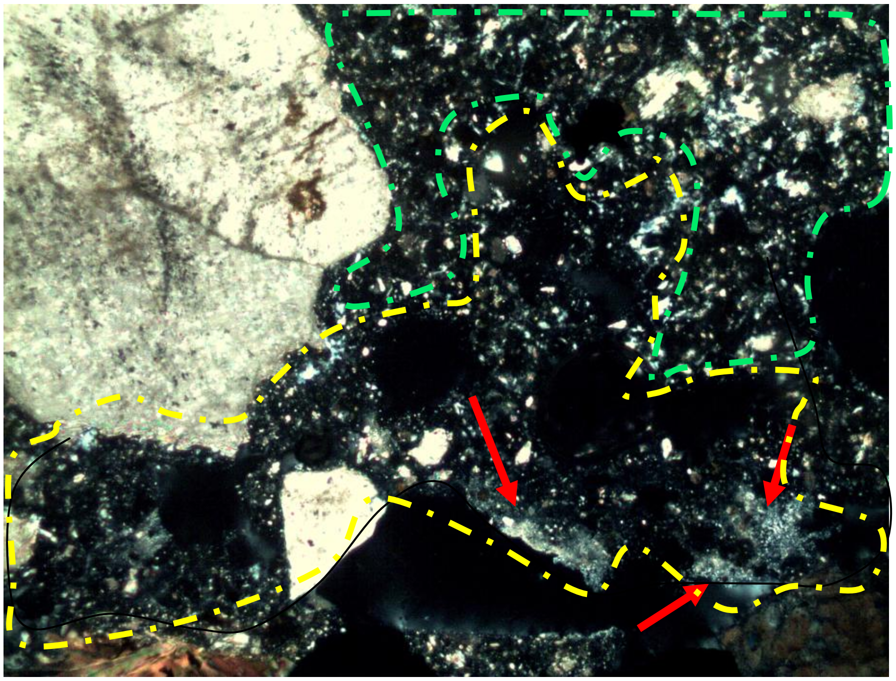


Figure 11. Thin section photomicrograph of the same area as Figure 10, only in cross-polarized light. Red arrows point to very large masses of calcium hydroxide. Area within yellow dashed circle is devoid of normal hydration. Area with green dashed circle shows normal hydration. 100x magnification.

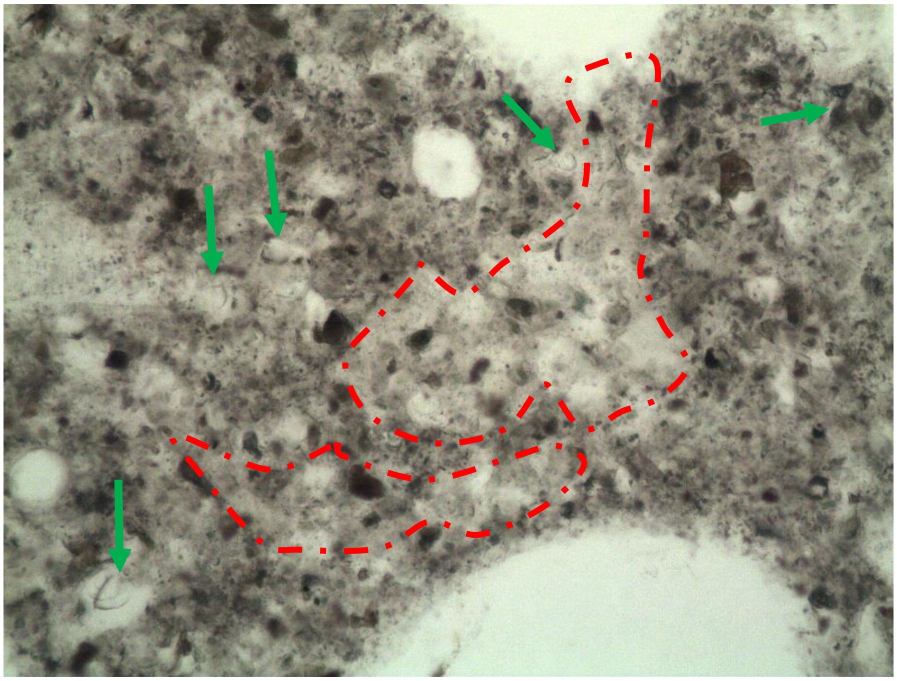


Figure 12. Thin section photomicrograph of an area of lower water-to-cement ratio (in the range of 0.55-to-0.65) where residual cement particles are present (green arrows). Within the red dashed circles are small areas of high water-to-cement ratio. Plane-polarized light. 200x magnification.

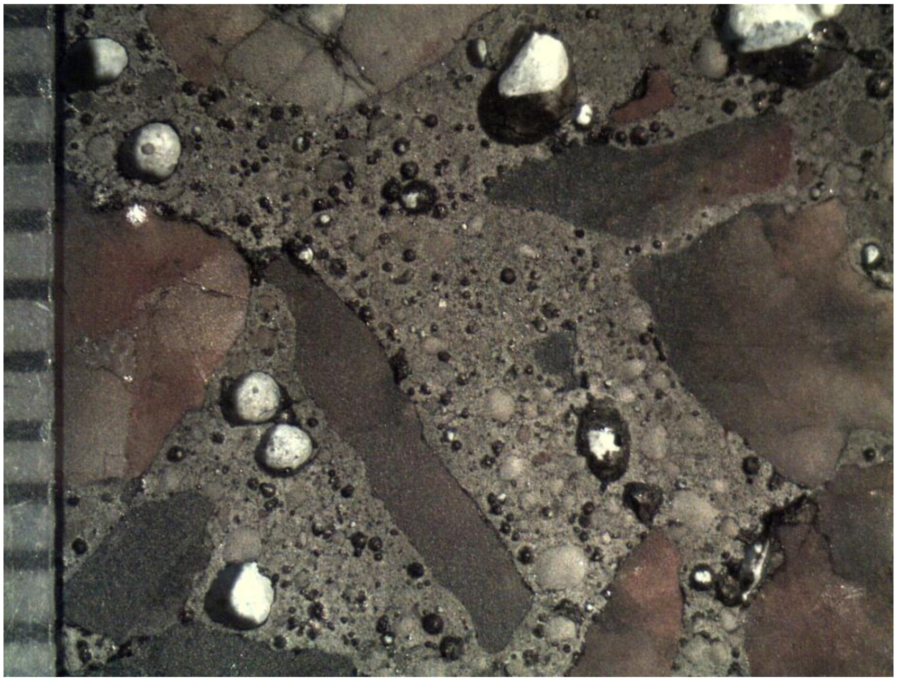


Figure 13. Photomicrograph along a lapped section of the core that has an estimated water-cement ratio in the range of 0.55-to-0.65. The surface has been dyed black to bring out the air voids. Voids are both large and irregular (entrapped air) and tiny and spherical (entrained air). Air content is estimated to be 6-to-7%, by volume of concrete. Scale is in millimeters.

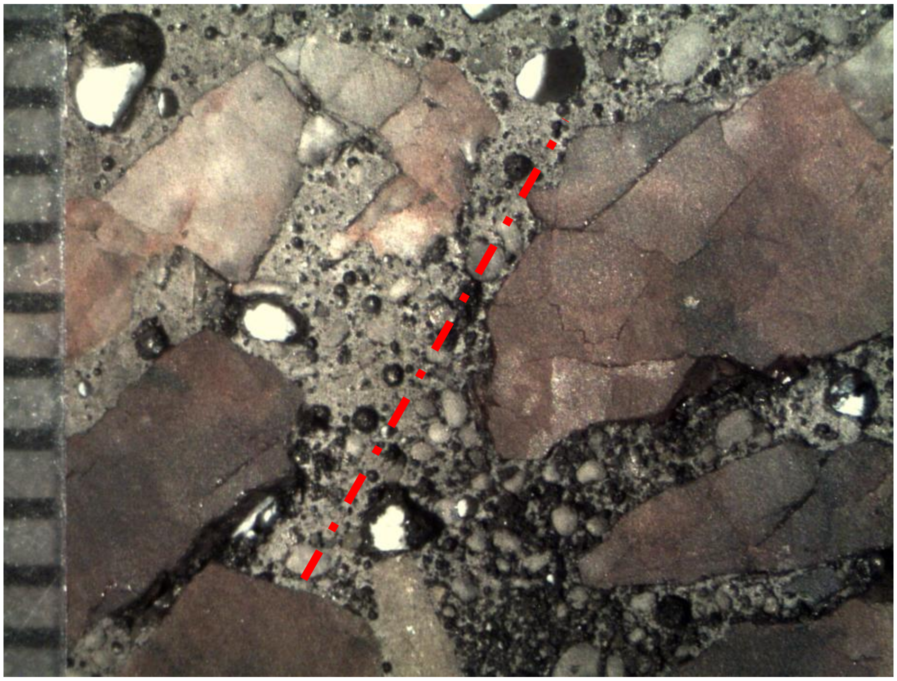


Figure 14. Photomicrograph along a lapped section of the core that is on the border of an area that has an estimated water-cement ratio in the range of 0.55-to-0.65 (left of red dashed line) and an area of very high water-to-cement ratio (right of red dashed line). The surface has been dyed black to bring out the air voids. The area of high water-to-cement ratio has an excessively high air content and a significant amount of void clustering, which is typical of retempered concrete. Scale is in millimeters.

APPENDIX
DOCUMENT QUALIFICATIONS

Standard of Care

This report has been prepared for the exclusive use of the Client for specification application to their project. This report is not intended for use by others. Schmitt Technical Services, Inc. (STS) has provided professional services consistent with generally accepted evaluative and geologic practices. No other warranties are expressed or implied. The opinions and recommendations submitted in this report are based on interpretation of field observations, samples taken from specific locations and/or field and/or laboratory test results.

Samples

The samples taken during the field observations depict conditions only at specific locations and times indicated in the report. Conditions at other locations may differ from conditions where sampling was conducted. The passage of time may also result in changes in conditions interpreted to exist at the locations where sampling was conducted.

Completion of Characterization of Site Conditions

The scope of services described in this report is based on a limited number of samples. The nature and variations in other locations may exist and may not become evident until repairs are performed. If variations or other latent conditions become evident, additional evaluation and testing may be warranted.

Conceptual Level of Project Scope

The field activities, testing procedures and evaluative approaches used in this study are consistent with those normally used in testing of construction materials and products. The number of samples and tests and scope of testing were done within Client's budget, but may or may not represents less data than that generally needed to evaluate the areal extent of less than expected performance.

Test Repair and Repair Observations and Testing

Since findings, discussion and observations are based on limited numbers of observations and tests, the Client should be particularly sensitive to the potential need for adjustment in extent of repair, repair procedures and repair materials in the field. It is in the best interest of the client to retain STS to observe and test repair materials and repairs to observe general compliance with repair design concepts, specifications and contractor/manufacturer recommendations and to assist in development of changes should field conditions differ from those anticipated before the start of repair construction.

Limitations-Repair Construction Considerations

The recommendations made in the report are not intended to dictate type of repair materials to be used, construction methods or construction sequences. Prospective contractors and material suppliers must evaluate potential repair problems on the basis of their knowledge and experience in the local area and on the basis of similar project in other localities, taking into account their own proposed repair construction methods and procedures.

Testing Conducted by Others

When subcontracted outside field and/or laboratory services and analyses are used, STS will rely upon the data provided by the outside field service or laboratory, and will not conduct an independent evaluation of the reliability of their data.