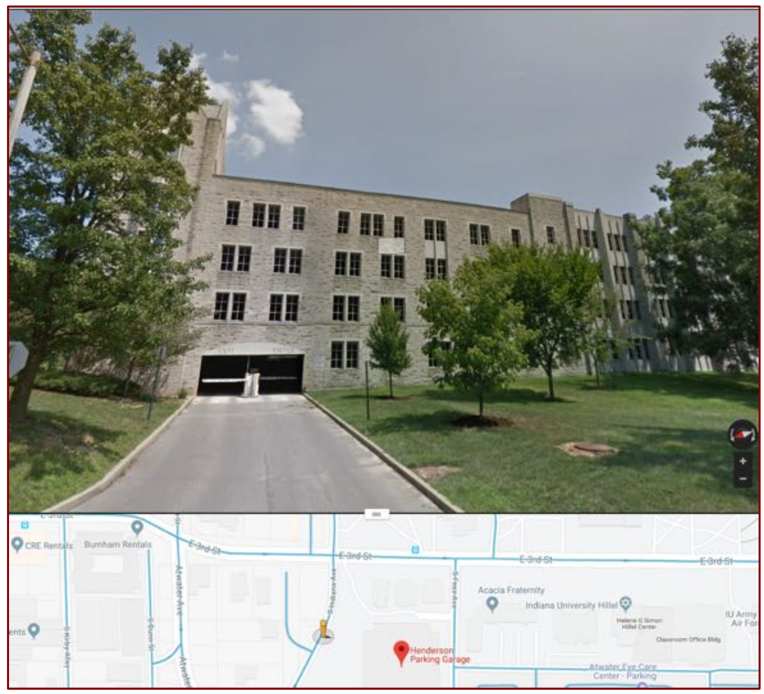
CONSTRUCTION MATERIALS CONSULTANTS, INC.

Petrographic Examinations of A Concrete Core To Investigate Quality & Condition of A Concrete Parking Garage Deck



Henderson Parking Garage
Indiana University
Bloomington, Indiana 47401

April 24, 2019
CMC 0419114

TABLE OF CONTENTS

Attached Reading:

Jana, D., "Concrete, Construction Or Salt – Which Causes Scaling? Part I: Importance Of Air-Void System In Concrete", *Concrete International*, American Concrete Institute, November 2004, Pp. 31-38.

Jana, D., "Concrete, Construction Or Salt – Which Causes Scaling? Part Ii: Importance Of Finishing Practices", *Concrete International*, American Concrete Institute, December 2004, Pp. 51-56.

EXECUTIVE SUMMARY

Reported herein are the results of detailed petrographic examinations of a hardened concrete core received from the exposed deck of Henderson Parking Garage at Indiana University in Bloomington, Indiana. The purpose of the examinations is to determine the composition, quality, and condition of concrete in the deck. A field photograph of the core retrieval process showed sound, fine broom-finished surface of the deck without any visible cracking, scaling, spalling, or any other surface distress. The core was examined by detailed petrographic examinations *a la* ASTM C 856.

Based on petrographic examinations, the concrete is determined to be adequately air-entrained, and made using: (a) sound crushed limestone coarse aggregate having a nominal maximum size of 1 in. (25 mm) where aggregate particles are sound, well-graded, and well-distributed; (b) natural siliceous-calcareous sand fine aggregate having a nominal maximum size of $^3/_8$ in. (9.5 mm) and containing major amounts of siliceous components (quartz, quartzite, feldspar, granite, chalcedonic and dolomitic chert, quartz siltstone, sandstone), subordinate amounts of calcareous components (limestone, dolomite), and minor amount of argillaceous and ferruginous components (shale, ferruginous and argillaceous siltstone), where particles are well-graded, well-distributed, and have been sound during their service in the concrete; (c) a dense cement paste made using Portland cement and fly ash, having cementitious materials content estimated to be equivalent to 6 to $6^1/_2$ bags of Portland cement per cubic yard of which 15 to 20 percent is estimated to be fly ash, and, a water-cementitious materials ratio (*w/cm*) estimated to be from 0.40 to 0.44 in the body; and (d) adequate air entrainment having an air content estimated to be 6 to 7 percent.

According to common industry (e.g., ACI) recommendations, an outdoor concrete exposed to moisture and freezing should be air entrained having an air content usually between $4^1/_2$ to $7^1/_2$ percent, an air-void specific surface of at least 600 in^2/in^3, and an air-void spacing factor of maximum 0.008 in. The observed air-void system of concrete is found to be in conformance to common industry recommendation in having adequate fine air bubbles needed for protection of paste during freezing at critically saturated conditions. The estimated 6 to 7 percent air is well within the common industry-recommended range for an air-entrained concrete to be durable in a moist outdoor environment of cyclic freezing and thawing. There is no evidence any physical or chemical deterioration of concrete found in the core.

The crushed limestone coarse aggregates and natural siliceous-calcareous sand fine aggregates are present in sound conditions, and should not introduce any issue. There is no evidence of any potential deleterious reactions of aggregates in the concrete to affect its future performance.

There is no evidence of any soft, porous, high *w/cm* paste at the surface region to indicate finishing in the presence of bleed water or addition of water during finishing. There is no evidence of entrapment of bleed water beneath the finished surface to indicate premature finishing prior to the cessation of bleeding. Concrete is found to be well-consolidated without any coarse entrapped voids. Curing of the finished surface is found to be normal without any issue. Shallow depth of carbonation (only 1 to 2 mm) at the core top indicates a dense, well-consolidated concrete.

The observed concrete is judged to have attained at least 4000 psi compressive strength and was 'matured' prior to the first exposure to freezing conditions.

The estimated water-cementitious materials ratio (*w/cm*) of concrete (0.40 to 0.44) is well within the common industry-recommended range of 0.40 to maximum 0.45 for an outdoor concrete exposed to moisture, and cyclic freezing and thawing.

Deicing salts, usually, do not cause surface scaling in a properly air-entrained concrete having a good air-void system that is made using sound aggregates, and has been placed, finished, cured, and was matured properly (Jana 2004, 2007), *unless*: (i) salt is applied prior to the attainment of maturity of concrete, and/or (ii) a chemically aggressive (e.g., magnesium or ammonium sulphate or urea-based) salt is applied that can chemically decompose the paste (calcium silicate hydrate, the heart of concrete). Due to the adequate air entrainment and overall dense, well-consolidated nature, the concrete is judged to be resistant to application of deicing chemicals. However, use of harmful corrosive deicers can affect the surface by causing decomposition of paste and other chemical or physical salt attacks.

Based on petrographic examinations, the concrete should be serviceable in its intended exposure conditions as long as it is not exposed to any harmful deicing chemicals.

INTRODUCTION

Reported herein are the results of detailed petrographic examinations of a hardened concrete core received from a parking garage deck at Indiana University in Bloomington, Indiana. The purpose of the examinations is to determine the composition, quality, and condition of concrete in the deck.

BACKGROUND INFORMATION

The parking garage is located at 319 S Fess Avenue in Bloomington, Indiana shown in Figure 1. The proposed testing is part of renovation of the preexisting parking garage to check quality of concrete in the deck. No background information regarding placement, weather condition, or mix design of the concrete are available.

FIELD PHOTOGRAPH

Figure 2 shows core retrieval process from sound broom-finished surface of existing parking garage deck. No cracking, scaling, spalling or any other surface distress is found in the field photo.

PURPOSE OF PRESENT INVESTIGATION

The purposes of the present investigation are to determine:

a. The compositions, qualities, and overall conditions of concrete in the core;
b. Evidence of any physical or chemical deterioration of concrete in the core; and,
c. Based on detailed petrographic examinations, investigation of future durability and serviceability of concrete in the deck.

SAMPLE

Figure 3 shows the core, as received, which is 2^1/4 in. (55 mm) in diameter and 1^1/2 in. in. (40 mm) in nominal length. The core has a finished surface with exposures of fine aggregate particles at the top and freshly fractured bottom end. No visible cracking or other distress are found. No reinforcing steel, wire mesh, fibers, or other embedded items are present in the core. The core has a ringing resonance when hammered. The core was received in intact, surface dry condition.

Figure 1: Henderson Parking Garage at Indiana University in Bloomington, Indiana.

Figure 2: Field photograph showing sound, broom-finished concrete surface and core retrieval from the parking deck.

Figure 3: Photographs of core as received – Top left – Exposed surface with exposed fine aggregate particles; Top right – partially fresh fractured bottom end of core; and bottom row – three cylindrical side views of the core showing overall sound, crack-free nature of concrete in the core.

METHODOLOGIES

PETROGRAPHIC EXAMINATIONS

The core was examined by petrographic examinations by following the methods of ASTM C 856 "Standard Practice for Petrographic Examination of Hardened Concrete." Details of petrographic examinations and sample preparation are described in Jana (1997a, b, 2001, 2004a, b, 2005a, b, 2006, 2007).

The steps of petrographic examinations include (Jana 2006):

i. Visual examinations of the sample, as received;
ii. Low-power stereomicroscopical examinations of as-received, saw-cut and freshly fractured sections, and lapped cross sections of core for evaluation of textures, and composition;
iii. Low-power stereomicroscopical examinations of air content and air-void system of concrete in the core;
iv. Examinations of oil immersion mounts in a petrographic microscope for mineralogical compositions of specific areas of interest;
v. Examinations of blue dye-mixed (to highlight open spaces, cracks, etc.) epoxy-impregnated large area (50 mm × 75 mm) thin section of concrete in a petrographic microscope for detailed compositional and microstructural analyses;
vi. Photographing sample, as received and at various stages of preparation with a digital camera and a flatbed scanner;
vii. Photomicrographs of lapped section and thin section of sample taken with stereomicroscope and petrographic microscope, respectively to provide detailed compositional and mineralogical information of concrete.

Figure 4: Nikon Eclipse E600POL Petrographic Microscope with Jenoptik Gryphax Camera (left), Olympus SZH (middle), and Nikon SMZ-10A Stereomicroscope (right) used for petrographic examinations.

PETROGRAPHIC EXAMINATIONS

LAPPED CROSS SECTIONS OF CORE

Figure 5: Two lapped cross sections of core showing crushed stone coarse aggregate, natural siliceous-calcareous sand fine aggregate, dense and well-consolidated nature of concrete, good grading and distribution of aggregates and absence of any visible cracking in the concrete.

PHOTOMICROGRAPHS OF LAPPED CROSS SECTIONS

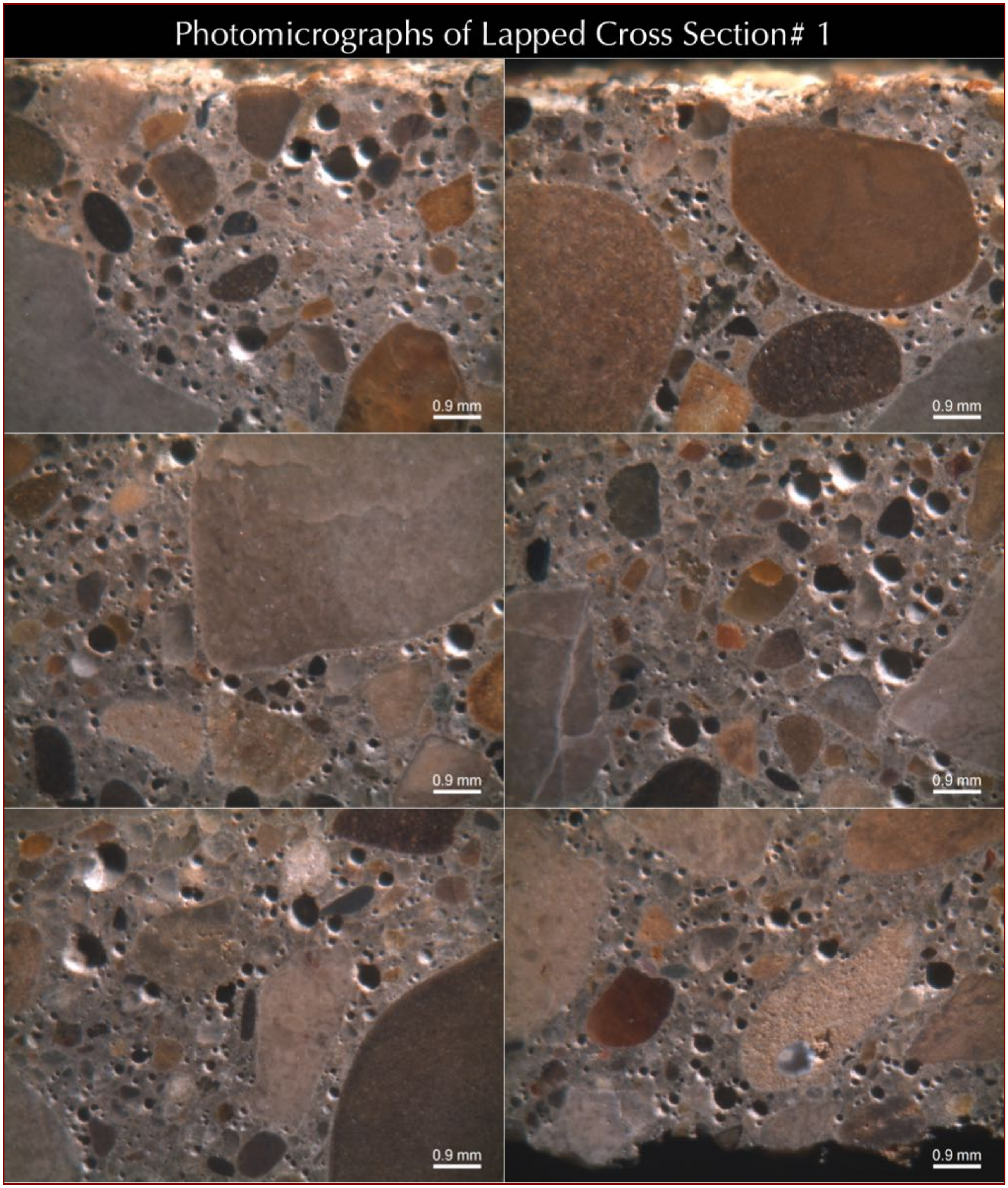


Figure 6: Photomicrographs of first lapped cross section of core showing: (a) sound surface region of concrete (top row), (b) air-entrained nature of concrete all throughout the depth of core having abundant fine, discrete spherical and near-spherical entrained air voids uniformly distributed all throughout the core; air content is estimated to be 6 to 7 percent (all photos).

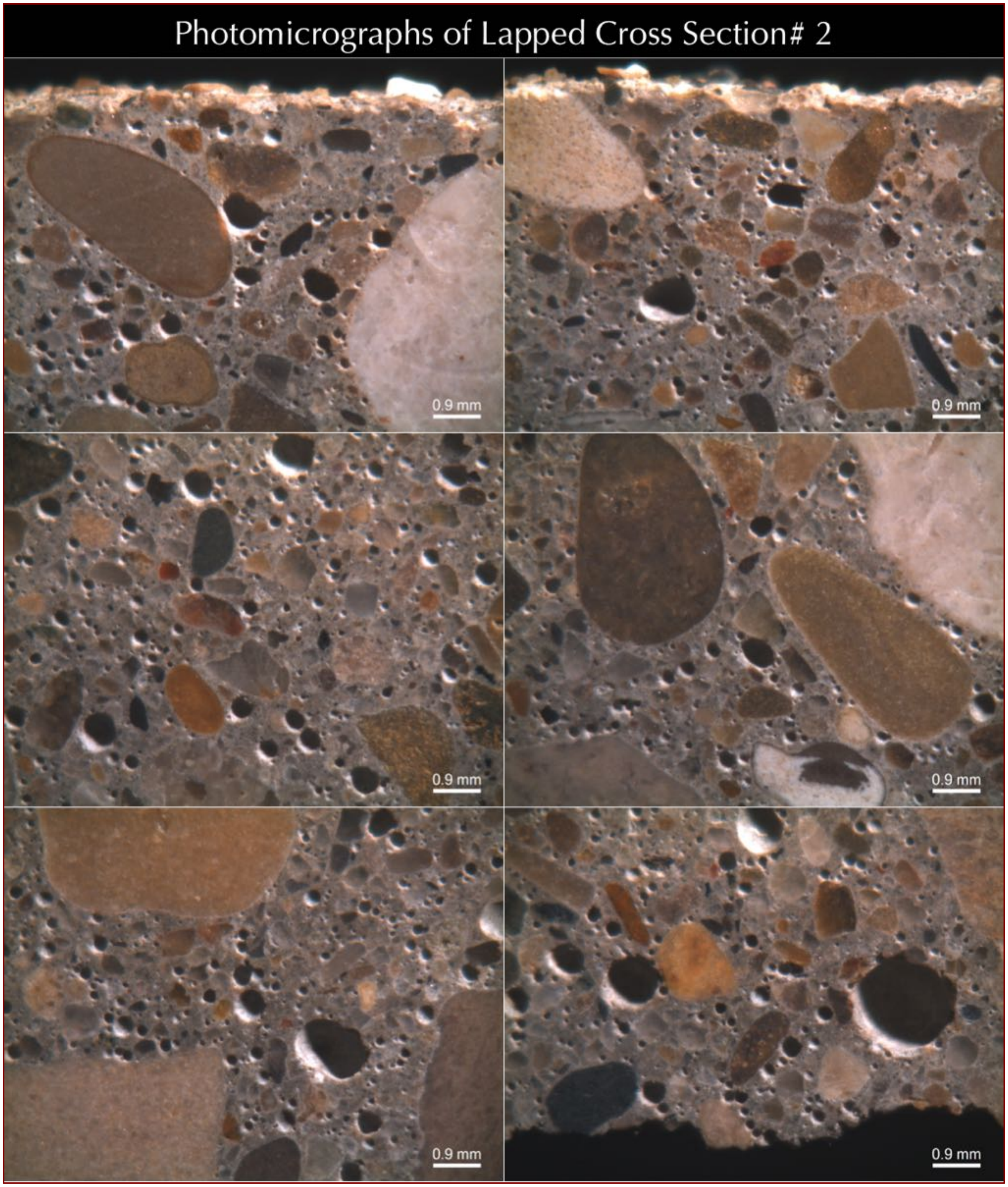


Figure 7: Photomicrographs of second lapped cross section of core showing: (a) sound surface region of concrete (top row), (b) air-entrained nature of concrete all throughout the depth of core having abundant fine, discrete spherical and near-spherical entrained air voids uniformly distributed all throughout the core; air content is estimated to be 6 to 7 percent (all photos).

BLUE DYE-MIXED EPOXY-IMPREGNATED THIN SECTION

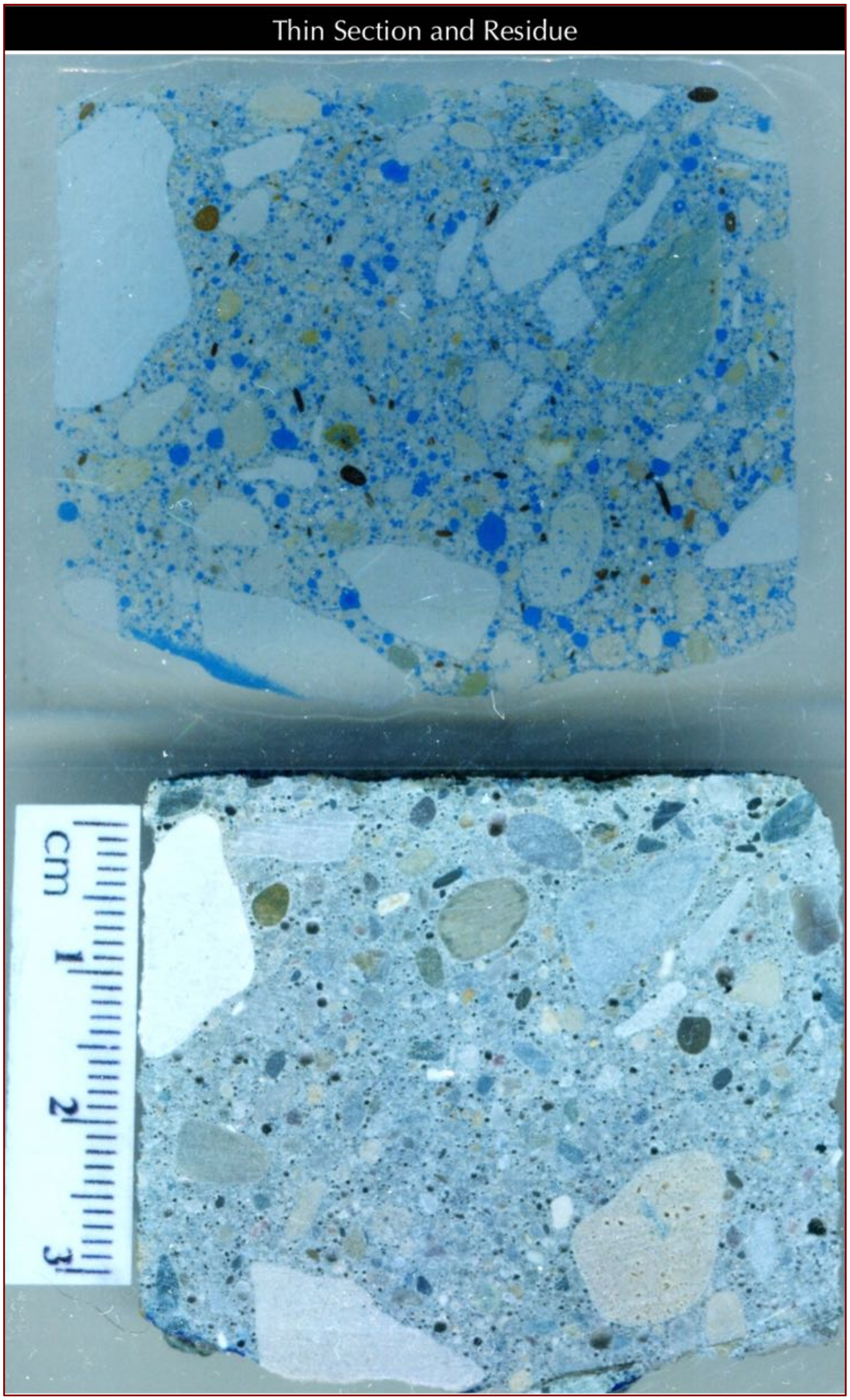


Figure 8: Blue dye-mixed epoxy-impregnated thin section (top) and corresponding solid residue (bottom) after thin section preparation of the core where air voids and pore spaces are highlighted with blue epoxy.

PHOTOMICROGRAPHS OF THIN SECTION

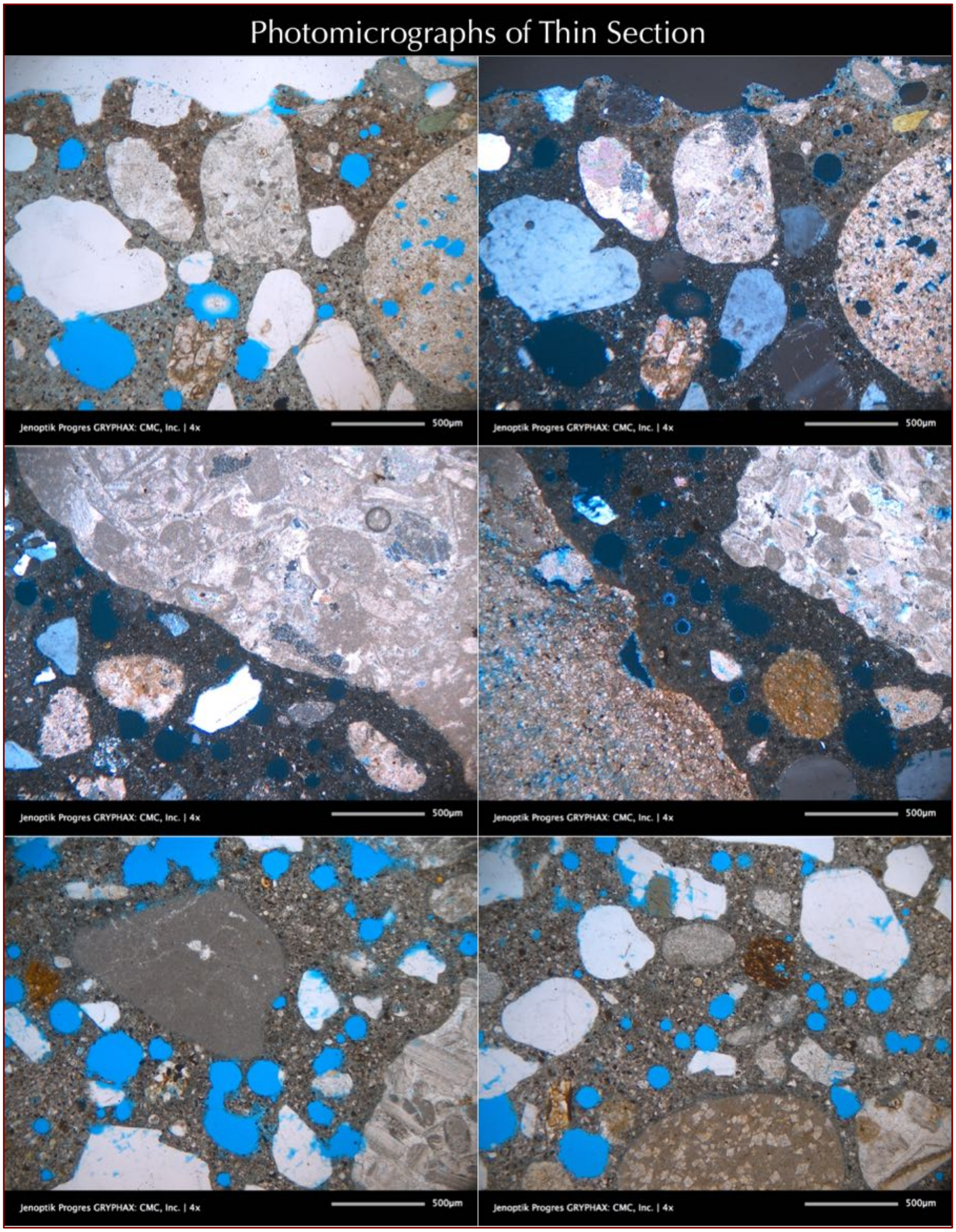


Figure 9: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of concrete taken with a petrographic microscope showing: (a) dense paste and shallow carbonation at the top exposed surface region in the top row; (b) crushed limestone coarse aggregate and natural siliceous-calcareous sand fine aggregate (middle row), and (c) air-entrained nature of concrete where air voids are highlighted by blue epoxy used to impregnate the thin section. Notice the absence of any macro or microcracking or any distress in the concrete.

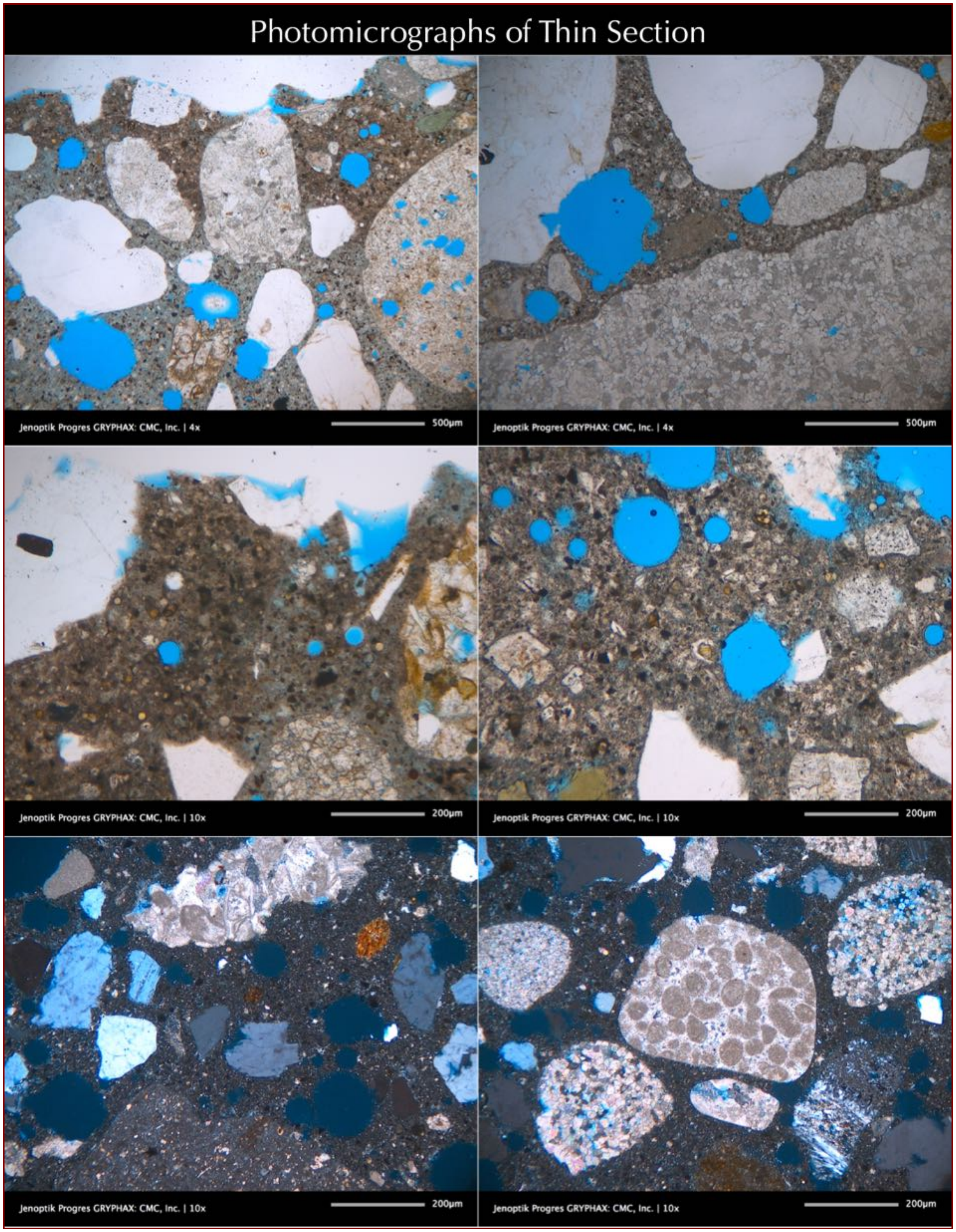


Figure 10: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of concrete taken with a petrographic microscope showing: (a) dense paste at the top exposed surface region in the top left photo and dense paste in the interior body in top right photo; (b) dense paste having many residual Portland cement and spherical fly ash particles in paste in middle row; and (c) natural siliceous-calcareous sand fine aggregate in non-carbonated mortar fraction of concrete in the body in the bottom row.

COARSE AGGREGATE

Coarse aggregate is crushed limestone having a nominal maximum size of 1 in. (25 mm). Particles are medium to dark gray, dense, hard, angular, massive textured, equidimensional to elongated, unaltered, uncoated, and uncracked. Coarse aggregate particles are well-graded and well-distributed. There is no evidence of alkali-aggregate reactions of coarse aggregate particles in the core. Coarse aggregate particles have been sound during their service in the concrete.

FINE AGGREGATE

Fine aggregate is natural siliceous-calcareous sand having major amounts of siliceous components (quartz, quartzite, feldspar, granite, chalcedonic and dolomitic chert, quartz siltstone, sandstone), subordinate amounts of calcareous components (limestone, dolomite), and minor amount of argillaceous and ferruginous components (shale, ferruginous and argillaceous siltstone). Fine aggregate has a nominal maximum size of 3/8 in. (9.5 mm). Particles are variably colored, rounded to subangular, dense, hard, equidimensional to elongated, unaltered, uncoated, and uncracked. Fine aggregate particles are well-graded and well-distributed. Despite the presence of a few potentially alkali-silica reactive particles (e.g., chert), there is, however, no evidence of alkali-aggregate reaction of fine aggregate particles in the concrete. Fine aggregate particles have been sound during their service in the concrete.

The following Table summarizes properties of coarse and fine aggregates.

Properties and Compositions of Aggregates	Core From Parking Garage Deck
Coarse Aggregate	
Types	Crushed Limestone
Nominal maximum size (in.)	1 in. (25 mm)
Rock Types	Fossiliferous and micritic limestone (biomicrite and micrite)
Angularity, Density, Hardness, Color, Texture, Sphericity	Angular, dense, hard, dark gray, massive textured, equidimensional to elongated
Cracking, Alteration, Coating	Unaltered, Uncoated, and Uncracked
Grading & Distribution	Well-graded and Well-distributed
Soundness	Sound
Alkali-Aggregate Reactivity	None
Fine Aggregate	
Types	Natural siliceous-calcareous sand
Nominal maximum size (in.)	3/8 in. (9.5 mm)
Rock Types	Major amounts of siliceous components (quartz, quartzite, feldspar, granite, chalcedonic and dolomitic chert, quartz siltstone, sandstone), subordinate

Properties and Compositions of Aggregates	Core From Parking Garage Deck
	amounts of calcareous components (limestone, dolomite), and minor amounts of argillaceous and ferruginous components (shale, ferruginous and argillaceous siltstone)
Cracking, Alteration, Coating	Variably colored, rounded to subangular, dense, hard, equidimensional to elongated
Grading & Distribution	Well-graded and Well-distributed
Soundness	Sound
Alkali-Aggregate Reactivity	None

Table 1: Properties of coarse and fine aggregates of concrete.

PASTE

Properties and composition of hardened cement pastes are summarized in Table 2. Paste is medium gray throughout the depth of the core, moderately dense and moderately hard; freshly fractured surfaces of interior pastes have subvitreous lusters and subconchoidal textures. Residual and relict Portland cement particles are present and estimated to constitute 6 to 8 percent of the paste volumes. Distributed throughout the paste are fine, discrete, spherical clear to light to dark brown to black glassy particles of fly ash having the fineness of Portland cement. Hydration of Portland cement is normal.

Properties and Compositions of Paste	Core From Parking Garage Deck
Color, Hardness, Porosity, Luster	Medium gray all throughout the core, moderately dense and moderately hard; freshly fractured surfaces of interior pastes have subvitreous lusters and subconchoidal textures
Residual Portland Cement Particles	Normal, 6 to 8 percent by paste volume
Calcium hydroxide from cement hydration	Normal, 10 to 14 percent by paste volume
Pozzolans, Slag, etc.	Fly ash
Water-cementitious materials ratio (*w/cm*), estimated	0.40 to 0.44
Cementitious Materials Contents (bags per cubic yard)	6 to $6^1/_2$ bags of which 15 to 20 percent is estimated to be fly ash
Secondary Deposits	None
Depth of Carbonation, mm	1 to 2 mm
Microcracking	None
Aggregate-paste Bond	Tight
Bleeding, Tempering	None
Chemical deterioration	None

Table 2: Proportions and composition of hardened cement paste.

The textural and compositional features of the paste are indicative of a cementitious materials content estimated to be equivalent to 6 to 6$^{1}/_{2}$ bags of Portland cement per cubic yard of which 15 to 20 percent is estimated to be fly ash, and, a water-cementitious materials ratio (*w/cm*) estimated to be from 0.40 to 0.44 in the body.

There is no evidence of any deleterious deposits found in the core. Carbonation is shallow, 1 to 2 mm, which is not unusual and indicative of the dense well-consolidated nature of concrete. Bonds between the coarse and fine aggregate particles and paste are tight. There is no evidence of microcracking due to deleterious reactions.

The overall quality and condition of the concrete are judged to be sound with no evidence of any physical or chemical deterioration in the concrete.

AIR

Air occurs as: (a) numerous, fine, discrete, spherical and near-spherical voids of sizes up to 1 mm, and (b) a few coarse, near-spherical and irregularly shaped voids of sizes coarser than 1 mm. The former voids are characteristic of intentionally introduced entrained air, whereas latter voids are accidentally formed entrapped air. Air-void system of concrete is suggestive of intentional addition of an air-entraining agent in the mix, which is beneficial for providing necessary durability of concrete in a moist outdoor environment of cyclic freezing and thawing.

Air content is estimated to be 6 to 7 percent, which is adequate for providing necessary durability of concrete in the outdoor environment of cyclic freezing and thawing. Figures 6 and 7 show numerous photomicrographs of concrete throughout the depth showing air-entrained nature of concrete.

DISCUSSIONS

AIR CONTENTS AND AIR-VOID SYSTEMS

Parking deck concrete is found to be air entrained, which is a necessary requirement of an outdoor concrete exposed to moisture and cyclic freezing and thawing. Air voids provide necessary room for expansion of water during freezing, this releases freezing-related tensile stresses in concrete. According to common industry (e.g., ACI) recommendations, an outdoor concrete exposed to moisture and freezing should be air entrained having an air content usually between 4$^{1}/_{2}$ to 7$^{1}/_{2}$ percent, an air-void specific surface of at least 600 in^2/in^3, and an air-void spacing factor of maximum 0.008 in. The observed air-void system of concrete is found to be in conformance to common industry recommendations in having adequate fine air bubbles needed for protection of paste during freezing at critically saturated conditions. The air content is estimated to be 6 to 7 which is well within the common industry-recommended range for an air-entrained concrete.

AGGREGATES

The crushed limestone coarse aggregates and natural siliceous-calcareous sand fine aggregates are present in sound conditions, and should not introduce any issue. There is no evidence of any potentially deleterious reactions of aggregates in the concrete to affect its future performance.

PLACEMENT, FINISHING, AND CURING

There is no evidence of any soft, porous, high *w/cm* paste at the surface region to indicate finishing in the presence of bleed water or addition of water during finishing. There is no evidence of entrapment of bleed water beneath the finished surface to indicate premature finishing prior to the cessation of bleeding. Concrete is found to be well-consolidated without any coarse entrapped voids. Curing of the finished surface is found to be normal without any issue. Shallow depth of carbonation (only 1 to 2 mm) indicates dense, well-consolidated concrete.

COMPRESSIVE STRENGTH & CONCRETE MATURITY

The maturity of concrete is defined as: (i) a period of air drying and (ii) a compressive strength of at least 4000 psi – both prior to the first exposure of salts and snow so that the concrete does not contain any 'freezable' water in its capillary pores to freeze, expand, and thus cause distress (hence the importance of at least a period of air drying), and is strong enough to resist freezing-related stresses (hence the importance of adequate strength of at least 4000 psi) both prior to the first exposure of snow and salt (Jana 2004, Jana 2007). A concrete is, therefore, needed to be 'matured' prior to the first exposure of freezing, especially during the winter weather constructions. The observed concrete is judged to have attained maturity prior to exposure to freezing conditions.

WATER-CEMENTITIOUS MATERIALS RATIO AND DURABILITY

The estimated water-cementitious materials ratio (*w/cm*) of concrete (0.40 to 0.44) is well within the common industry-recommended range of 0.40 to maximum 0.45 for an outdoor concrete exposed to moisture, and cyclic freezing and thawing.

DEICING SALTS

Deicing salts, usually, do not cause surface scaling in a properly air-entrained concrete having a good air-void system that is made using sound aggregates, and has been placed, finished, cured, and was matured properly (Jana 2004, 2007), *unless*: (i) salt is applied prior to the attainment of maturity of concrete, and/or (ii) a chemically aggressive (e.g., magnesium or ammonium sulphate or urea-based) salt is applied that can chemically decompose the paste (calcium silicate hydrate, the heart of concrete).

Due to the adequate air entrainment and overall dense, well-consolidated nature, the concrete is judged to be resistant to application of deicing chemicals. However, use of harmful corrosive deicers can affect the surface by causing decomposition of paste and other chemical or physical salt attacks.

BENEFICIAL ASPECT OF A SURFACE SEALER

It is the concrete itself, i.e. an adequately air-entrained concrete made using 'optimum' air content and good air-void system, sound aggregates, good paste, placed, finished, and cured properly, and has been matured prior to the first exposure to freezing, salts, and snow, which should provide the necessary adequate durability. When all these basic factors are fulfilled from concrete materials to construction practices, having an additional surface sealer is not needed for protection. A surface sealer, however, does provide an additional protection, particularly when the inherent concrete quality and/or construction practices is/are questionable. There are, however, many incidences of surface scaling in many outdoor slabs that did receive surface sealers, simply because sealer did not provide a long-term protection, and needed repeated applications. On the other hand, there are many incidences of perfectly sound outdoor slabs without any sealer that were exposed to freezing, salts, and snow but no distress at all simply because the concretes were made using sound durable materials and were constructed and matured properly, as in this present case. Therefore, having or not having a sealer is not the paramount factor for providing the first-hand protection against the environment. Sealer becomes more important when the inherent quality of concrete is questionable when concrete surface has poor scaling resistance, which is not the case here.

CONCLUSIONS

Based on detailed petrographic examinations, concrete in the core received is found to be air-entrained and made using sound crushed limestone coarse aggregate, natural siliceous-calcareous sand fine aggregate, dense Portland cement and fly ash based paste having a cementitious materials content estimated to be equivalent to 6 to $6^1/_2$ bags of Portland cement per cubic yard of which 15 to 20 percent is estimated to be fly ash, and, a water-cementitious materials ratio (*w/cm*) estimated to be from 0.40 to 0.44 in the body, and adequate air entrainment having an air content estimated to be 6 to 7 percent. Concrete is dense, well-consolidated with no evidence of chemical or physical deterioration. Based on petrographic examinations, the concrete should be serviceable in its intended exposure conditions.

REFERENCES

ACI Committee Report 116R-00, Guide to Durable Concrete, ACI Manual of Concrete Practice, Vol. 1, American Concrete Institute, 2008.

ACI Committee Report 201.2R, Guide to Durable Concrete, ACI Manual of Concrete Practice, Vol. 1, American Concrete Institute, 2008.

ASTM C 457 "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete," Vol. 4.02, ASTM International, West Conshohocken, PA, 2010.

ASTM C 856 "Standard Practice for Petrographic Examination of Hardened Concrete," Vol. 4.02, ASTM International, West Conshohocken, PA, 2014.

Jana, D., "Concrete Scaling – A Critical Review", *Proceedings of the 29th Conference on Cement Microscopy*, Quebec City, PQ, Canada, 2007.

Jana, D., Peterson, K., Thaulow, N., Baumgart, C., Furuichi, H., and Casper, M., "A Round Robin Test on Measurements of Air Void Parameters in Hardened Concrete by Various Automated Image Analyses and ASTM C 457 Methods", *Proceedings of the 29th Conference on Cement Microscopy*, Quebec City, PQ, Canada, 2007.

Jana, D., "Concrete, Construction or Salt – Which Causes Scaling? Part I: Importance of Air-void System in Concrete", *Concrete International*, American Concrete Institute, November 2004, pp. 31-38.

Jana, D., "Concrete, Construction or Salt – Which Causes Scaling? Part II: Importance of Finishing Practices", *Concrete International*, American Concrete Institute, December 2004, pp. 51-56.

Jana, D., Erlin, B., and Pistilli, M., "A Closer Look at Entrained Air in Concrete", *Concrete International*, American Concrete Institute, June 2005, pp. 31-38.

Jana, D., and Erlin, B., "Scaling Revisited", Letters, *Concrete International*, American Concrete Institute, September 2001, pp. 25-26.

Jana, D., "Petrography: A Powerful Tool For Solving Common Concrete Problems", *Civil Engineering NEWS*, March 1997, pp. 40-44.

Jana, D., and Cole, A.A., "Microscopy: A Practical Solution to Concrete Problems", *Bulletin of Concrete Industry Board*, September 1997, pp. 18-22.

✪ ✪ ✪ END OF TEXT ✪ ✪ ✪

END OF REPORT[1]

[1] The CMC logo is made using a lapped polished section of a 1930's concrete from an underground tunnel in the U.S. Capitol.