Appendix A.

Petrographic Reports

CTL Structural/Architectural Engineering,
Testing and Materials Technology

5420 Old Orchard Road, Skokie, Illinois 60077-1030
847/ 965-7500 **800/ 522-2CTL** Fax: 847/ 965-6541

PETROGRAPHIC SERVICES

CTL Project No. 050860 Date: September 26, 1996

RE: Addendum to Petrographic Report for Michigan Department of Transportation

The following comments are provided to address questions raised in response to our previous report on the cracking of the concrete pier caps, I-75 bridge over the River Rouge in Detroit, Michigan.

1. Results of all ASTM C 457 linear traverse data were previously forwarded. Two full C 457 analyses were performed. Partial analyses, conducted over traverse lengths of 20 to 25 in. were performed only to confirm the petrographer's estimates of air content. It is not our practice to save the computer files for these partial analyses.

2. Photographs included in the August 7 report show representative lapped surfaces of longitudinally cut concrete cores treated with uranyl acetate. The method is used to screen cores for evidence of potential alkali-silica reaction products (gel). The arrows on the photographs show bright fluorescence attributed to alkali-silica gel. The amount of gel detected is very small.

3. Residual portland cement clinker grains probably do not constitute a significant source of additional alkalies. The residual grains are composed of C_2S crystals and intergrown C_3A and C_4AF. These formulae are given in cement chemist's notation. These phases do not incorporate significant alkalies. Generally, the alkalies present in cement are readily soluble alkali sulfates precipitated in the clinker pore spaces. Grinding clinker to make cement exposes most of these pores, thus the readily soluble alkalies are released early during cement hydration.

4. Potential alkali reactivity of the slag coarse aggregate appears to be negligible based on the service record, i.e. the slag has not reacted after 30 years in service. The report "Iron Blast-Furnace Slag Production, Processing, Properties, and Uses", by Josephson et al. does not provide insight into expressed concerns for reactivity. The report discusses the agricultural applications of slag as a fertilizer, and the treatment of soil to neutralize acidity. The report refers to 'soluble silica in slag' (referenced, 1900) and 'easily liberated silicic acid' (reference

not provided, but before 1949) as being beneficial to plants. Differences in the behavior of ground slag in an aerated soil with organic constituents and that of slag coarse aggregates embedded in concrete would be anticipated. Blast-furnace slag is alkaline and is stable in the highly alkaline environment provided by portland cement paste. The pH of slag, typically between 9 and 10, is essentially the same as the pH of carbonated paste, which can be as low as 9.0 to 9.5. ASTM tests designed to identify alkali-reactive aggregates have not identified blast-furnace slag as reactive. Unless the slag has an unusual composition, not typical of the tested slags, it is presumed nonreactive.

L. J. Powers-Couche
Senior Petrographer
Petrographic Services

050860

ACCUMULATED LINEAR TRAVERSE DATA

Originator- R. Detwiler
Operator--- R. Sturm
Date------- 06/05/96
File------- 050860-1
Measured Paste Content = 29.4%
Field:4 x 3.25 in.

Sample ID- Pier 38 #5 NB
Project #- 050860

Total Travel Executed	95.0	in
Total Area Covered	12.5	Sq. in
Total Void Length	6.6	in
Total Number of Voids	814	

Void Size Breakdown (increments of 0.0001 inches)

Voids less than 10	64	(7.86%)	[0.05%]
Voids 10 to 20	116	(14.25%)	[0.18%]
Voids 21 to 30	105	(12.90%)	[0.28%]
Voids 31 to 40	96	(11.79%)	[0.35%]
Voids 41 to 50	76	(9.34%)	[0.36%]
Voids 51 to 60	78	(9.58%)	[0.45%]
Voids 61 to 70	68	(8.35%)	[0.47%]
Voids 71 to 80	38	(4.67%)	[0.30%]
Voids 81 to 90	38	(4.67%)	[0.34%]
Voids 91 to 100	18	(2.21%)	[0.18%]
Voids 101 to 200	73	(8.97%)	[1.05%]
Voids 201 to 393.6	19	(2.33%)	[0.52%]
Voids 393.7 (1mm) and greater	25	(3.07%)	[2.47%]

LINEAR TRAVERSE CALCULATIONS

Average Chord Intercept	0.0082	in
Voids per Inch	8.57	
Specific Surface (1/in)	490.2	
Paste to Air Ratio	4.20	
Air Content	6.99	%
Spacing Factor	0.0086	in

Values in "( )" next to "Void Size" columns show void "Count" distribution relative to "Total Number of Voids".
Values in "[ ]" next to "Void Size" columns show void "Length" distribution relative to total "Air Content".

ACCUMULATED LINEAR TRAVERSE DATA

Originator- R. Detwiler
Operator--- R. Sturm
Date------- 06/05/96
File------- 050860-2
Measured Paste Content = 25.9%
Field: 4 x 3.25 in.

Sample ID- Pier 39 #7 NB
Project #- 050860

Total Travel Executed	95.0	in
Total Area Covered	12.5	Sq. in
Total Void Length	6.0	in
Total Number of Voids	633	

Void Size Breakdown (increments of 0.0001 inches)

Voids less than 10	47	(7.42%)	[0.03%]
Voids 10 to 20	97	(15.32%)	[0.15%]
Voids 21 to 30	92	(14.53%)	[0.24%]
Voids 31 to 40	69	(10.90%)	[0.25%]
Voids 41 to 50	69	(10.90%)	[0.32%]
Voids 51 to 60	53	(8.37%)	[0.31%]
Voids 61 to 70	44	(6.95%)	[0.30%]
Voids 71 to 80	22	(3.48%)	[0.17%]
Voids 81 to 90	19	(3.00%)	[0.17%]
Voids 91 to 100	8	(1.26%)	[0.08%]
Voids 101 to 200	59	(9.32%)	[0.84%]
Voids 201 to 393.6	29	(4.58%)	[0.86%]
Voids 393.7 (1mm) and greater	25	(3.95%)	[2.54%]

LINEAR TRAVERSE CALCULATIONS

Average Chord Intercept	0.0094	in
Voids per Inch	6.66	
Specific Surface (1/in)	425.3	
Paste to Air Ratio	4.14	
Air Content	6.27	%
Spacing Factor	0.0097	in

Values in "( )" next to "Void Size" columns show void "Count" distribution relative to "Total Number of Voids".
Values in "[ ]" next to "Void Size" columns show void "Length" distribution relative to total "Air Content".

CTL Structural/Architectural Engineering, Testing and Materials Technology

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7 August 1996

Mr. Phil Mohr
Department of Civil and Environmental Engineering
1326 G.G. Brown Building
2350 Hayward
Ann Arbor, Michigan 48109-2125
Phone: (313) 763-6824

MDOT Rouge River Bridge Piers 38 and 39: Petrographic Report

Dear Phil:

Here is our petrographer's report detailing her examination of the cores by the uranyl acetate test. Together with her reports date 3 May and 8 July, this is the information that should be included in Section 2.4 of the final report. If you would like me to summarize these reports in a format and style consistent with the other sections I submitted to you earlier, just let me know and I will get you something as soon as possible. (You may want to do it yourself so that you can choose the photographs you want to include and get the layout the way you want.) I assume that the original reports would appear as an appendix to the final report.

If there is anything else you would like me to help you with, feel free to contact me. I would like to review the final report when you have it ready. I plan to be in Skokie all this month, but have several trips planned for September.

Best regards,

Rachel

Rachel J. Detwiler, Ph.D.
Senior Engineer

CTL Structural/Architectural Engineering, Testing and Materials Technology

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PETROGRAPHIC SERVICES REPORT

CTL Project No.: 050860-A *Date:* August 7, 1996

Re: Petrographic Screening of Samples for Evidence of Alkali-Silica Reaction

The sawcut surfaces of concrete core samples previously examined petrographically for CTL Project 050860 were treated with uranyl acetate solution in accordance with the procedures described in SHRP-C/FR-91-101, 'Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures.' The methodology is used to rapidly screen samples for evidence of alkali-silica reaction. Treated samples yield a brilliant yellow-green fluorescence where alkali-silica reaction product (gel) is present; however, confirmation of gel by microscopical methods is required because fluorescence may arise from other sources. Findings from this work are presented below.

FINDINGS

Treated samples exhibit only a limited occurrence of alkali-silica gel associated with the major cracks (see attached figures). Small amounts of gel line air voids near reactive chert sand grains. Many of the slag coarse aggregate particles exhibit fluorescence; however, this yellow-orange or pink-orange fluorescence is natural and is not associated with deleterious reaction. Based on these observations, reaction of the slag aggregate is not implicated as the cause of cracking. Alkali-silica reaction involving the fine aggregate does not appear to be extensive enough to account for the severity of cracking in the concrete structure.

L. J. Powers-Couche
Senior Petrographer
Petrographic Services

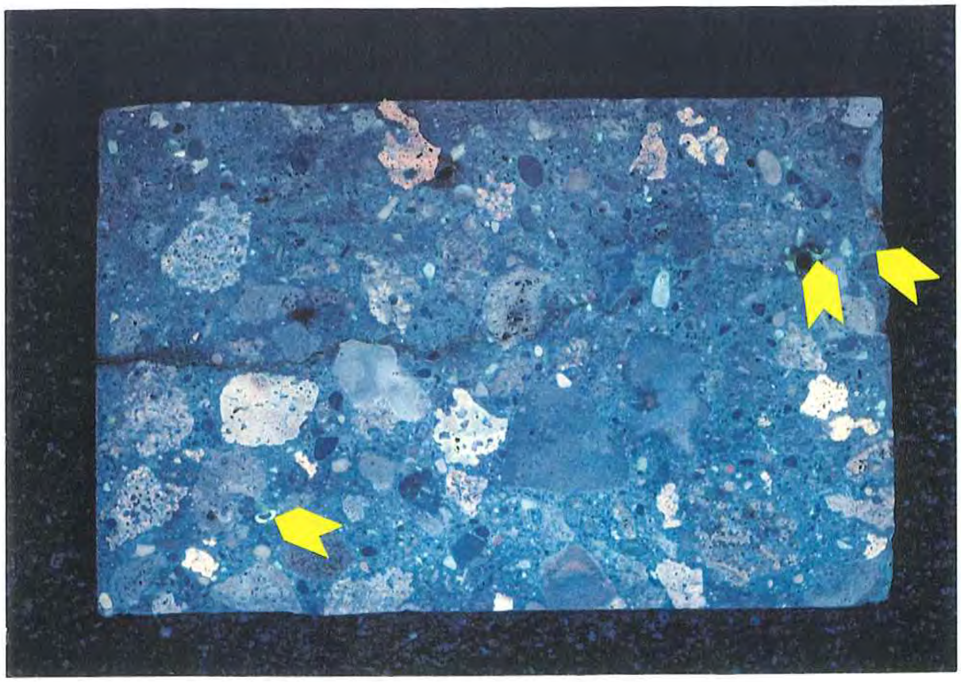
LJPC

050860-A

Attachments

CTL

1a. Surface Photographed in Ordinary Light

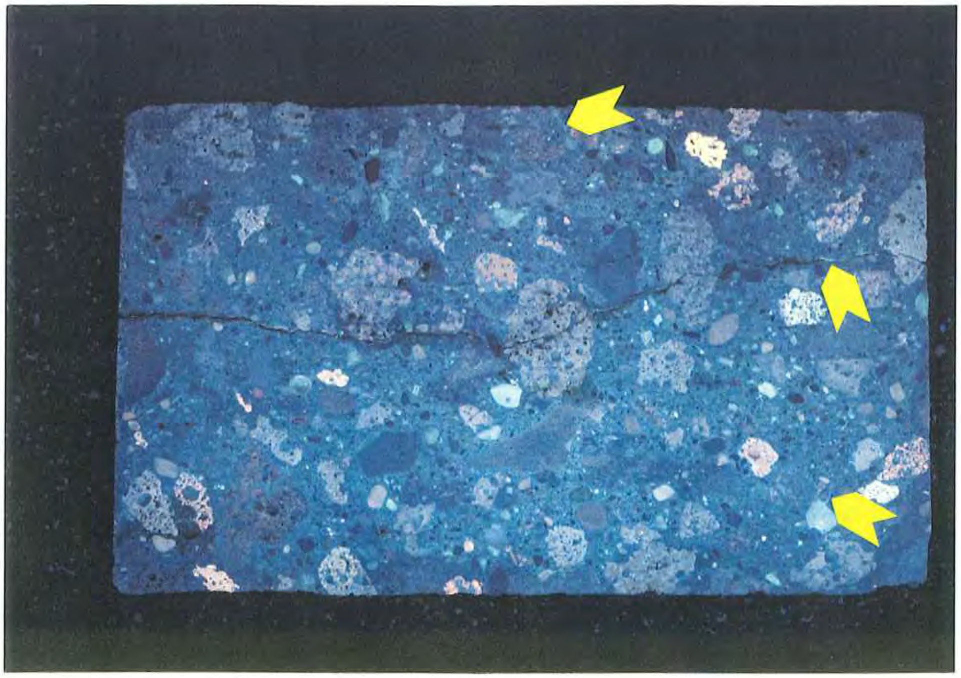


1b. Surface Photographed in Ultraviolet Light

FIG. 1 PIER 39 #2 NB TREATED SAMPLE.

CTL

2a. Surface Photographed in Ordinary Light



2b. Surface Photographed in Ultraviolet Light

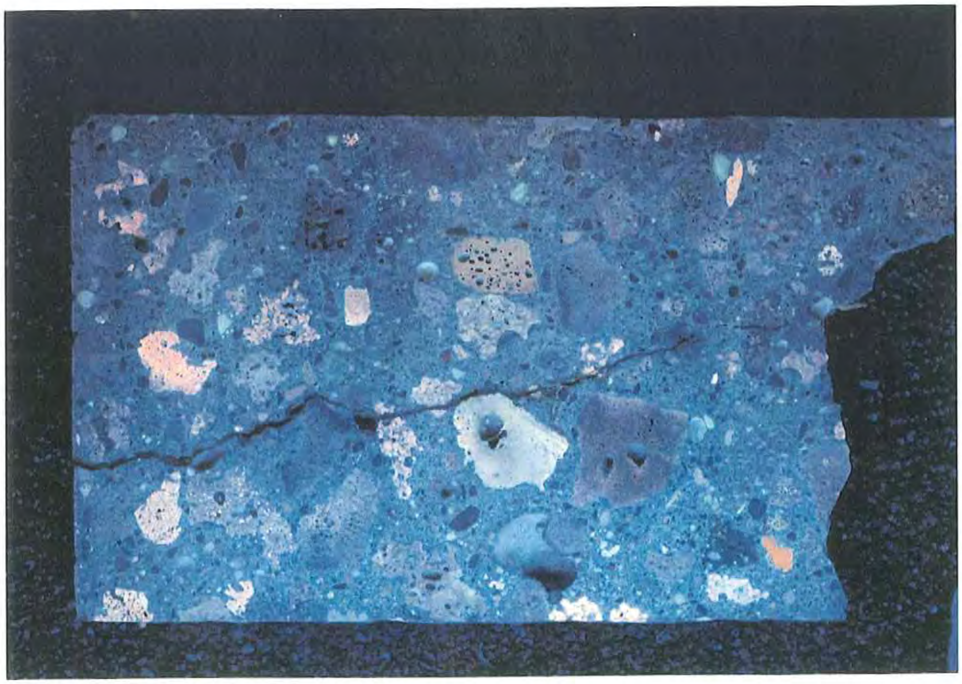
FIG. 2 PIER 39 #2 NB TREATED SAMPLE.

3a. Surface Photographed in Ordinary Light

3b. Surface Photographed in Ultraviolet Light

FIG. 3 PIER 38 #3 TREATED SAMPLE.

4a. Surface Photographed in Ordinary Light



4b. Surface Photographed in Ultraviolet Light

FIG. 4 PIER 39 S.F. 1C NB.

CTL Structural/Architectural Engineering, Testing and Materials Technology

5420 Old Orchard Road, Skokie, Illinois 60077-1030
847/ 965-7500 **800/ 522-2CTL** Fax: 847/ 965-6541

July 8, 1996

RE: MDOT Bridge Pier Samples

Sawcut cores, lapped surfaces and broken fragments of samples from the piers were screened for alkali-silica gel using the uranyl acetate method described in SHRP-C/FR-91-101. This method is considered to be a field test. Positive results require laboratory verification of the presence of gel. Negative results indicate ASR is not present.

Sample screening revealed the following:
1. Reaction rims and radial cracks filled with alkali-silica gel are not associated with the slag coarse aggregate. Many slag fragments fluoresce red, orange, and yellow. Gel fluorescence is bright yellow-green.

2. Characteristic yellow-green fluorescence is observed surrounding some chert particles (fine aggregate). Radial cracks with gel linings are not common and where they do occur, the cracks do not extend far from the reactive particle.

3. Gel linings occur in several air voids and gel is observed in portions of narrow microcracks; however, the occurrence of limited quantities of alkali-silica reaction products associated with fine aggregate particles does not fully explain the major cracks in the cores examined.

Laura J. Powers-Couche
Senior Petrographer

Project 050860
Copy to RJD
Files

CTL Structural/Architectural Engineering, Testing and Materials Technology

5420 Old Orchard Road, Skokie, Illinois 60077-1030
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8 May 1996

Dr. Will Hansen
Associate Professor
Department of Civil and Environmental Engineering
2340 G.G. Brown Building
2350 Hayward
Ann Arbor, Michigan 48109-2125

Evaluation of Pier Cap Nos. 38 and 39 of the I-75 Bridge over Rouge River in Detroit, Michigan

Dear Will:

Here are the chloride analysis and the petrographer's report on the cores you sent us from the I-75 Bridge. Note that at the level of the steel, the chloride content is much the same as the background chloride content, consistent with our visual observations in the field.

As noted in her report, our petrographer found signs of alkali-silica reaction but does not believe it to be the principal cause of distress.

If you would like to discuss these findings, please do not hesitate to call me.

Best regards,

Rachel

Rachel J. Detwiler
Senior Engineer
Materials Research and Consulting

050860

CTL Structural/Architectural Engineering, Testing and Materials Technology

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PETROGRAPHIC SERVICES REPORT

CTL Project No.: 050860 *Date:* May 3, 1996

Re: Petrographic Examination of Concrete Cores from Pier Caps, I-75 Bridge over the Rouge River, Michigan

Eighteen cores, labeled Pier 38 South Face #2 and #3, South Bound, and Pier 38 North Face #1 through #7, North Bound, and Pier 39 South Face #1 and #1C, #2 through #7, North Bound, and Pier 39 North Face #3, South Bound (Figs. 1 through 9) were received on January 26, 1996 from Dr. Rachel Detwiler, CTL Senior Engineer. The cores were submitted on behalf of Mr. Phil Mohr, University of Michigan, Ann Arbor, Michigan. The cores were taken from deteriorated pier caps of the above specified structure in Detroit, Michigan, in order to address the cause of cracking. The six cores listed below were chosen for detailed petrographic examination (ASTM C 856):

Pier 38 North Face #5 North Bound
Pier 38 North Face #2 North Bound
Pier 38 South Face #3 South Bound
Pier 39 South Face #7 North Bound
Pier 39 South Face #1 North Bound
Pier 39 South Face #2 North Bound

FINDINGS AND CONCLUSIONS

The results of the petrographic examinations do not fully reveal the cause of concrete cracking. Based on the widespread occurrence of small amounts of alkali-silica gel, expansion caused by alkali-silica reaction (ASR) may have contributed to the deterioration; however, it does not appear to be the principal cause of distress. Alkali-silica reaction, mainly involving chert in the fine aggregate, may influence the long-term durability of the concrete. Observations from the petrographic examinations are presented in Table 1. Additional findings are presented below.

1. The six cores examined represent similar concrete composed of manufactured slag (predominantly crystalline) coarse aggregate and natural sand fine aggregate in a portland cement paste.

   a. Aggregates are well graded to 3/4 in. top size.

   b. The fine aggregate consists of quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet (in approximate order of decreasing abundance).

   c. The paste is hard and dense with a subvitreous luster (except near cracks). Paste color ranges from mottled brown-gray to buff and dark green. Dark green paste occurs adjacent to some slag aggregates.

   d. Interpreted water-cement ratio is low, less than 0.40 in cores from Pier 38 and 0.38 to 0.43 in cores from Pier 39, based on microscopical observations (thin-section study) and macroscopical paste properties.

   e. The concrete is air entrained. Pier 39 South Face #77 North Bound contains an estimated 3 to 5% entrained air voids. The estimated air content in the remaining cores is 5 to 7%. Air voids are mostly small and nonuniformly distributed (clustered) A substantial amount of entrapped air is observed; however, these air voids are widely scattered and typically smaller than 1/2 in.

2. Major longitudinal cracks are relatively old based on the presence of substantial paste carbonation along the crack walls. Water infiltration along cracks has locally leached calcium hydroxide from the paste and deposited ettringite in available space. Much of the evidence of alkali-silica reaction indicates incipient (early) ASR: gel-soaked paste around aggregates, small concentrations of gel adjacent to aggregates, accumulations in air voids, dark rims on aggregates, peripheral microcracks and zonal degradation of the aggregate. Evidence of active ASR includes local deposits of interlayered gel and calcite coatings on the walls of major cracks (Fig. 10) and branching, gel-filled microcracks extending from reactive aggregates into the paste (Fig. 11).

TABLE 1: SUMMARY OF SELECTED PETROGRAPHIC OBSERVATIONS

Core Sample	Cracks	Microcracks	Secondary Deposits/Alkali-Silica Reaction
Pier 38			
North Face #5 North Bound	None	Many in exterior 3 in.; some associated with ASR.	Minor. Gel-soaked paste around chert; gel in microcracks.
North Face #2 North Bound	Longitudinal Transverse	Few; passing through aggregates.	Ettringite and calcium hydroxide in air voids. Minor ASR. Gel and calcite line portions of major crack.
South Face #3 South Bound	Longitudinal Transverse	Few; passing through aggregates.	Minor ettringite in voids. Gel-soaked paste around chert, graywacke, and schist.
Pier 39			
South Face #7 North Bound	None	None	Minor ettringite in air voids. Gel-soaked paste around some chert particles.
South Face #1 North Bound	Longitudinal Transverse	Few; some microcracks radiating from reactive chert.	Abundant ettringite, minor calcium hydroxide and calcite in air voids. Alkali-silica gel in cracks.
South Face #2 North Bound	Longitudinal	Many parallel to major crack; many associated with ASR.	Abundant ettringite in air voids. Alkali-silica gel in microcracks and voids. Gel-soaked paste around chert.

METHODS OF TEST

Petrographic examination of the cores was performed in accordance with ASTM C 856-83 (reapproved 1988), "Standard Practice for Petrographic Examination of Hardened Concrete."

The cores were photographed and visually examined. A 0.7-in.-thick slice was cut longitudinally from the cores and one side of each was lapped. Lapped and freshly broken surfaces were studied with a stereomicroscope at magnifications up to 45X. Secondary deposits were removed using a fine tungsten probe and placed in refractive index media on glass microscope slides. The mounted samples were studied using a polarized-light microscope at magnifications up to 1000X. A rectangular block, measuring about 2 in. long, 1 in. wide, and 0.5 in. thick, was cut from each core and placed on separate glass microscope slides with epoxy resin. The mounted samples were reduced to a thickness of about 0.0008 in. (20 μm) and examined using a polarized-light microscope at magnifications up to 400X, to determine aggregate and paste mineralogy and microstructure.

Laura J. Powers-Couche

L. J. Powers-Couche
Senior Petrographer
Petrographic Services

LPC/djp

050860

Attachments

FIG. 1 SIDE VIEWS OF CORES AS RECEIVED FOR EXAMINATION.

FIG. 2 SIDE VIEW OF CORE, AS RECEIVED.

FIG. 3 TWO SIDE VIEWS OF CORE, AS RECEIVED. ARROWS SHOW FRESH ALKALI-SILICA GEL AROUND CHERT AGGREGATES.

FIG. 4 SIDE VIEWS OF CORES, AS RECEIVED.

FIG. 5 SIDE VIEWS OF CORES, AS RECEIVED.

FIG. 6 SIDE VIEWS OF CORES, AS RECEIVED.

FIG. 7 SIDE VIEWS OF CORES, AS RECEIVED.

FIG. 7 SIDE VIEWS OF CORES, AS RECEIVED.

FIG. 8 SIDE VIEWS OF CORES, AS RECEIVED.

FIG. 9 SIDE VIEWS OF CORES, AS RECEIVED.

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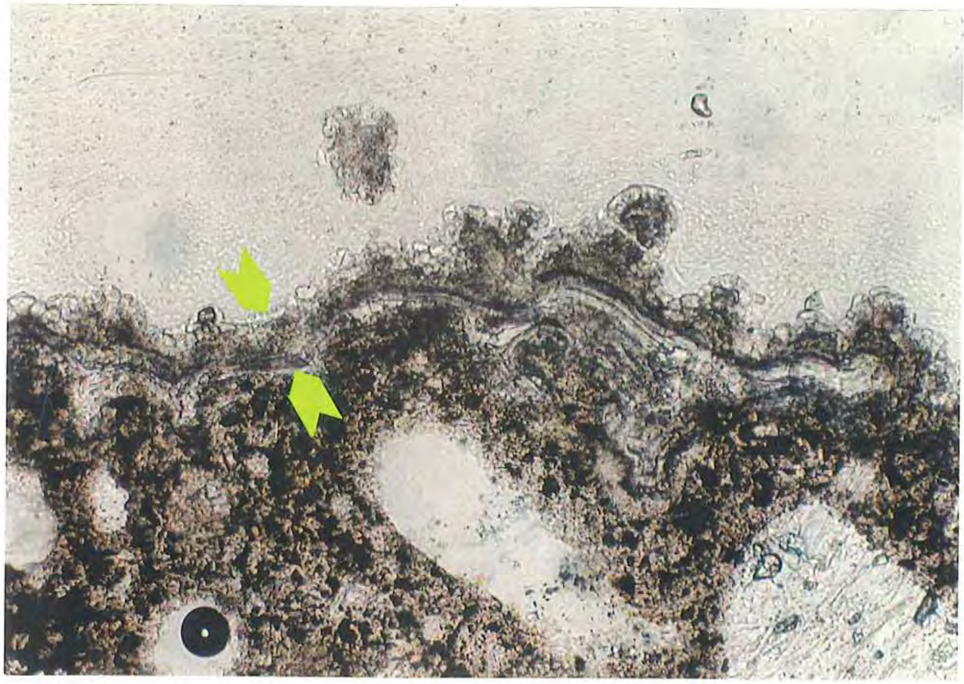

FIG. 10 THIN-SECTION PHOTOMICROGRAPH OF CORE PIER 38 NF #2NB SHOWING INTERLAYERED ALKALI-SILICA GEL AND CALCIUM CARBONATE DEPOSITS (BETWEEN ARROWS) ON CRACK WALL. PLANE-POLARIZED LIGHT. WIDTH OF FIELD IS ABOUT 350 μM.

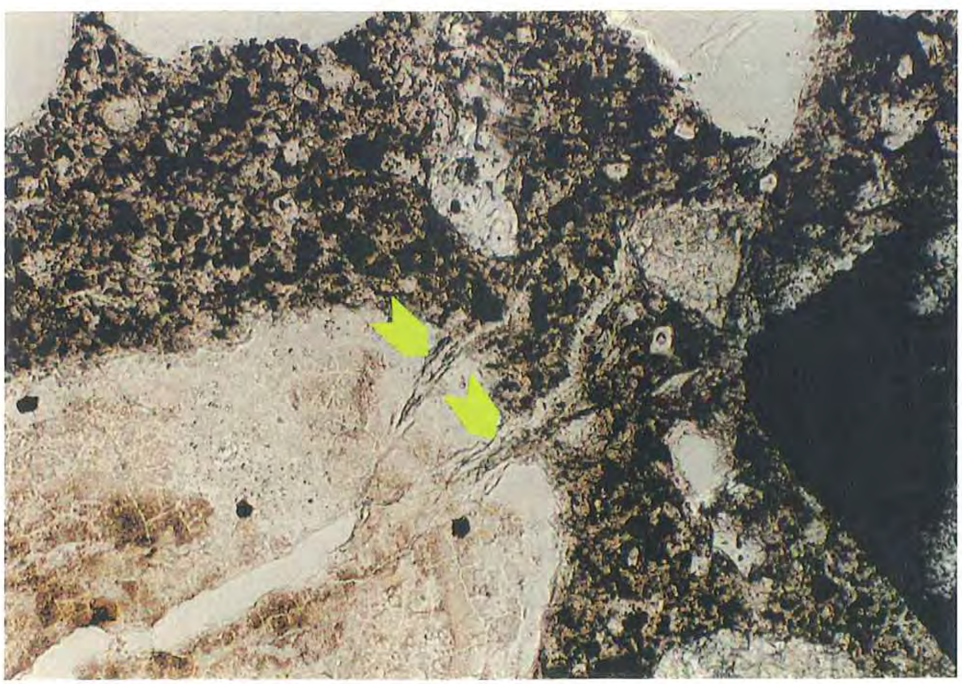

FIG. 11 THIN-SECTION PHOTOMICROGRAPH OF CORE PIER 39 SF #2NB SHOWING GEL-FILLED MICROCRACKS (ARROWS) EMANATING FROM REACTIVE CHERT PARTICLES. PLANE-POLARIZED LIGHT. WIDTH OF FIELD IS ABOUT 700 μM.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 050860

CLIENT: Michigan Department of Transportation

STRUCTURE: Bridge Pier Caps

LOCATION: I-75 Bridge
Rouge River, Detroit, Michigan

DATE: May 3, 1996

REPORTED PROBLEM: Cracking

EXAMINED BY: L. Powers-Couche

SAMPLE

Identification: Pier 38 North Face #5 North Bound.

Dimensions: Diameter = 3.9 in. Length = 10.5 in.

Exterior Surface: Even, paste-rich, formed surface with scattered, small irregular air voids (bugholes).

Interior Surface: Irregular surface broken through aggregates.

Cracks, Joints, Large Voids: No significant cracks are present. No joints are observed. A few large irregular air voids up to 0.6 in. long are present.

Reinforcement: None present in core.

AGGREGATES (A)

Coarse (C): Manufactured, mostly crystalline slag.

Fine (F): Natural sand composed of siliceous and calcareous rocks and minerals. In approximate order of decreasing abundance: quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet.

Gradation & Top Size: Well graded to 0.8 in. top size.

Shape & Distribution: CA - angular to subrounded, blocky to oblong, and uniformly distributed. FA - rounded to angular, equant to oblong, and uniformly distributed.

PASTE

Color: Mottled shades of brown-gray.

Hardness: Hard to moderately hard.

Luster: Subvitreous to dull locally.

Depth of Carbonation: The paste is carbonated to a depth of 0.2 to 0.3 in. from the exterior surface.

Air Content: Air entrained with 5 to 7% small, spherical air voids.

Paste-Aggregate Bond: Tight. Lab-induced fractures pass through the coarse aggregates.

Calcium Hydroxide*: 5 to 7% uniformly distributed tabular crystals.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 15 to 22% somewhat nonuniformly distributed UPC's and partly hydrated clinker particles.

Pozzolans*: None observed. A small amount of slag is present, presumably fragments derived from the coarse aggregate.

Secondary Deposits: Calcium hydroxide occurs in a few air voids. Most voids are empty. Alkali-silica gel lines several air voids and fills microcracks in a reactive chert particle.

MICROCRACKING: A few random microcracks and many microcracks oriented parallel to the exterior end of the core occur in the outer 3 in. Most microcracks pass through aggregates.

ESTIMATED WATER-CEMENT RATIO: <0.40.

MISCELLANEOUS: Dark, gel-soaked paste occurs around a few chert particles; however, distress caused by ASR is limited to microcracks.

*percent by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 050860

DATE: May 3, 1996

CLIENT: Michigan Department of Transportation

REPORTED PROBLEM: Cracking

STRUCTURE: Bridge Pier Caps

EXAMINED BY: L. Powers-Couche

LOCATION: I-75 Bridge
Rouge River, Detroit, Michigan

SAMPLE

Identification: Pier 38 North Face #2 North Bound.

Dimensions: Diameter = 3.7 in. Length = 10.5 to 11.5 in.

Exterior Surface: Even, paste-rich, formed surface with scattered irregular air voids (bugholes) and two irregular cracks across the surface.

Interior Surface: Irregular surface broken through aggregates.

Cracks, Joints, Large Voids: One longitudinal crack extends the length of the core. One longitudinal crack extends from the exterior surface to a depth of 3 in. and another extends from the 6 in. transverse crack to the 9 in. transverse crack. Transverse cracks occur at depths of 6 in. and 9 in. The latter extends part way through the core.

Reinforcement: None present in core.

AGGREGATES (A)

Coarse (C): Manufactured, mostly crystalline slag.

Fine (F): Natural sand composed of siliceous and calcareous rocks and minerals. In approximate order of decreasing abundance: quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet.

Gradation & Top Size: Well graded to 0.8 in. top size.

Shape & Distribution: CA - angular to subrounded, blocky to oblong, and uniformly distributed. FA - rounded to angular, equant to oblong, and uniformly distributed.

PASTE

Color: Mottled shades of brown-gray.

Hardness: Hard to moderately hard.

Luster: Subvitreous to dull locally.

Depth of Carbonation: Unevenly carbonated to a depth of 0.1 to 0.4 in. from the exterior surface; thin layer of paste carbonation along major longitudinal crack.

Air Content: Air entrained with 5 to 7% small, spherical air voids. Air voids are clustered; nonuniformly distributed.

Paste-Aggregate Bond: Tight. Lab-induced fractures pass through the coarse aggregates.

Calcium Hydroxide*: 5 to 7% tabular and patchy calcium hydroxide; nonuniform distribution.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 15 to 22% nonuniformly distributed UPC's.

Pozzolans*: None observed. Slag particles observed in the paste are large and resemble the crystalline slag coarse aggregate.

Secondary Deposits: Ettringite and bladed calcium hydroxide occur in air voids in moderate amounts. Portions on the major longitudinal crack are coated with layered deposits of alkali-silica gel and calcium carbonate.

MICROCRACKING: A few random microcracks passing through aggregates are observed.

ESTIMATED WATER-CEMENT RATIO: <0.40.

MISCELLANEOUS: Dark, gel-soaked paste occurs around a few chert particles, however, distress caused by ASR is limited to microcracks.

*percent by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 050860

CLIENT: Michigan Department of Transportation

STRUCTURE: Bridge Pier Caps

LOCATION: I-75 Bridge
Rouge River, Detroit, Michigan

DATE: May 3, 1996

REPORTED PROBLEM: Cracking

EXAMINED BY: L. Powers-Couche

SAMPLE

Identification: Pier 38 South Face #3 South Bound.

Dimensions: Diameter = 3.9 in. Length = 9.0 in.

Exterior Surface: Even, paste-rich, formed surface with scattered, irregular air voids (bugholes) and two intersecting cracks up to 0.05 in. wide across surface.

Interior Surface: Irregular surface broken through aggregates.

Cracks, Joints, Large Voids: One major longitudinal crack passes around the coarse aggregates and extends through the core. Transverse cracks at 3.0 and 3.7 in. also pass around aggregates (offset by longitudinal crack). Minor transverse cracks branch from the major cracks.

Reinforcement: None present in core.

AGGREGATES (A)

Coarse (C): Manufactured, mostly crystalline slag.

Fine (F): Natural sand composed of siliceous and calcareous rocks and minerals. In approximate order of decreasing abundance: quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet.

Gradation & Top Size: Well graded to 0.8 in. top size.

Shape & Distribution: CA - angular to subrounded, blocky to oblong, and uniformly distributed. FA - rounded to angular, equant to oblong, and uniformly distributed.

PASTE

Color: Mottled shades of brown-gray with green staining adjacent to some aggregates.

Hardness: Hard to moderately hard.

Luster: Subvitreous to dull locally.

Depth of Carbonation: The paste is carbonated from the exterior surface to a depth of 0.2 in.; carbonation layer is present on the walls of the longitudinal crack.

Air Content: Air entrained with 5 to 7% small, spherical air voids. Air void distribution is nonuniform with many minute voids tightly clustered.

Paste-Aggregate Bond: Tight. Lab-induced fractures pass through the coarse aggregates.

Calcium Hydroxide*: 4 to 6% nonuniformly distributed irregular patches and tabular crystals.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 15 to 22% nonuniformly distributed UPC's. Partial rims of tightly packed UPC's occur around some slag aggregates.

Pozzolans*: A small amount of residual finely ground slag is observed.

Secondary Deposits: A small amount of ettringite is present in a few air voids. Voids and cracks are mostly empty.

MICROCRACKING: A few random tight microcracks, some passing through aggregates; generally oriented parallel to outside end of core.

ESTIMATED WATER-CEMENT RATIO: <0.40.

MISCELLANEOUS: Dark rims occur around many chert particles and some graywacke and schist particles.

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*percent by volume of paste

CTL

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 050860

CLIENT: Michigan Department of Transportation

STRUCTURE: Bridge Pier Caps

LOCATION: I-75 Bridge
Rouge River, Detroit, Michigan

DATE: May 3, 1996

REPORTED PROBLEM: Cracking

EXAMINED BY: L. Powers-Couche

SAMPLE

Identification: Pier 39 South Face #7 North Bound.

Dimensions: Diameter = 3.9 in. Length = 11.8 in.

Exterior Surface: Somewhat rough abraded or eroded surface with a few scattered shallow irregular air voids (bugholes).

Interior Surface: Irregular surface broken through aggregates.

Cracks, Joints, Large Voids: No joints, major cracks, or large air voids are observed.

Reinforcement: None present in core.

AGGREGATES (A)

Coarse (C): Manufactured, mostly crystalline slag.

Fine (F): Natural sand composed of siliceous and calcareous rocks and minerals. In approximate order of decreasing abundance: quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet.

Gradation & Top Size: Well graded to 0.8 in. top size.

Shape & Distribution: CA - angular to subrounded, blocky to oblong, and uniformly distributed. FA - rounded to angular, equant to oblong, and uniformly distributed.

PASTE

Color: Mottled shades of brown-gray with green rims on some aggregates.

Hardness: Hard to moderately hard.

Luster: Subvitreous to dull locally.

Depth of Carbonation: The paste is carbonated to a depth of 0.4 to 0.6 in. from the exterior surface.

Air Content: Air entrained with 3 to 5% small, spherical, nonuniformly distributed air voids.

Paste-Aggregate Bond: Tight. Lab-induced fractures pass through the coarse aggregates.

Calcium Hydroxide*: 5 to 7% uniformly distributed small crystals and larger crystals in paste-aggregate gaps.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 12 to 18% nonuniformly distributed UPC's and partly hydrated clinker particles. Concentrations of residual cement occur around some aggregates.

Pozzolans*: A small amount of residual slag is present.

Secondary Deposits: Most air voids are empty or contain clumps of small ettringite needles. Alkali-silica gel is observed adjacent to reactive chert aggregates. A few air voids are lined with ettringite.

MICROCRACKING: None observed.

ESTIMATED WATER-CEMENTITIOUS RATIO: 0.38 to 0.43.

MISCELLANEOUS: Gel-soaked paste surrounds some chert aggregates.

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*percent by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 050860

CLIENT: Michigan Department of Transportation

STRUCTURE: Bridge Pier Caps

LOCATION: I-75 Bridge
Rouge River, Detroit, Michigan

DATE: May 3, 1996

REPORTED PROBLEM: Cracking

EXAMINED BY: L. Powers-Couche

SAMPLE

Identification: Pier 39 South Face #1 North Bound.

Dimensions: Diameter = 3.9 in. Length = 11.0 in.

Exterior Surface: Even, paste-rich, formed surface with scattered irregular air voids (bugholes) with one major crack, 0.04 in. wide, extending across the surface.

Interior Surface: Irregular surface broken through aggregates.

Cracks, Joints, Large Voids: One longitudinal crack extends to a depth of 6 in. One transverse crack, through the core, occurs at a depth of 6 to 7 in. Both cracks pass mainly around aggregates. No joints are present. The concrete contains a few entrapped air voids with diameters up to 0.6 in.

Reinforcement: None present in core.

AGGREGATES (A)

Coarse (C): Manufactured, mostly crystalline slag.

Fine (F): Natural sand composed of siliceous and calcareous rocks and minerals. In approximate order of decreasing abundance: quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet.

Gradation & Top Size: Well graded to 0.8 in. top size.

Shape & Distribution: CA - angular to subrounded, blocky to oblong, and uniformly distributed. FA - rounded to angular, equant to oblong, and uniformly distributed.

PASTE

Color: Mottled shades of brown-gray.

Hardness: Hard to moderately hard.

Luster: Subvitreous to dull locally.

Depth of Carbonation: The paste is unevenly carbonated from the exterior surface to a depth of 0.2 to 0.5 in.; carbonation layer occurs along major crack.

Air Content: Air entrained with 5 to 7% small, spherical, nonuniformly distributed air voids.

Paste-Aggregate Bond: Tight. Lab-induced fractures pass through the coarse aggregates.

Calcium Hydroxide*: 5 to 7% somewhat nonuniformly distributed small crystals, larger tabular crystals and irregular patches.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 15 to 22% nonuniformly distributed UPC's.

Pozzolans*: None observed other than particles presumably derived from the coarse aggregate.

Secondary Deposits: Abundant ettringite partly filling air voids. Calcium hydroxide and secondary calcite occur in a few voids. Alkali-silica gel fills microcracks in and near chert particles. Interlayered gel and carbonate line the longitudinal crack.

MICROCRACKING: A few short microcracks radiating from reactive chert into the paste. Elsewhere a few narrow, random microcracks.

ESTIMATED WATER-CEMENT RATIO: 0.38 to 0.43.

MISCELLANEOUS:

1. Many chert particles show incipient ASR.
2. A few chert particles have gel-lined microcracks and cracks radiating a short distance into the paste.
3. Calcium hydroxide is leached from the paste adjacent to the longitudinal crack.
4. Paste at the exterior end of the core exhibits characteristics of late hydration of cement, i.e. ferrite phase hydration.

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*percent by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 050860

DATE: May 3, 1996

CLIENT: Michigan Department of Transportation

REPORTED PROBLEM: Cracking

STRUCTURE: Bridge Pier Caps

EXAMINED BY: L. Powers-Couche

LOCATION: I-75 Bridge
Rouge River, Detroit, Michigan

SAMPLE

Identification: Pier 39 South Face #2 North Bound.

Dimensions: Diameter = 3.9 in. Length = 12 in.

Exterior Surface: Even, paste-rich, formed surface with scattered, irregular air voids (bugholes) and a narrow crack (0.01 in. wide) extending across the surface.

Interior Surface: Irregular surface broken through aggregates.

Cracks, Joints, Large Voids: One major crack, tightening with depth, extends to a depth of 9 in. The crack passes through several coarse aggregates. No joints are present. The concrete contains scattered entrapped air voids with diameters up to 0.3 in.

Reinforcement: None present in core.

AGGREGATES (A)

Coarse (C): Manufactured, mostly crystalline slag.

Fine (F): Natural sand composed of siliceous and calcareous rocks and minerals. In approximate order of decreasing abundance: quartz, quartzite, limestone, chert, feldspar, granite, schist, graywacke, and garnet.

Gradation & Top Size: Well graded to 0.8 in. top size.

Shape & Distribution: CA - angular to subrounded, blocky to oblong, and uniformly distributed. FA - rounded to angular, equant to oblong, and uniformly distributed.

PASTE

Color: Mottled shades of brown-gray.

Hardness: Hard to moderately hard.

Luster: Subvitreous to dull locally.

Depth of Carbonation: The paste is carbonated to a depth of 0.1 to 0.3 in. from the exterior surface and adjacent to the longitudinal crack in the outer 1 in. of the core.

Air Content: Air entrained with 5 to 7% small, spherical, nonuniformly distributed air voids.

Paste-Aggregate Bond: Tight. Lab-induced fractures pass through the coarse aggregates.

Calcium Hydroxide*: 5 to 7% somewhat nonuniformly distributed small crystals, larger tabular crystals and irregular patches.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 15 to 22% nonuniformly distributed UPC's.

Pozzolans*: Small amounts of slag presumably derived from the coarse aggregate. These particles do not exhibit the "fineness" or optical properties of GBFS.

Secondary Deposits: Abundant ettringite in air voids and alkali-silica gel in microcracks.

MICROCRACKING: Random microcracks associated with ASR and passing through fine aggregates are abundant. A network of microcracks, parallel to the major longitudinal crack, occurs on both sides of the crack.

ESTIMATED WATER-CEMENT RATIO: 0.38 to 0.43.

MISCELLANEOUS: Chert sand particles may be somewhat more abundant in this sample and most have reacted or show incipient reaction. Gel-soaked paste occurs around many aggregates, voids, and cracks.

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*percent by volume of paste

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The University of Michigan
2340 Brown Building
An Arbor
Michigan 48109-2125
USA

Att. Dr. Will Hansen

18. June 1996

Ref. 9624will.rap
Case: 625-96

Dear Will

Subject: Slag concrete cores from I-75 Rouge River Bridge, Detroit

We have now made petrographic analysis of the 2 concrete cores received from you and have the following conclusions:

1. The concrete is distressed due to alkalisilica reactions. Alkalisilica gel is present in airvoids and along cracks.

2. The reactive particles are identified as different variants of chert. (Opaline chert, porous chalcedony). The chert has a grain size of approximately 1 to 4 mm.

3. The slag aggregates do not show any sign of reaction and are therefore determined as innocuous in this concept.

4. The petrographic analysis of slag aggregates indicates that slag particles are different in macro porosity. The slag particles are in general build up of crystalline phases probably with Mullite ($3Al_2O_3 \cdot SiO_2$) as main mineral.

5. The concrete contains at least 2 generations of crack evidence. Coarse cracks are present with smooth appearance and are interpreted as developed in early age. Fine cracks and microcracks in connection with reactive chert have a sharp appearance and cut aggregate particles. These cracks are interpreted to be a result of alkalisilica reactions.

The alkalisilica reaction present in this concrete is very similar to the reaction type present in Denmark as the reactive particles are chert minerals. In Danish concrete specification the maximum amount of reactive chert is 2 vol. % determinate with petrographic analysis of 0/4 mm sand. The analysed concrete has presumably more than 2 % reactive chert particles in size fraction 0/4, but no analysis has been carried out.

Yours Sincerely

PC Laboratoriet A/S

Ele Yde

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Analysis

The 2 concrete samples have undertaken fluorescence epoxy impregnation before preparation of plan section, fluorescence macro plan sections and thin sections for petrographic analysis. The petrographic analysis is divided into a macroanalysis (plan sections and fluorescence plan section) and microanalysis (thin sections).

Core sample 625-96-1

Macroanalysis

The core sample has a length of approximately 177 mm with a diameter of approximately 97 mm and consist of mainly subangular aggregates with grain size up to approximately 30 mm in a grey cement paste. The larger aggregates are present as slag particles with different macro porosity. The smaller aggregate (grain size less than 5 mm) are present as rounded mainly white and grey grains.

The concrete core is penetrated by one major crack running perpendicular to the surface though sample section, see photo 1. The crack has a wide of approximately 0.5 mm at the upper approximately 50 mm and has a smooth run and do not penetrate aggregates. At lower level the cracks are narrower and aggregate grains are cut. In the fluorescence plan section the penetrating crack has a crack wide of approximately 0.5 mm through the hole section, see photo 3. In areas in upper section (marked with open arrows in photo 4) separation cracks/elongated airvoids are present. Partly cracked white particles are present (marked with closed arrows) and cracks are penetrating into the cementpaste. Coarse and fine cracks are detected in adhesion zone between aggregate and cementpaste (marked with small closed arrow). In areas slag particles are penetrated by cracks as well.

Microanalysis

The sand aggregates are well distributed and dominated by rounded quartz and feltspatic minerals in fraction size below 2 mm. Chert and calcareous rock minerals are dominated in fraction size 2 - 4 mm. The chert is present as porous opaline together with porous and dense chalcedony. In places chert is mixed with calcareous substance. Several of the chert particles show sign of intense cracking and alkalisilica gel are present in cracks and airvoids close to chert particles, see photo 7, 8, 9, 10. The is a relative high amount of reactive chert particles in the 2 - 4 mm fraction size.

Slag particles are present with different appearing and different macroporosity. Some slagparticles are macrocrystalline with elongate minerals (presumably Mullite) together with more brown particles. Other slag particles are more microcrystalline containing minerals with needle shape. It can not be excluded that slag aggregate with amorphous part are present. In general the slag particles do not show any sign of cracking, but slag particles are cut by cracks. These cracks are in general running from cementpaste into the slag particles.

The cementpaste is inhomogeneous and unhydrated Portland cementminerals are present. At surface cementpaste is carbonated to a depth of approximately 7 mm, but in connection with coarse crack the cementpaste is carbonated to a depth of approximately 30 mm. The water/cement-ratio is relative low and estimated to approximately 0.35 - 0.50. The cementpaste contain a relative moderate amount of airvoids, see enclosed airvoid analysis. In airvoids secondary precipitation's of fibrous minerals and alkalisilica gels are present.

The cementpaste contain a high amount of cracks and the cracks can be dived into at least two generation. At surface coarse crack is present with smooth event. The crack do not cut aggregate particles in upper part, but aggregates (slag) are cut in lower part of section. Fine cracks cutting aggregate and steams of microcracks are present in relation to reactive chert aggregates, see photo 7, 8, 9, 10.

Core sample 625-96-2

Macroanalysis

The core sample has a length of approximately 270 mm with a diameter of approximately 97 mm and consist of mainly subangular aggregates with grain size up to approximately 30 mm in a grey cement paste. The larger aggregates are present as slag particles with different macro porosity. The smaller aggregate (grain size less than 5 mm) are present as rounded mainly white, black and grey grains.

The aggregates are inhomogeneous distributed as an area of approximately 30 x 80 mm with out coarse aggregate is present in a depth of approximately 155 mm. The area is cracked with cracks running parallel to surface, see photo 5. Cracks are present in connection with reactive chert grain, see photo 6.

At upper surface a light approximately 2 mm thick layer is present. The layer is only present at surface and do not enter cracks at surface, see photo 2.

At concrete surface two cracks running perpendicular to the surface to a depth of approximately 40 - 50 mm, see photo 2. The cracks have a wide of approximately 0.2 mm and do cut some aggregates. In the fluorescence plan section only one crack at surface is detected, see photo 5. Fine cracks are detected in cement paste and in adhesion zone between aggregate and cementpaste.

Microanalysis

The upper layer (presumably epoxy layer) is build up of an amorphous matrix mixed with up to approximately 0.2 mm subangular quartz grains. Good adhesion is present between underlying cementpaste and layer, but the layer do not penetrate into cracks.

The sand aggregates are well distributed and dominated by rounded quartz, feltspatic and calcareous minerals. Chert and calcareous rock minerals are dominated in fraction size 2 - 4 mm. The chert is present as porous opaline together with porous and dense chalcedony. Chert particles show sign of cracking and alkalisilica gel are present in cracks and airvoids close to chert particles as described in sample 625-96-1. The amount of reaction is not as intensive as detected in sample 625-96-1.

Slag particles are present with same appearing as previous described. In general the slag particles do not show any sign of cracking, but slag particles are cut by cracks.

The cementpaste is inhomogeneous and unhydrated Portland cementminerals are present. At surface cementpaste is carbonated to a depth of approximately 3 mm, but in connection with coarse crack the cementpaste is carbonated to a depth of approximately 30 mm. The water/cement-ratio is relative low and estimated to approximately 0.35 - 0.50. The cementpaste contain a relative moderate amount of airvoids. In airvoids secondary precipitation's of fibrous minerals and alkalisilica gels are present.

The cementpaste contain a high amount of cracks and the cracks can be dived into at least two generation. At surface coarse crack is present with smooth event. The crack do cut some aggregate particles. Fine cracks cutting aggregate and steams of microcracks are present in relation to reactive chert aggregates.

Discussion

The concrete is cracked and contains at least 2 generations of crack evidence. Coarse cracks are present with smooth appearance and are interpreted as developed in early age. In part the coarse cracks cut slag aggregates, but there is no evidence of chemical reaction in connection to slag aggregates.

Fine cracks and microcracks in connection with chert have a sharp appearance and cut aggregate particles. These cracks are interpreted to be a result of alkalisilica reactions as alkalisilica gel is present in connection to chert aggregates, in airvoids and along cracks.

The reactive particles are identified as different variants of chert. (Opaline chert, porous Chalcedony). The chert has a grain size of approximately 1 to 4 mm, but is dominated in size 2 to 4 mm.

The slag aggregates do not show any sign of reaction and are therefore determined as innocuous in this concept. Due to high degree of macroporosity slag particles may have lower or same strength as cementpaste. It is there for very possible that cracks generated in the concrete will have a tendency to cut slag aggregates. The petrographic analysis of slag aggregates indicates that slag particles have different macro porosity. The slag particles are in general build up of crystalline phases probably with Mullite ($3Al_2O_3 \cdot SiO_2$) as main mineral, but more microcrystalline to amorphous slag particles are present.

The crack structures indicate, that some of the cracks have been developed in a very early state of the concrete age. These macrocracks have presumably developed further in time due to external condition such as freeze/thaw.

The present of cracks, alkalimetals and high humidity have then later given rise to alkalisilica reaction and there by intense cracking.

The mortar rich area observed in sample 625-96-2 is presumeably a product of non prober workman ship. The high amount of mortar has probaly resulted in the cracking parallel to surface, but alkalisilica reactions are present in this area as well.

In sample 625-96-2 a relative high amount of potential reactive chert aggregates have not reacted and further alkalisilica reaction are therefor possible.

The alkalisilica reaction present in this concrete is very similar to the reaction type present in Denmark as the reactive particles are chert minerals. In Danish concrete specification the maximum amount of reactive chert is 2 vol. % determinate with petrographic analysis of 0-4 mm sand. The analysed concrete has presumably more than 2 % reactive chert particles in size fraction 0-4, but no analysis has been carried out.

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Photo 1. Macrofoto of sample 625-96-1. The concrete contains homogenous distributed slag particles in Portland cement paste. A macro crack penetrates the core perpendicular to surface.

Photo 2. Macrofoto of sample 625-96-2. At surface grey epoxy layer is present. The layer do not penetrate the concrete. Surface crack is present, see arrow.

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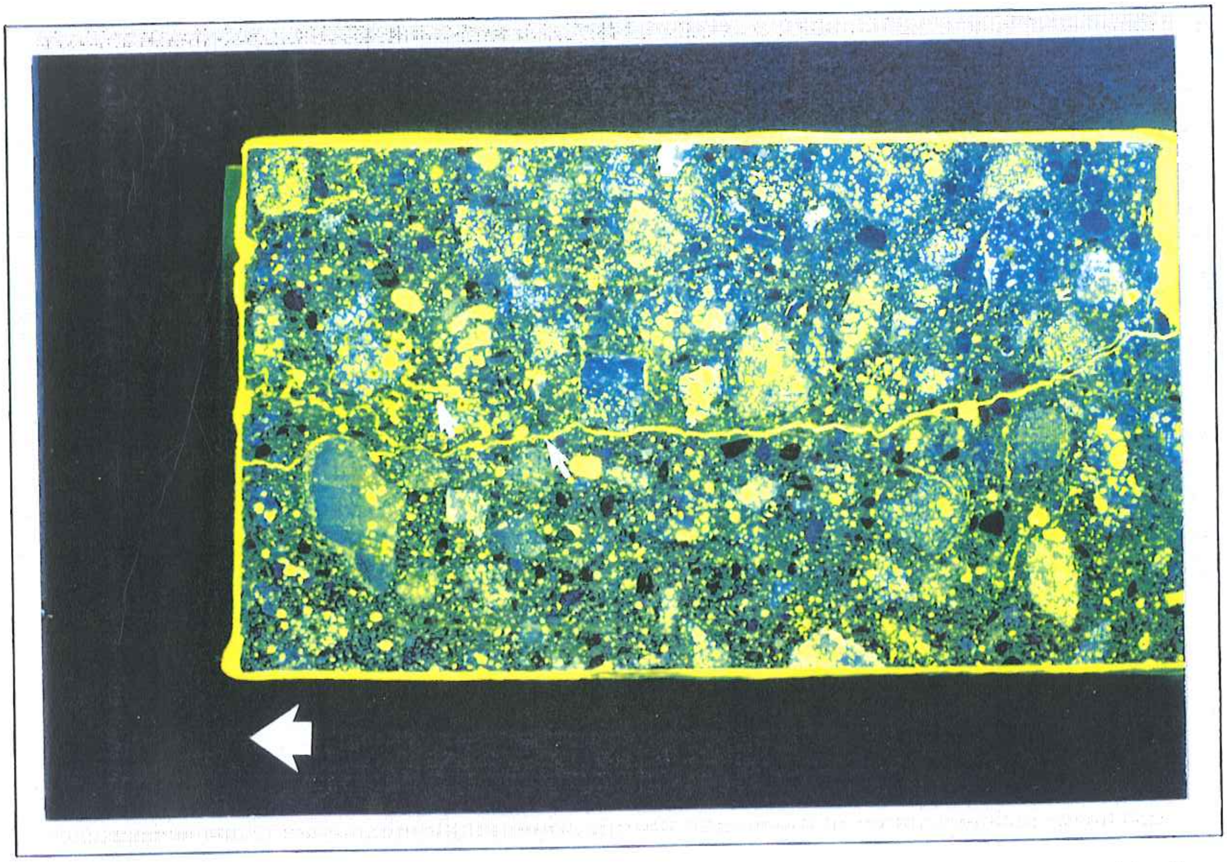

Photo 3. Macrofoto of fluorescence impregnated sample 625-96-1. The total length is represented in the fluorescence photo and cracks are high lighted, see arrows. The macro cracks have a smooth run and do not cut aggregate in upper area.

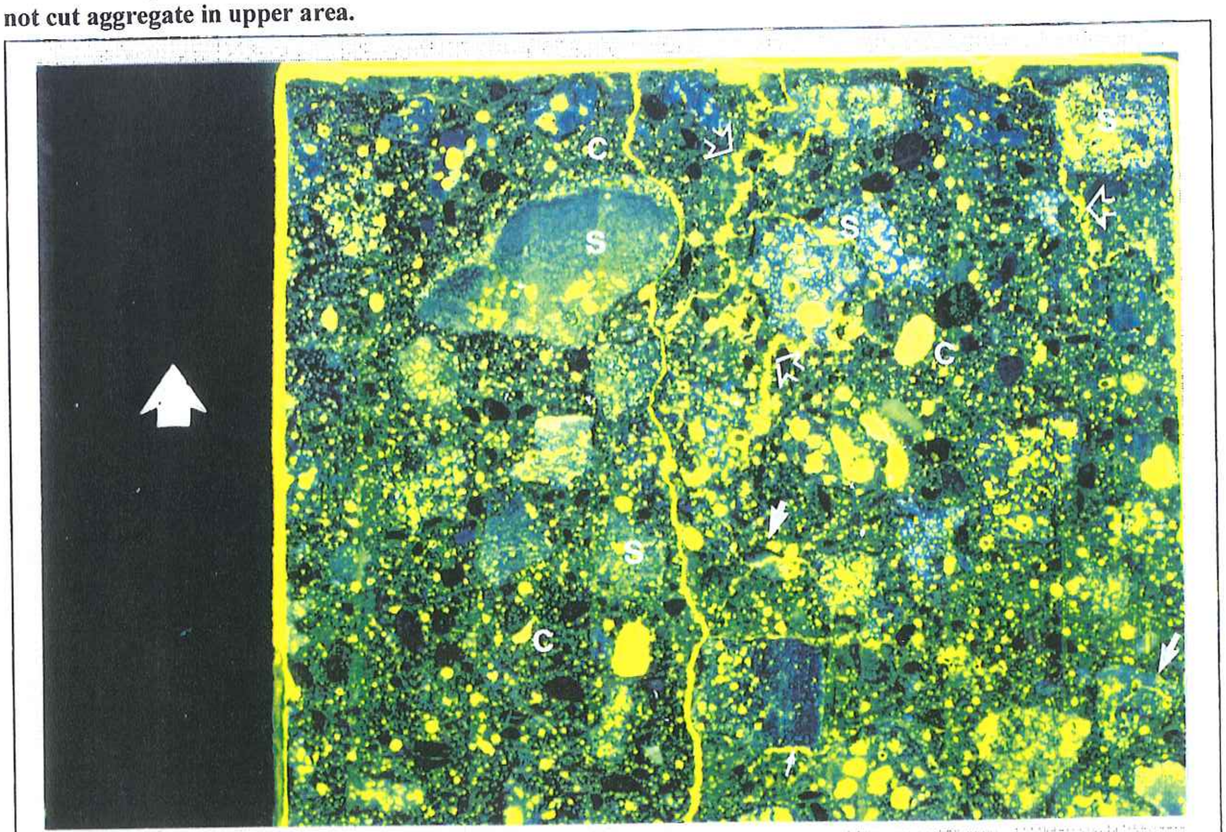

Photo 4. Close up macrofoto of fluorescence impregnated sample 625-96-1 in upper area. The large arrow indicate surface. Open arrows indicates separation cracks/elongated air voids. Closed arrows indicates cracked white aggregates.

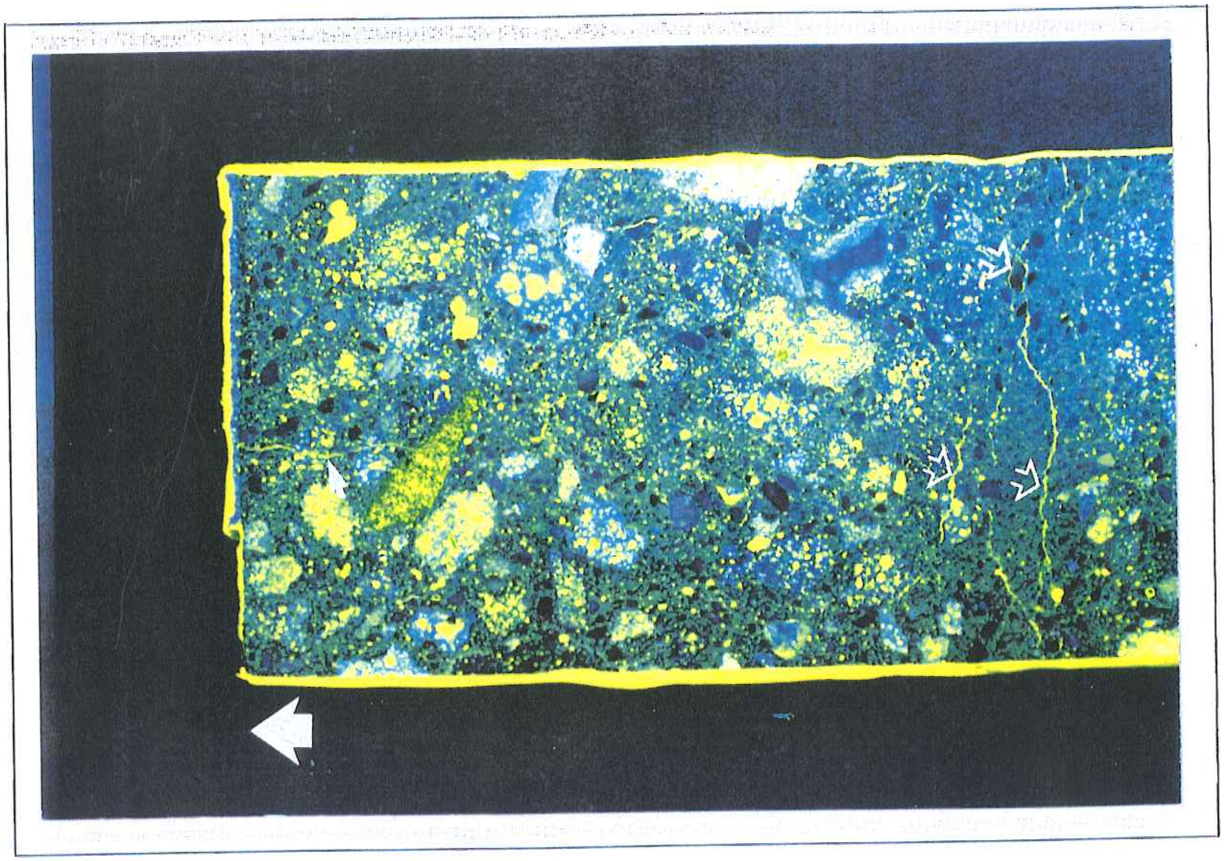

Photo 5. Macrofoto of fluorescence impregnated sample 625-96-2. Macro crack is present at surface, see arrow. In area macro cracks are present orientated parallel to surface, see open arrows.

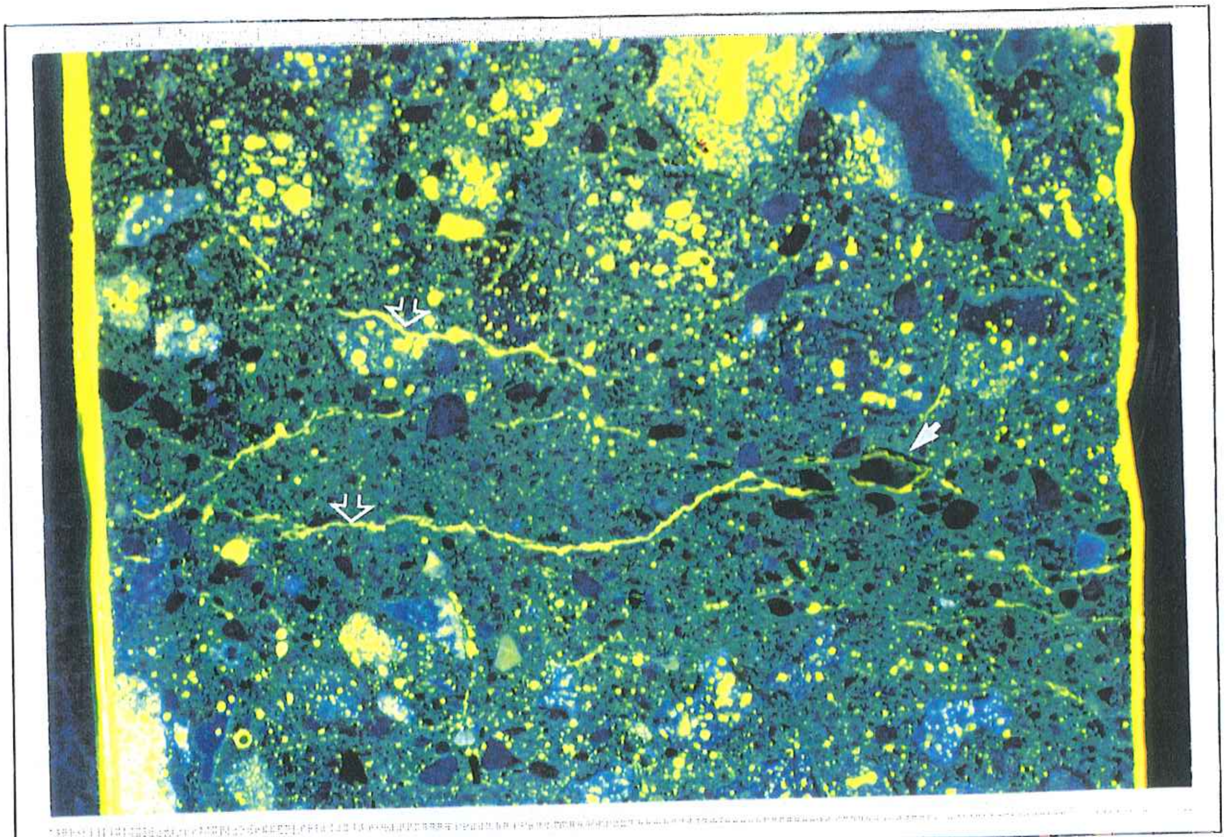

Photo 6. Close up macrofoto of fluorescence impregnated sample 625-96-1 of area with cracks parallel to surface. The cracks are present in mortar rich part. Closed arrows indicates cracked white aggregates. Other cracks have a more smooth run and do not cut aggregates, open arrows.

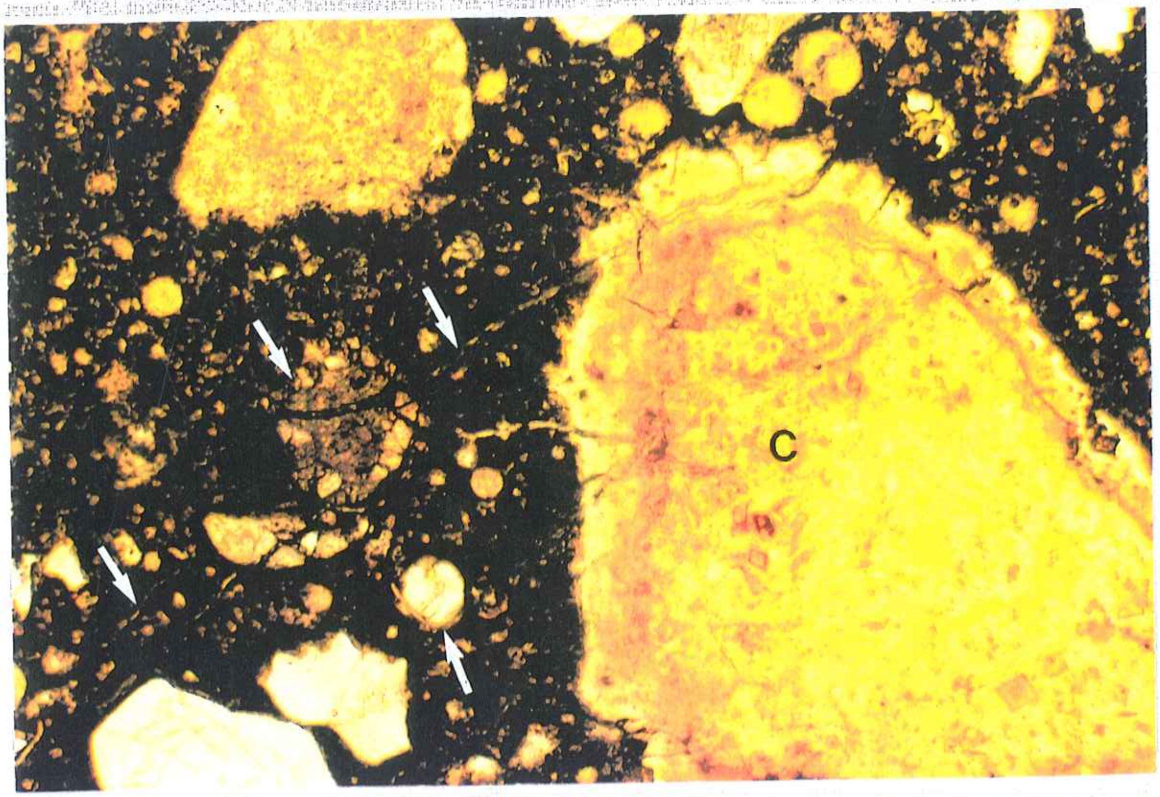

Photo 7. Microphoto sample 625-96-1. Transparent light, 1 cm = 0.26 mm. Porous chert (C) is cracked and alkali silica gel is present in chert, cracks and airvoids, see arrows.

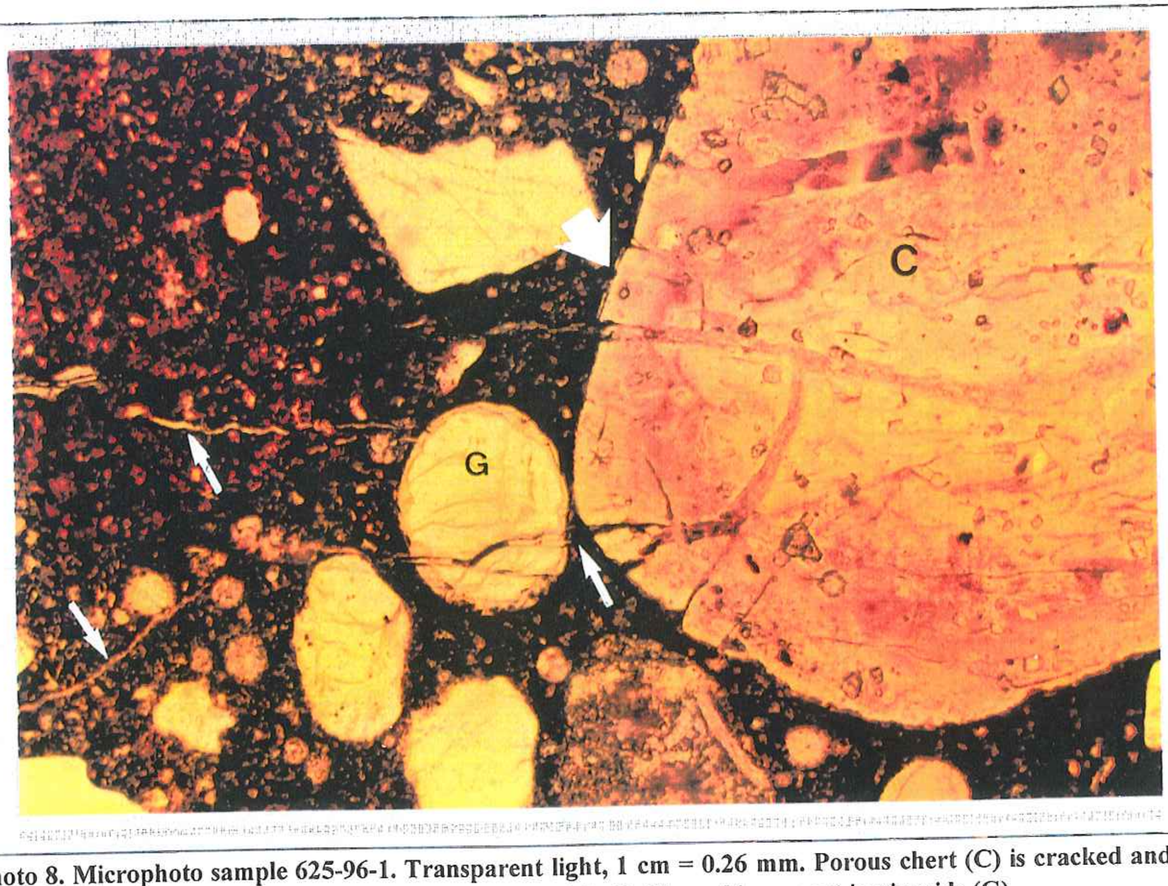

Photo 8. Microphoto sample 625-96-1. Transparent light, 1 cm = 0.26 mm. Porous chert (C) is cracked and alkali silica gel is present in chert, cracks, see arrows. Alkali silica gel is present in airvoids (G).

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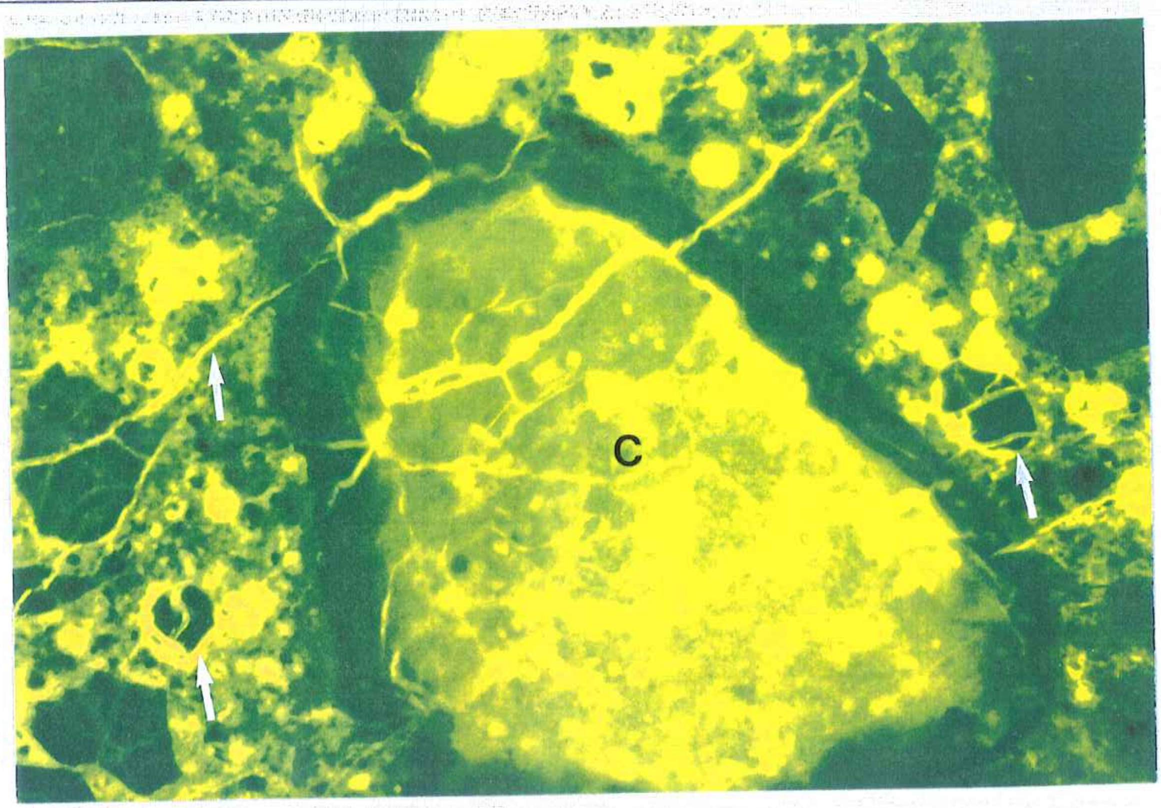

Photo 7. Microphoto sample 625-96-1. Transparent light, 1 cm = 0.11 mm. Porous chert (C) is cracked and alkali silica gel is present in chert, cracks and airvoids, see arrows.

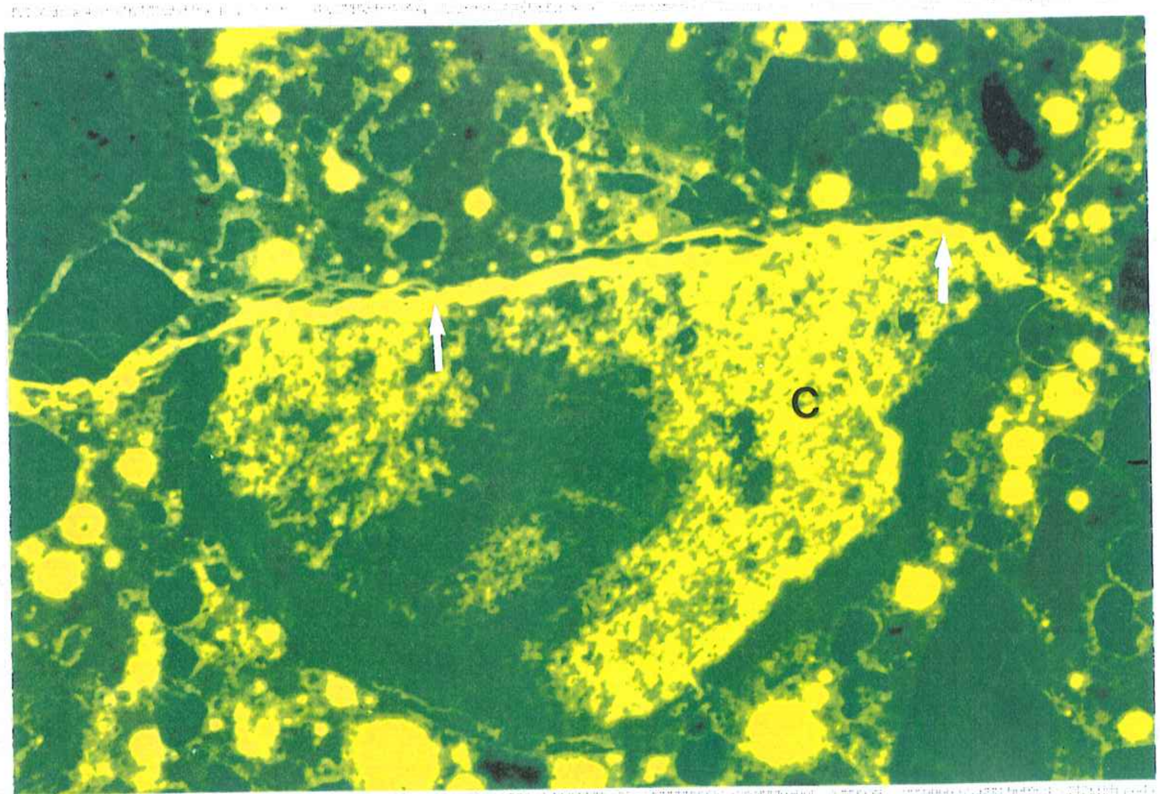

Photo 8. Microphoto sample 625-96-1. Transparent light, 1 cm = 0.26 mm. Porous chert (C) is cracked and alkali silica gel is present in chert, cracks, see arrows.

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The University of Michigan
2340 Brown Building
An Arbor
Michigan 48109-2125

Date: 13/06/96

Report No.: 618-96

Lab. No.: 507-96

DANAK
Reg.nr. 179

TEST REPORT

Client	The University of Michigan
Sample identification	Slag concrete cores from I-75 Rouge River Bridge, Detroit.
Methods, results	Measurement af air voids in hardened concrete TI-B 4.

Kind regards

PC LABORATORIET A/S

Signature

Elo Yde

PC LABORATORIET A/S
MÅGEVEJ 7 9690 FJERRITSLEV

AUTORISATIONSREG. NR. 179
DATO 13/06/96

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
LAB. NO.: 507-96-1
REPORT NO. : 618-96
SAMPLE LABEL: I-75 ROUGE RIVER BRIDGE

AIR-VOID ANALYSIS

Perf. by FS

TOTAL AIR CONTENT	(vol%):	3.6
AIR IN VOIDS > 2 mm	(vol%):	0.3
SPECIFIC SURFACE	(mm-1):	39
SPACING FACTOR	(mm):	0.14
AIR IN BINDER	(vol%):	11.6
PASTE VOLUME	(vol%):	27.5

Comments:
POROUS SLAG PARTICLES ARE PAINTED OVER THEREBY NOT INCLUDED IN ANALYSIS.