Sengupta, Abhijit

From: Williams, Charles R. [Charles.Williams@pgnmail.com]
Sent: Monday, January 11, 2010 5:49 PM
To: Lake, Louis; Thomas, George; Carrion, Robert; 'nausdj@ornl.gov'; Souther, Martin; 'Archer, John C. (Reading)'; 'Wells, Richard P. (Reading)'
Cc: Miller, Craig L
Subject: FM 5.8 Draft for Review
Attachments: FM 5.8 Exhibit 3b Petrographic CTL.pdf; FM 5.8 Exhibit 3c Petrographic Mactec 2009-11-11.pdf; FM 5.8 Exhibit 4 WC ratio RB-15.pdf; FM 5.8 Exhibit 5a Petrographic Mactec 2009-12-23.pdf; FM 5.8 Exhibit 6 permeability v w2c from Mehta.pdf; FM 5.8 Exhibit 7 Petrographic CTL.pdf; FM 5.8 Exhibit 8 - ASR test report - PII.pdf; FM 5.8 Exhibit 9 ASTM C1260.pdf; FM 5.8.pdf; FM 5.8 Exhibit1 ACI 201.2R-01 Durability.pdf; FM 5.8 Exhibit 2 Mix Design- from Dome Repair Report-cgp.pdf; FM 5.8 Exhibit 3a Petrographic Erlin Hime May 1976.pdf

Mr Lake and others,

Attached for your review is draft of FM 5.8 and its exhibits. Note that Exhibit 5b will be sent separately due to file size. If you have any questions, please contact me or Craig Miller.

Thank you,

Charles Williams
919-516-7417

The message is ready to be sent with the following file or link attachments:

FM 5.8 Exhibit 3b Petrographic CTL.pdf
FM 5.8 Exhibit 3c Petrographic Mactec 2009-11-11.pdf FM 5.8 Exhibit 4 WC ratio RB-15.pdf FM 5.8 Exhibit 5a Petrographic Mactec 2009-12-23.pdf FM 5.8 Exhibit 6 permeability v w2c from Mehta.pdf FM 5.8 Exhibit 7 Petrographic CTL.pdf FM 5.8 Exhibit 8 - ASR test report - PII.pdf FM 5.8 Exhibit 9 ASTM C1260.pdf FM 5.8.pdf FM 5.8 Exhibit1 ACI 201.2R-01 Durability.pdf FM 5.8 Exhibit 2 Mix Design- from Dome Repair Report-cgp.pdf FM 5.8 Exhibit 3a Petrographic Erlin Hime May 1976.pdf

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PETROGRAPHIC STUDIES OF CONCRETE

FOR

CONSTRUCTION ENGINEERING CONSULTANTS

* * * * * * * *

SUMMARY AND DISCUSSION

The specimen represented air-entrained concrete made with crushed fossiliferous coarse aggregate ~~and siliceous fine aggregate and a~~ low water-cement ratio paste. There was no evidence that the aggregates had been either chemically or physically unsound.

The specimen was from an area where fractures had existed for a period of time and where moisture had been present. That was demonstrated by secondary deposits on fracture surfaces.

The specimen was relatively small. Larger specimens from different areas of the structure would be desirable for examination in order to obtain a better representation of the concrete.

* * * * * *

INTRODUCTION

Reported herein are the results of petrographic studies of a concrete fragment submitted by J. Artuso of Construction Engineering Consultants. The specimen is from the dome of the containment structure of the Florida Power Corporation, Crystal River, Unit III.

Requested by Mr. Artuso were petrographic studies for evaluating the specimen, and particularly for evidence of features that would cause volume instability.

STUDIES

Specimen - The specimen was an elongated fragment having nominal lateral dimensions of 5 inches, and a maximum thickness of about 3/4 inch.

All surfaces were fracture surfaces except for a shallow channel about 3/32 inch wide and 1/8 inch deep. The channel appears to be the terminal area of a saw cut.

Petrographic Studies - Coarse aggregate of the specimen was a buff to light brown, fine-grained, fossiliferous limestone having a maximum nominal size of 3/4 inch. The fine aggregate was a siliceous sand composed principally of quartz.

The aggregates were not particularly well graded, as evidenced by deficiencies of the finer sizes of the coarse aggregate and the coarser sizes of the fine aggregate.

There was no evidence that the aggregates had been chemically or physically unsound. Particular attention was directed to alkali-silica reactivity with respect to the coarse aggregate because a similar type of aggregate does contain a highly reactive variety of chert. Neither the chert nor the product of the reaction of the chert with alkalies (alkali-silica gel) was present.

Paste of the specimen was medium dark grey, firm, and contained abundant residual and relict cement. The quality of the paste reflects a low water-cement ratio.

Air occurred as small, discrete, spherical voids that occasionally were very slightly distorted, and as coarser irregularly shaped voids. The spherical voids are characteristic of entrained air voids; the irregularly shaped voids, of entrapped air. The air content of the specimen is estimated to be 5½ percent and the parameters of the air-void system are judged to be effective for protecting critically saturated concrete exposed to cyclic freezing.

On one of the lateral surfaces were secondary deposits composed of tufts of fine acicular ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$), and calcite ($CaCO_3$). Ettringite was also present as tufts in some air voids just below the fracture surface.

The fragment was not uniformly thick; it tapered to a knife-like edge. Along that edge, were fine fractures

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oriented subparallel to the long axis of the fragment. The fractures transected coarse aggregate particles. On those fracture surfaces were secondary deposits similar to those described above.

The secondary compounds demonstrate that the fragment was from an area where fractures present for a period of time had been exposed to moisture.

May 10, 1976

Erlin, Hime Associates, Inc.

Bernard Erlin wgl

by Bernard Erlin, President
Petrographer

1B

APPROVED DESIGN MIX FORMULAS

C. A. T-21510 (3000) -4

#67

Cement:	517	lbs.
C. A. :	1800	"
F. A. :	1237	"
Dx:	4.0	oz.
Dtd.:	16.5	oz.
Water:	271	lbs.

C. A. T-2151[illegible] Mod. (3000) -4

#67

Cement:	562	lbs.
C.A.:	1800	"
F.A.:	1220	"
Dx:	4.0	ozs.
Dtd:	16.5	ozs.
Water:	271	"

C. A. DM-5 (5000) -3

#67

Cement:	635	lbs.
C.A.:	1800	"
F.A.:	1140	"
Dx:	3.6	ozs.
Dtd.:	21.0	ozs.
Water:	276	lbs.

DM-5 Mod. (5000) -3

#67

Cement:	682	lbs.
C.A.:	1800	"
F.A.:	1100	"
Dx:	3.6	ozs.
Dtd:	21.0	ozs.
Water:	275	lbs. - 33.1

APPROVED

727550-2 (5000) -4

#67

Cement:	705	lbs.
C.A.:	1800	"
F.A.:	1080	"
Dx:	4.5	ozs.
Dtd:	23.0	ozs.
Water:	286	lbs.

USED FOR DOME

727550-2 Mod. (5000) -4

#67

Cement:	752	lbs.
C.A.:	1800	"
F.A.:	1050	"
Dx:	4.5	ozs.
Dtd:	23.0	ozs.
Water:	286	lbs.

DM-7 (5000 Chstt) -3

#67

Cement:	895	lbs.
C.A.:	1650	"
F.A.:	1070	"
Dx:	5.0	ozs.
Dtd:	25.0	ozs.
Water:	335	lbs.

DM-16 (1500) -5

#67

Cement:	365	lbs.
C.A.:	1700	"
F.A.:	1490	"
Dx:	1.3	ozs.
Dtd:	10.5	ozs.
Water:	290	lbs.

DM-16 Mod. (1500) -5

#67

Cement:	413	lbs.
C.A.:	1700	"
F.A.:	1490	"
Dx:	1.3	ozs.
Dtd:	10.5	ozs.
Water:	290	lbs.

736441-4 1/2 (5000)

#67

Cement:	752	lbs.
C.A.:	1650	"
F.A.:	1185	"
Dx:	4.5	ozs.
Dtd:	20	ozs.
Water:	294	lbs.

Table 2.3—Requirements to protect against damage to concrete by sulfate attack from external sources of sulfate

Severity of potential exposure	Water-soluble soluble sulfate (SO_4)*	Sulfate (SO_4)* in water, ppm	*w/cm* by mass, max.†‡	Cementitious material requirements
Class 0 exposure	0.00 to 0.10	0 to 150	No special requirements for sulfate resistance	No special requirements for sulfate resistance
Class 1 exposure	> 0.10 and < 0.20	> 150 and < 1500	0.50‡	C 150 Type II or equivalent§
Class 2 exposure	0.20 to < 2.0	1500 to < 10,000	0.45‡	C 150 Type V or equivalent§
Class 3 exposure	2.0 or greater	10,000 or greater	0.40‡	C 150 Type V plus pozzolan or slag§
Seawater exposure	—	—	See Section 2.4	See Section 2.4

*Sulfate expressed as SO_4 is related to sulfate expressed as SO_3, as given in reports of chemical analysis of portland cements as follows: $SO_3\% \times 1.2 = SO_4\%$.
†ACI 318, Chapter 4, includes requirements for special exposure conditions such as steel-reinforced concrete that may be exposed to chlorides. For concrete likely to be subjected to these exposure conditions, the maximum *w/cm* should be that specified in ACI 318, Chapter 4, if it is lower than that stated in Table 2.3.
‡These values are applicable to normalweight concrete. They are also applicable to structural lightweight concrete except that the maximum *w/cm* ratios 0.50, 0.45, and 0.40 should be replaced by specified 28 day compressive strengths of 26, 29, and 33 MPa (3750, 4250, and 4750 psi) respectively.
§For Class 1 exposure, equivalents are described in Sections 2.2.5, 2.2.6, and 2.2.9. For Class 2 exposure, equivalents are described in Sections 2.2.5, 2.2.7, and 2.2.9. For Class 3 exposure, pozzolan and slag recommendations are described in Sections 2.2.5, 2.2.8, and 2.2.9.

35% by mass, calculated as percentage by mass of the total cementitious material.

For silica fume, the portland-cement portion of the test mixture should consist of a cement with Bogue calculated C_3A[3] of not less than 7%. The silica fume proportion should be between 7 and 15% by mass, calculated as percentage by mass of the total cementitious material.

For slag, the portland-cement portion of the test mixture should consist of a cement with Bogue calculated C_3A[3] of not less than 7%. The slag proportion should be between 40 and 70% by mass, calculated as percentage by mass of the total cementitious material.

Material qualification tests should be based on passing results from two samples taken at times a few weeks apart. The qualifying test data should be no older than one year from the date of test completion.

The reported calcium-oxide content[4] of the fly ash used in the project should be no more than 2.0 percentage points greater than that of the fly ash used in qualifying test mixtures. The reported aluminum-oxide content[4] of the slag used in the project should be no more than 2.0 percentage points higher than that of the slag used in qualifying test mixtures.

2.2.6 *Type II Equivalent for Class 1 Exposure*

- A. ASTM C 150 Type III cement with the optional limit of 8% max. C_3A; C 595M Type IS(MS), Type IP(MS), Type IS-A(MS), Type IP-A(MS); C 1157 Type MS; or
- B. Any blend of portland cement of any type meeting ASTM C 150 or C 1157 with fly ash or natural pozzolan meeting ASTM C 618, silica fume meeting ASTM C 1240, or slag meeting ASTM C 989, that meets the following requirement when tested in accordance with ASTM C 1012. Any fly ash, natural pozzolan, silica fume, or slag used should have been previously qualified in accordance with Section 2.2.5.
- Expansion ≤ 0.10% at 6 months.

2.2.7 *Type V Equivalent for Class 2 Exposure*

- A. ASTM C 150 Type III cement with the optional limit of 5% max. C_3A; ASTM C 150 cement of any type having expansion at 14 days no greater than 0.040% when tested by ASTM C 452; ASTM C 1157 Type HS; or
- B. Any blend of portland cement of any type meeting ASTM C 150 or C 1157 with fly ash or natural pozzolan meeting ASTM C 618, silica fume meeting ASTM C 1240, or slag meeting ASTM C 989 that meets the following requirement when tested in accordance with ASTM C 1012:

  Expansion ≤ 0.05% at 6 months. Any fly ash, natural pozzolan, silica fume, or slag used should have been previously qualified in accordance with Section 2.2.5 in order for a test of only 6 months to be acceptable.

  If one or more of the fly ash, natural pozzolan, silica fume, or slag has not been qualified in accordance with Section 2.2.5, then 1-year tests should be performed on the proposed combination and the expansion should comply with the following limit: Expansion ≤ 0.10% at 1 year.

2.2.8 *Class 3 Exposure*—any blend of portland cement meeting ASTM C 150 Type V or C 1157 Type HS with fly ash or natural pozzolan meeting ASTM C 618, silica fume meeting ASTM C 1240, or slag meeting ASTM C 989, that

[3]The C_3A should be calculated for the sum of the portland cement plus calcium sulfate in the cement. Some processing additions, if present in sufficient proportions, can distort the calculated Bogue values. Formulas for calculating Bogue compounds may be found in ASTM C 150.

[4]Analyzed in accordance with ASTM C 114.

5.8 Chemical Attack

Description:

Concrete is vulnerable to multiple mechanisms of chemical attack that may lead to deterioration over time and potential failure. In porous materials, water can be the source of chemical processes of degradation by transporting aggressive ions. Therefore, controlling permeability is the main method for limiting water related damage. The two other factors affecting durability are the availability of aggressive ions, and the presence of concrete constituents that are vulnerable to these ions. Chemical attack may be prevented by reducing permeability, using non-reactive concrete components, and preventing aggressive ions from penetrating the concrete.

Chemical attack may be the result of Sulfate attack, soft-water attack, acid and base attack, aggressive water attack, phosphate ion attack, and biological attack. A detailed discussion of these mechanisms is beyond the scope of this document and may be found in external sources.

The effects of chemical attack vary, but generally include loss of concrete cover accompanied by staining, erosion, reduction of concrete constituents, cracking, and spalling.

A visual survey is considered (ACI 349) an effective way of quantifying the effects of damage and identifying possible sources and composition of the aggressive chemicals.

This document will attempt to identify potential reactions and determine if any occurred in a way that impacted the observed failure.

Data to be collected and Analyzed:

1. Permeability of the concrete (Industry Standards; mix design; Petrographic reports; pour card analysis)
2. Availability of reactive concrete components (Petrographic reports)
3. Availability of aggressive ions
4. Visual inspections (exhaustive search of IWL inspections was conducted)
5. Reports of damage related to chemical attacks (exhaustive search of IWL inspections was conducted)

Verified Supporting Evidence: None

Verified Refuting Evidence:

a. The concrete meets industry standards for low permeability required for durability (FM 5.8 Exhibit 1 – ACI 201 table 2.3; FM 5.8 Exhibit 2 – mix design; FM 5.8 Exhibit 3 – representative Petrographic reports; FM 5.8 Exhibit 4 – graph of water/cement ratio from pour cards).

DRAFT 1

b. Petrographic reports (FM 5.8 Exhibit 3 and 5) found no evidence of destructive Alkali Aggregate Reaction (AAR). Although reactive components were found in some aggregates, the quantities were small and did not present an AAR problem.
c. Accelerated ASR test (ASTM C1260 - FM 5.8 Exhibit 9) confirmed that the concrete exhibits innocuous behavior with expansion of 0.1% or lower (FM 5.8 Exhibit 8).
d. The structure was not exposed to aggressive chemicals.
e. Inspections over the life of the structure did not detect any indication of damage due to chemical attack.

Discussion:

a. Industry standards, as demonstrated in FM 5.8 Exhibit 1 from ACI 201, use water to cement (W/C) ratio as an indication of concrete's permeability. It has been established that concrete with W/C of 0.4 or lower has voids system that is mostly made of disconnected discreet small voids – making it practically impermeable (FM 5.8 Exhibit 6).
   FM 5.8 Exhibit 4 is a graph based on data from all pour cards of concrete used in panel RB-15 (between buttresses 4 and 3) of the containment structure. It shows that all the concrete was placed with W/C ratio of less than 0.41, with an average of 0.40.
   FM 5.8 Exhibit 2 is a summary of mix designs used in the construction. These designs were prepared with W/C of either 0.41 or 0.38.
   FM 5.8 Exhibit 3 includes pages from representative Petrographic reports that made an attempt at estimating the W/C ratio. Estimating W/C is notoriously inaccurate, as demonstrated by the estimates that range from 0.4 to 0.6 and as explained in the body of the CTL report (FM 5.8 Exhibit 3c).
   Based on the above it is concluded that the concrete has very low permeability.
b. Alkali Aggregate Reaction (AAR) requires the presence of reactive aggregates in sufficient quantities to cause destructive expansion, as well as sufficient moisture. According to Petrographic reports (FM 5.8 Exhibits 3 and 5), reactive aggregates were not present in quantities that support destructive expansion. After over 30 years in service the concrete did not exhibit typical AAR damage. Accelerated tests performed in 2009 confirm this conclusion (FM 5.8 Exhibit 8 and FM 5.8 Exhibit 9),
c. Sulfate attack is a process of forming expansive products in the hardened concrete by converting cement components into Ettringite and/or Gypsum. This process requires permeable concrete, moisture, and availability of sulfate ions.
   As demonstrated above, the concrete at CR3 has very low permeability and there are no readily available sources of sulfate ions, either from the soil or the environment.
   Petrographic analysis found no evidence of sulfate attack (FM 5.8 Exhibit 7).
d. Leaching and efflorescence are a process and indication of moisture transfer through the concrete, resulting in the removal of dissolved salts. These salts crystallize into white powder on the exposed surface when the water evaporates. No indications of

5.8 Chemical Attack (cont.)

such process were reported in IWL inspection reports over the life of the structure, nor were any observed during visual inspections of the containment structure by PII in 2009.

e. Exposure to acids has the potential to cause significant damage to concrete. There is no indication that the containment structure was exposed to acids during its lifetime.

Conclusion:

The containment structure's concrete did not undergo chemical attack . Therefore, chemical attack was not a contributor to the delamination.

DRAFT 1

the zero reading to the end of the 16 day period.

11. Precision and Bias

11.1 *Within-Laboratory Precision*—It has been found that the average within-laboratory coefficient of variation for materials with an average expansion greater than 0.1 % at 14 days is 2.94 % **(5)** (Note 7). Therefore, the results of two properly conducted tests within the same laboratory on specimens of a sample of aggregate should not differ by more than 8.3 % (Note 7) of the mean expansion.

11.2 *Multi-Laboratory Precision*—It has been found that the average multilaboratory coefficient of variation for materials with an average expansion greater than 0.1 % at 14 days is 15.2 % **(5)** (Note 7). Therefore, the results of two properly conducted tests in different laboratories on specimens of a sample of aggregate should not differ by more than 43 % (Note 7) of the mean expansion.

NOTE 7—These numbers represent, respectively, the (1s %) and (d2s %) limits as described in Practice C 670.

11.3 *Bias*—Since there is no accepted reference material for determining the bias of this test method, no statement on bias is being developed.

12. Keywords

12.1 aggregate; alkali-silica reactivity; length change; mortar; sodium hydroxide

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF TEST RESULTS

X1.1 There is good agreement in the published literature **(1,2,7-10)** for the following expansion limits:

X1.1.1 Expansions of less than 0.10 % at 16 days after casting are indicative of innocuous behavior in most cases (see Note X1.1).

X1.1.2 Expansions of more than 0.20 % at 16 days after casting are indicative of potentially deleterious expansion. (See 3.3.)

X1.1.3 Expansions between 0.10 and 0.20 % at 16 days after casting include both aggregates that are known to be innocuous and deleterious in field performance. For these aggregates, it is particularly important to develop supplemental information as described in 3.3. In such a situation, it may also be useful to take comparator readings until 28 days **(8,10)**.

NOTE X1.1—Some granitic gneisses and metabasalts have been found to be deleteriously expansive in field performance even though their expansion in this test was less than 0.10 % at 16 days after casting **(10)**. With such aggregate, it is recommended that prior field performance be investigated. In the absence of field performance data, mitigative measures should be taken as discussed in 3.4.

REFERENCES

(1) Oberholster, R. E., and Davies, G.," An Accelerated Method for Testing the Potential Alkali Reactivity of Siliceous Aggregates." *Cement and Concrete Research*, Vol 16, 1986, pp. 181–189.

(2) Davies, G., and Oberholster, R. E., "Use of the NBRI Accelerated Test to Evaluate the Effectiveness of Mineral Admixtures in Preventing the Alkali-Silica Reaction," *Cement and Concrete Research*, Vol 17, 1987, pp. 97–107.

(3) Davies, G., and Oberholster, R. E., "An Interlaboratory Test Programme on the NBRI Accelerated Test to Determine the Alkali-Reactivity of Aggregates," National Building Research Institute, CSIRO, Special Report BOU 92-1987, Pretoria, RSA, 1987, 16 pp.

(4) Oberholster, R. E., "Alkali Reactivity of Siliceous Rock Aggregates: Diagnosis of the Reaction, Testing of Cement and Aggregate and Prescription of Preventative Measures," *Alkali in Concrete, Research and Practice*, Copenhagen, 1983, Danish Concrete Association, pp. 419–433.

(5) Rogers, C.A., "Multi-laboratory Study of the Accelerated Mortar Bar Test (ASTM Test Method C 1260) for Alkali-Silica Reaction," *Cement, Concrete, and Aggregates*, Vol 21, 1999, pp. 185–194.

(6) Hooton, R. D.," Interlaboratory Study of the NBRI Rapid Test Method and CSA Standardization Status," *Report EM-92*, Ontario Ministry of Transport, March 1990, pp. 225–240.

(7) Hooton, R. D., and Rogers, C. A., "Evaluation of Rapid Test Methods for Detecting Alkali-Reactive Aggregates," *Proceedings*, Eighth International Conference on Alkali-Aggregate Reaction, Kyoto, 1989, pp. 439–444.

(8) Hooton, R. D.," New Aggregate Alkali-Reactivity Test Methods," *Report MAT-91-14*, Ontario Ministry of Transportation, November 1991.

(9) Fournier, B., and Berube, M. A., "Application of the NBRI Accelerated Mortar Bar Test to Siliceous Carbonate Aggregates Produced in the St. Lawrence Lowlands, Part 2: Proposed Limits, Rates of Expansion, and Microstructure of Reaction Products," *Cement and Concrete Research*, Vol 21, 1991, pp. 1069–1082.

(10) Hooton, R. D., and Rogers, C. A., "Development of the NBRI Rapid Mortar Bar Test Leading to its Use in North America," *Proceedings*, Ninth International Conference on AAR in Concrete, London, 1992, pp. 461–467.

Accelerated ASR tests on CR3 concrete performed at the University of Colorado

Testing Methods

- There are two driving forces for ASR in Portland cement concrete:

  Alkali in cement paste and reactive silica in aggregate. The two driving forces must act together to start ASR.

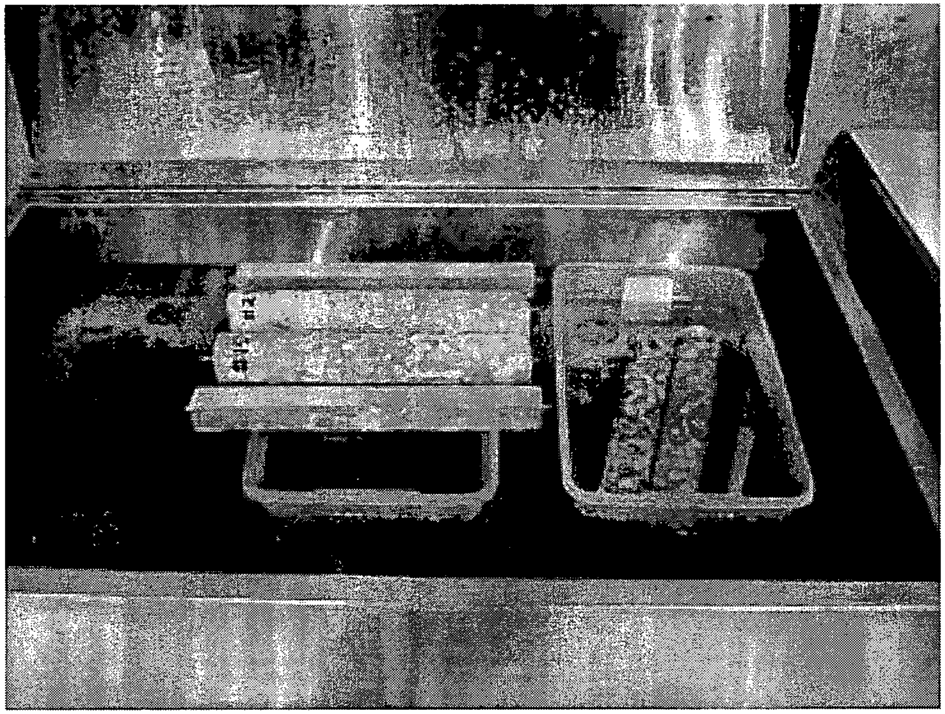
- Two testing methods were used to examine the reactive potentials of the two driving forces

  1. To measure the expansion of the concrete specimens in 100% relative humidity at 80 °C for examining if the cement paste still has sufficient alkali to form ASR gel.

  2. To measure the expansion of the concrete submerged in NaOH solution (1M concentration, at 80 °C) for investigating the reaction potential of the aggregate. This testing method is based on ASTM C1260.

- Testing period : 14 days for both tests (same as ASTM C1260).

Experimental set up for the two tests



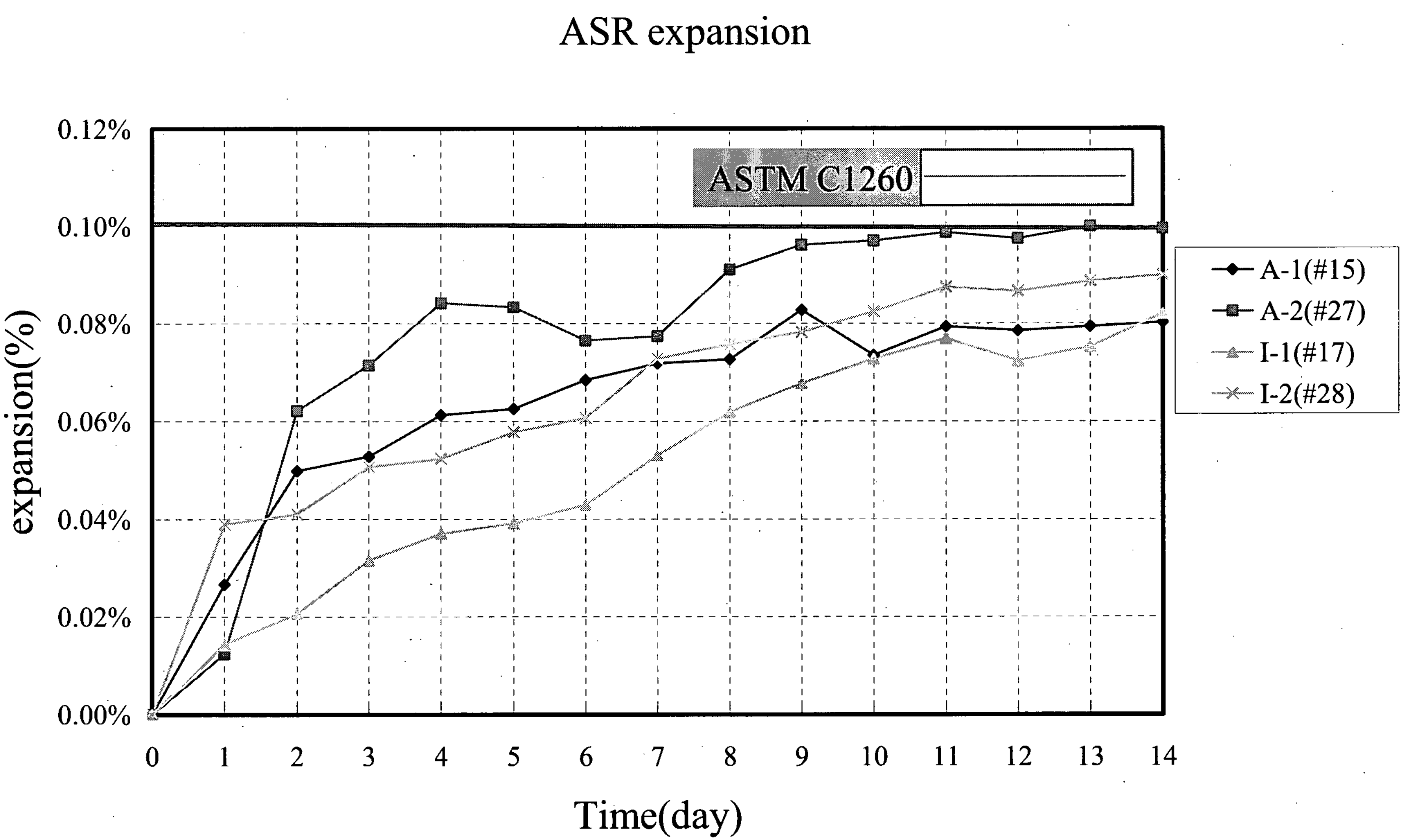
Two specimens were placed in NaOH solution and the other two on top of a water bath.

ASR expansion test results

		Lengths; inch				Strain			
Date	No	A-1(#15)	A-2(#27)	I-1(#17)	I-2(#28)	A-1(#15)	A-2(#27)	I-1(#17)	I-2(#28)
Nov.28	initial	0.334700	0.250500	0.384050	0.444550	0.00%	0.00%	0.00%	0.00%
Nov.29	1	0.337850	0.251950	0.385750	0.449200	0.03%	0.01%	0.01%	0.04%
Nov.30	2	0.340600	0.257800	0.386500	0.449450	0.05%	0.06%	0.02%	0.04%
Dec.1	3	0.340950	0.258900	0.387800	0.450600	0.05%	0.07%	0.03%	0.05%
Dec.2	4	0.341950	0.260400	0.388450	0.450800	0.06%	0.08%	0.04%	0.05%
Dec.3	5	0.342100	0.260300	0.388700	0.451450	0.06%	0.08%	0.04%	0.06%
Dec.4	6	0.342800	0.259500	0.389150	0.451800	0.07%	0.08%	0.04%	0.06%
Dec.5	7	0.343200	0.259600	0.390350	0.453250	0.07%	0.08%	0.05%	0.07%
Dec.6	8	0.343300	0.261200	0.391400	0.453600	0.07%	0.09%	0.06%	0.08%
Dec.7	9	0.344500	0.261800	0.392100	0.453900	0.08%	0.10%	0.07%	0.08%
Dec.8	10	0.343400	0.261900	0.392700	0.454400	0.07%	0.10%	0.07%	0.08%
Dec.9	11	0.344100	0.262100	0.393200	0.455000	0.08%	0.10%	0.08%	0.09%
Dec.10	12	0.344000	0.261950	0.392650	0.454900	0.08%	0.10%	0.07%	0.09%
Dec.11	13	0.344100	0.262250	0.393000	0.455150	0.08%	0.10%	0.08%	0.09%
Dec.12	14	0.344200	0.262200	0.393800	0.455300	0.08%	0.10%	0.08%	0.09%

- A-No. : the spcecimen to measure the expansion in 100% relative humidity at 80°C
- I-No. : the spcecimen to measure the expansion submerged in NaOH solution (1M concentration) at 80°C

ASR expansion test results



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REPORT OF PETROGRAPHIC EXAMINATION

Date: November 2, 2009

CTLGroup Project No.: 059169

Petrographic Examination of Concrete Half Core from Delaminated Containment Wall, Crystal River, Florida

One saw cut half concrete core labeled Core #5 (Figs. 1 and 2) was received on October 27, 2009 from Mr. Jerzy Zemajtis, Project Manager, CTLGroup on behalf of Mr. Paul Fagan of Progress Energy, Crystal River, Florida. According to Mr. Zemajtis, the core represents the outer portion of concrete from a containment wall and the core is fractured at its inner surface at a delamination that was found to be present when access was gained to the wall interior. The delamination is approximately at a depth of 200 mm (8.0 in.) where horizontal post tensioning ducts are present.

Petrographic examination (ASTM C856-04) of the core was requested in order to determine, if possible, if the delamination is a recent feature, or alternatively if it occurred at some earlier time in the age of the structure.

FINDINGS AND CONCLUSIONS

The following findings result from the petrographic examination.

Based on the general appearance, and both the physical and microstructural properties, the fracture at the point of delamination is most likely a fairly recent event. However, it is not possible to be completely definitive about the time frame since an older fracture, if subsequently well protected from air and moisture ingress, may also have similar characteristics.

The fracture surface passes through, not around the aggregates particles, is moderately hard, and does not exhibit loose surface debris. There is an absence of significant microcracking in the general vicinity of the fracture, and only limited evidence of surface deposits (slight efflorescence).

Carbonation to any significant depth from the fracture surface into the outer concrete is not observed (Fig. 3). Incipient carbonation is exhibited in thin section at the immediate fracture surface (Fig. 6a). However, an older delamination surface that was not exposed to air due to the depth of outer concrete, and other possible wall coverings, may also have such an absence of carbonation.

The cement hydration adjacent to the fracture is well advanced and comparable to that of the body of the core (Figs. 6b and 6c). This suggests that there was no moisture ingress to the fracture surface, over a period of time long enough, to change the general degree of hydration. This is supported by an absence of secondary deposits within air voids adjacent to the fracture surface.

Additional Comments

The concrete represented by Core #5 is well consolidated and free of any cracks or excessive microcracks (Fig. 4). The concrete consists of crushed carbonate rock coarse aggregate and natural sand fine aggregate, well distributed in a portland cement paste. No evidence is exhibited of any deleterious chemical reactions involving the cement paste and / or aggregates. The concrete could be considered marginally air entrained based on an approximate volume of 1 to 2% of small, spherical entrained air voids in the hardened cement paste (Fig. 5).

Based on the physical properties and microstructure of the hydrated cement paste, and the tight aggregate to paste bond, lack of major cracks and microcracks, and absence of a materials-related distress mechanism, the concrete is considered to be in good condition.

Further details of the petrographic examination are given in the following image and data sheets.

METHODS OF TEST

Petrographic examination of the provided sample was performed in accordance with ASTM C 856-04, "Standard Practice for Petrographic Examination of Hardened Concrete." The core was visually inspected and photographed as received. The core half was ground (lapped) on the saw cut surface to produce a smooth, flat, semi-polished surface. Lapped and freshly broken surfaces of the concrete were examined using a stereomicroscope at magnifications up to 45X.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Containment wall
DATE RECEIVED: October 27, 2009
LOCATION: Crystal River
EXAMINED BY: Derek Brown

SAMPLE

Client Identification: Core #5.

CTLGroup Identification: 2452601.

Dimensions: Core diameter = 95 mm (3.75 in.). Core length = approximately 197 mm (7.75 in.); partial wall thickness.

Top End: Even, slightly rough formed surface.

Bottom End: Uneven and rough, fractured core end.

Cracks, Joints, Large Voids: Text.

Reinforcement: None observed in the core supplied.

AGGREGATES

Coarse: Crushed rock composed of carbonate rock type.

Fine: Natural quartz sand.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 18 mm (0.75 in.).

Shape, Texture, Distribution: Coarse- Sub rounded to angular, slightly irregular to rough, evenly distributed. Fine- Rounded to sub angular, slightly smooth to somewhat rough, evenly distributed

PASTE

Color: Medium gray, uniform coloration throughout the length of the core.

Hardness: Moderately hard at the outer surface and in the body of the core. At the fracture surface the paste is also moderately hard.

Luster: Subvitreous.

Paste-Aggregate Bond: Tight. Freshly fractured surfaces pass through aggregate particles.

Air Content: Estimated 2 to 4% total. Approximately 1 to 2% of the total air is larger entrapped air voids of up to 3 mm (0.12 in.) in size, plus a few large voids of 4 to 10 mm (0.16

to 0.4 in.). Somewhat uneven distribution of voids. Marginally air entrained based on the very low volume of moderate to small sized spherical air voids in the hardened cement paste.

Depth of Carbonation: 4 to 5 mm (0.16 to 0.20 in.) as measured from the outer surface. Negligible when measured from the inner fractured core surface.

Calcium Hydroxide*: Estimated 6 to 12% of small to medium sized crystals evenly distributed throughout the paste, and around aggregate to paste interfaces. Estimation of the volume is difficult due to the presence of calcite fines in the cement paste.

Residual Portland Cement Clinker Particles*: Estimated 4 to 8%. Some large cement particles, particularly belite clusters, of up to 0.15 mm in size suggest a portland cement as produced more than 30 years ago.

Supplementary Cementitious Materials*: None observed by the core supplied.

Secondary Deposits: None observed either in the body of the core and or near the fracture surface.

MICROCRACKING: A small number of medium length (5 to 10 mm), randomly orientated microcracks are evenly distributed throughout the body of the core. At the fractured end of the core there was no observed increase in microcracking relative to the body of the core.

ESTIMATED WATER-CEMENT RATIO: Moderate to moderately high (0.50 to 0.60) but estimation may be biased upwards due to the well advanced degree of hydration / apparent old age of the concrete.

MISCELLANEOUS:

1. Water droplets applied to freshly fractured surfaces were somewhat slowly absorbed by the hardened cement paste.
2. Some small areas of the inner fractured surface of the core, as received, exhibit a thin white haze of efflorescence-like substance suggesting leaching of lime in solution from within the core, or alternatively, moisture on or flowing past the fractured surface at the delamination position within the wall.
3. A moderate volume of fine calcite particles is present within the hardened cement paste, most likely from coarse aggregate crusher fines.

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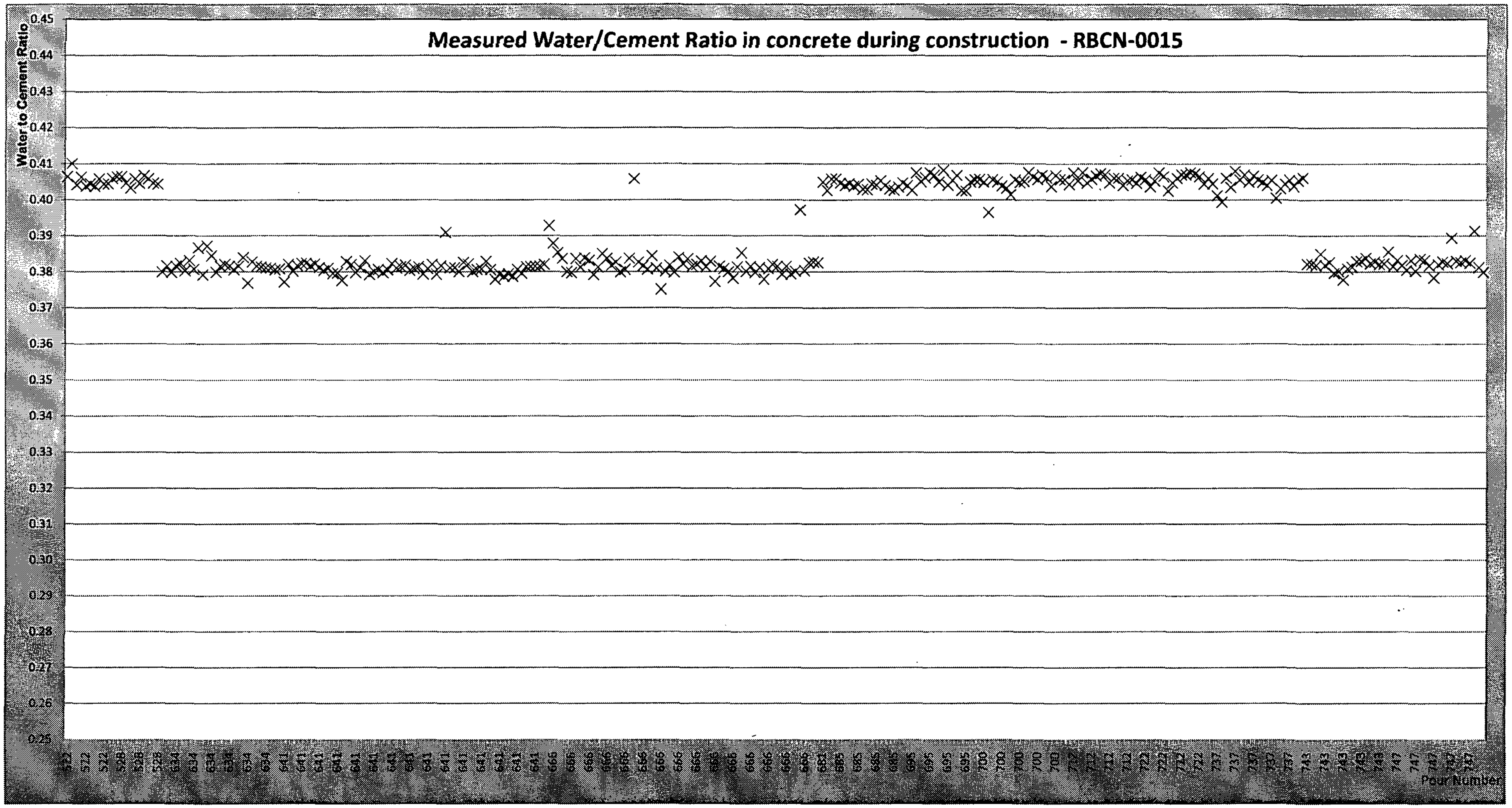
*percent by volume of paste


Measured Water/Cement Ratio in concrete during construction - RBCN-0015
Water to Cement Ratio
0.45
0.44
0.43
0.42
0.41
0.40
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0.25
Pour Number

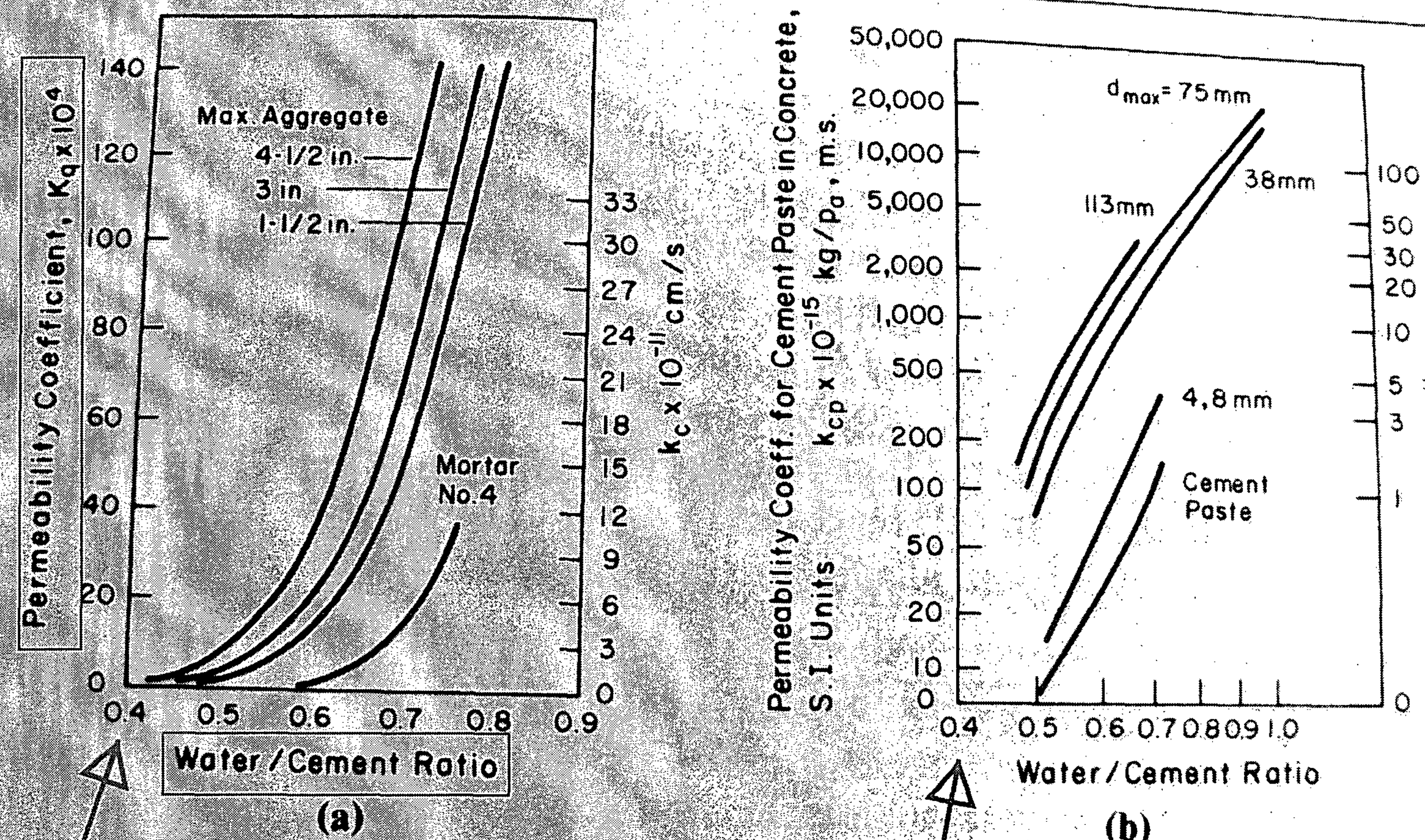


Figure 5-2 Influence of water/cement ratio and maximum aggregate size on concrete permeability: (a) K_q is a relative measure of the flow of water through concrete in cubic feet per year per square foot of area for a unit hydraulic gradient. [(a), From *Concrete Manual, 8th Edition*, U.S. Bureau of Reclamation, 1975, p. 37, (b), adapted from *Beton-Bogen*, Aalborg Cement Co., Aalborg, Denmark, 1979.]

The permeability of concrete to water depends mainly on the water/cement ratio (which determines the size, volume, and continuity of capillary voids) and maximum aggregate size (which influences the microcracks in the transition zone between the coarse aggregate and the cement paste).

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November 11 2009

Mr. Craig Miller
Progress Energy
(352) 795-6486 ex 1026
Craig.miller@pgnmail.com

Subject: **Report of Petrographic Observations**
Crystal River Containment Wall
Steam Generator Replacement Project
Crystal River Nuclear Generating Facility, Florida
MACTEC Project No. 6468-09-2535

Dear Mr.

MACTEC Engineering and Consulting, Inc. (MACTEC) is pleased to present this report of our petrographic observations performed on two concrete cores that were shipped to our laboratory under chain of custody. An additional core was received under chain of custody for limited observations. It is our understanding the two cores submitted for petrographic observations are from an area of the containment wall where a fracture was discovered running parallel to the surface at a depth of approximately 8 to 9 inches. We understand the core that was submitted for limited observations was from an area where the subject fracture had not occurred.

The cores submitted are as follows:

Core Number	Laboratory Number Assigned by MACTEC	Description of the Core
5	21269	From an area where the fracture had occurred
2	21270	From an area where the fracture had not occurred
7	21271	From an area where the fracture had occurred

Each core was photo documented as received and then saw cut longitudinally into halves. Each half was labeled with the same sample number and than A and B were added to designate the halves. As requested the B half for cores 21269 and 21270 were shipped to CTL Group in Skokie Illinois. The B half of core 21271 is being held for possible future use. The A half's of the cores were used for our analysis.
The purpose of our work was to perform a petrographic analysis of samples 21269A and 21271A and limited observations of sample 21270A. It is our understanding that you also require specific information

relative to the age of the fractured surfaces on samples 21269A and 21271A. Sample 21270A was used as a control sample that did not have a fractured surface.

Petrographic Observations

A Petrographic Analysis is a visual and microscopic analysis of cementitous materials performed by a qualified petrographer. Petrographic examinations are typically performed on polished sections or thin sections. Polished sections are generally cut sections that have been lapped (ground flat and smooth) and polished and are observed using reflected polarized light microscopes at magnifications of up to 80X. Thin sections are samples mounted to glass slides and ground to specific thicknesses (generally 20, 30, or 40 microns depending on the application) and observed using transmitted polarized light microscopes at magnifications of up to 600X.

A petrographic evaluation may be performed to identify and describe a specific item of interest such as the presence or extent of distress in concrete, or to provide a general characterization and measure of quality of the materials being evaluated. The petrographic evaluation of concrete examines the constituents of the concrete including coarse aggregates, fine aggregates, embedded items, hardened paste, and air void structure. The examination identifies cracking present in the concrete, indications of corrosion, extent of damage from external sources, aggregate reaction, chemical attack, sulfate attack, freeze thaw cracking, acid attack, and other mechanisms of deterioration. The petrographic examination can also estimate the water to cement ratio, look for indications of mineral additives and unhydrated cement particles in the paste, look for indications of bleed water and excess porosity in the concrete, look for indications of curing procedures used and methods of finishing, observe micro cracking present and other conditions within the concrete which might give information on the overall quality or the quality of any particular constituent material. Aggregate mineralogy, rock types, and mineral crystal structure can be identified when thin sections are viewed under a transmitted polarized light microscope.

TEST RESULTS AND OBSERVATIONS

PETROGRAPHIC OBSERVATIONS

The petrographic analysis was performed in general accordance with the applicable sections of ASTM C 856-04 Standard Practice for Petrographic Examination of Hardened Concrete. The results of our petrographic analysis are on the attached sheets, Summary of Petrographic Observations of Hardened Concrete. Photographs from our examination are attached. A summary of our observations and discussion are as follows.

Aggregate

The coarse aggregate generally consisted of a natural carbonate crushed rock with a maximum size of 3/4 inch. The rocks types observed included limestone, fossiliferous limestone, and a few particles of chert and/or limestone and chert. The particles were generally angular to sub-rounded in shape and fairly evenly distributed. The coarse aggregate appeared to comprise approximately 50% of the total aggregate quantity with the remaining fraction being fine aggregate.

On sample 21271, there were 4 coarse aggregate pieces on the cut surface of the core that retained moisture (and moisture in the surrounding paste) longer than other portions of the sample. These pieces are shown in Photographs 5, 6, 7, and 8. One of the pieces (Photograph 5 for core 21271) had a darkened rim. A thin section was prepared from the piece in photograph 7 and this piece contained microcrystalline quartz and radial silica and exhibited localized evidence of alkali silica reaction.

The fine aggregate was observed to be a natural siliceous sand consisting mostly of quartz. The particles were generally sub-angular to sub-rounded in shape and fairly evenly distributed.

Cement Paste

The cement paste was medium light gray (Reference colors from The Geological Society of America Rock-Color Chart, 1991). The paste appeared moderately hard and not easily scratched with a hardened steel point. The concrete appeared to have been placed at a moderately low water to cement ratio, possibly in the range of 0.4 to 0.5. Indication of placement at a high water to cement ratio such as significant bleed channels and water gain voids were not observed.

Air Voids, Voids, and Cracks

The concrete appeared to be air entrained and had a total air content estimated to be around 2 to 3%. The voids were generally small and spherical. Some air void clustering was observed around a few coarse aggregate particles. The air void distribution was moderately un-even and some small areas lacked air entrainment. There was limited mineral growth observed in some of the air voids. Calcium hydroxide was observed lining some air voids.

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- Location - Type	
Alteration: - Degree & Type - Reaction Products - Location - Identification	Not observed
Nature and Condition of Surface Treatments	There appeared to be white paint on the exterior surface of the core
Estimated water-cement ratio (based on visual observations only)	Appeared to have a moderately low w/c ratio possibly in the range of 0.4 to 0.5
Estimated cement content (based on visual observations only)	Appeared to have a moderately high cement content
PASTE:	
Color (GSA rock color chart 1991)	Medium light gray
Hardness	Appeared moderately hard when scratched with a hardened steel point
Porosity	Did not appear very porous. It took from 10 minutes to over 20 minutes to absorb 15 micro liter drops of water.
Carbonation	The outer ¼ to ½ inch of the exterior surface was carbonated. The fractured surface was not carbonated.
Residual un-hydrated Cement: - Distribution - Particle Size - Abundance - Composition	Some un-hydrated/partially hydrated cement particles were observed
Mineral Admixtures: - Size - Abundance - Identification	Fly-ash was not observed
Contamination: - Size - Abundance - Identification	Not observed

Equipment Used:

Cannon EOS Digital Rebel with 50mm macro lens and microscope adapters
AmScope 7X to 45X stereo zoom microscope (with and without polarized light)
Olympus BH-2 polarized light microscope
Zeiss Photomicroscope II polarized light microscope
Aven Digital Microscope
Starrett 6 inch rule SN 109000003

Note: No M&TE used is subject to calibration requirements.

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	particle.
Fractures	One end of the core contained a fractured surface. There were some other minor fractures on the end with the fractured surface. There were some fractures associated the chert particle discussed previously.
Embedded Items - Shape - Size - Location - Type	Not observed
Alteration: - Degree & Type - Reaction Products - Location - Identification	Not observed
Nature and Condition of Surface Treatments	There appeared to be white paint on the exterior surface of the core
Estimated water-cement ratio (based on visual observations only)	Appeared to have a moderately low w/c ratio possibly in the range of 0.4 to 0.5
Estimated cement content (based on visual observations only)	Appeared to have a moderately high cement content
PASTE:	
Color (GSA rock color chart 1991)	Medium light gray
Hardness	Appeared moderately hard when scratched with a hardened steel point
Porosity	Did not appear very porous. It took from 10 minutes to over 20 minutes to absorb 15 micro liter drops of water.
Carbonation	The outer ¼ to ½ inch of the exterior surface was carbonated. The fractured surface was not carbonated.
Residual un-hydrated Cement: - Distribution - Particle Size - Abundance - Composition	Some un-hydrated/partially hydrated cement particles were observed
Mineral Admixtures: - Size - Abundance - Identification	Fly-ash was not observed
Contamination: - Size - Abundance - Identification	Not observed

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December 23, 2009

Mr. Craig Miller
Progress Energy

Subject: **Report of Petrographic Observations**
Crystal River Containment Wall
Steam Generator Replacement Project
Crystal River Nuclear Generating Facility, Florida
MACTEC Project 6468-09-2535

Dear Mr. Miller

MACTEC Engineering and Consulting, Inc. (MACTEC) is pleased to present this report of our petrographic observations performed on a concrete chunk that was shipped to our laboratory under chain of custody. It is our understanding the chunk is from an area of the containment wall where a fracture was discovered running parallel to the surface at a depth of approximately 8 to 9 inches. We understand the submitted chunk contains the subject fractured surface and a portion of the concrete that was cast against a tendon duct.

The purpose of our work was to perform a petrographic analysis of the sample to observe the fractured surface and the surface that was cast against the tendon duct for depth of carbonation and other similarities or differences.

PETROGRAPHIC OBSERVATIONS

A Petrographic Analysis is a visual and microscopic analysis of cementitous materials performed by a qualified petrographer. Petrographic examinations are typically performed on polished sections or thin sections. Polished sections are generally cut sections that have been lapped (ground flat and smooth) and polished and are observed using reflected polarized light microscopes at magnifications of up to 80X. Thin sections are samples mounted to glass slides and ground to specific thicknesses (generally 20, 30, or 40 microns depending on the application) and observed using transmitted polarized light microscopes at magnifications of up to 600X.

A petrographic evaluation may be performed to identify and describe a specific item of interest such as the presence or extent of distress in concrete, or to provide a general characterization and measure of

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SUMMARY OF PETROGRAPHIC OBSERVATIONS OF HARDENED CONCRETE – ASTM C-856-04

PROJECT NAME	Crystal River Core Petrography Project
PROJECT NUMBER	6468-09-2535
DATE SAMPLED RECEIVED	12-2-09
SAMPLE I.D.	21378
SAMPLE SIZE AND DESCRIPTION AS RECEIVED	Chunk of Concrete identified as "small piece adjacent to sleeve". The chunk has a section that appears to have been cast against a tendon duct and reportedly has a section of the subject fractured surface adjacent to the surface cast against the duct.
OBSERVATIONS BY	David Wilson

CHARACTERISTICS	OBSERVATIONS
COARSE AGGREGATE:	
Shape	Angular to sub rounded
Grading	Approximately ¾ maximum size
Distribution	Even. Approximately 50% of the aggregates appeared to be coarse aggregates with the remaining fraction being the fine aggregate.
Texture	Fine
Composition	Carbonate
Rock Types	Limestone, fossiliferous limestone
Alteration: - Degree - Products	Not observed
Coatings	Not observed
Rims	Not observed
Internal Cracking	Generally not observed except in the vicinity of the fractured surface.
Contamination	Not observed
FINE AGGREGATE:	
Shape	Generally sub-rounded to sub-angular
Grading	#4 and smaller

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Distribution	Even
Texture	Fine
Composition	Siliceous
Rock Types	Quartz
Alteration: - Degree - Products	Not Observed
Coatings	Not Observed
Rims	Not Observed
Internal Cracking	A few internal fractures were observed
Contamination	Not observed

CHARACTERISTICS	***OBSERVATIONS***
CONCRETE:	
Air-Entrained or Not	Appeared to have some air entrainment. Total air content based on visual observations appeared to be 2 to 3%
Air Voids: - Shape - Size - Distribution	Mostly small and spherical. Some air void clustering was observed around a few coarse aggregate particles. The air void distribution was moderately un-even, some small areas lacked air entrainment. There was some limited mineral growth observed in some of the air voids. Calcium hydroxide was observed lining some air voids.
Bleeding	Not Observed
Segregation	Not Observed
Aggregate-Paste Bond	Coarse and fine aggregates appeared to have a good bond to the cement paste with few openings. Some aggregate particles had increased calcium hydroxide in the paste surrounding the perimeter of the particle.
Fractures	One long hairline crack was observed and is shown in the attached photograph #6. Some minor fractures were observed near the portion that was cast against the duct and the portion that contained the fractured surface.
Embedded Items - Shape	Not observed

Copy No. 1

Report for
Progress Energy

CTLGroup Project No. 059169

Petrographic Examination of Concrete Half Core from Delaminated Containment Wall, Crystal River, Florida

November 2, 2009

Submitted by:
Derek Brown

COA #4731

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Skokie, Illinois 60077-1030
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Columbia, Maryland 21045

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For thin-section study, small rectangular blocks were cut from the core inner surface fracture region and within the body of the core. One side of each block was lapped to produce a smooth, flat surface. The blocks were cleaned and dried, and the prepared surfaces mounted on separate ground glass microscope slides with epoxy resin. After the epoxy hardened, the thickness of the mounted blocks was reduced to approximately 20 μm (0.0008 in.). The resulting thin sections were examined using a polarized-light (petrographic) microscope at magnifications up to 400X to study aggregate and paste mineralogy and microstructure.

Estimated water-cement ratio (w/c), when reported, is based on observed concrete and paste properties including, but not limited to: 1) relative amounts of residual (unhydrated and partially hydrated) portland cement clinker particles, 2) amount and size of calcium hydroxide crystals, 3) paste hardness, color, and luster, 4) paste-aggregate bond, and 5) relative absorbency of paste as indicated by the readiness of a freshly fractured surface to absorb applied water droplets. These techniques have been widely used by industry professionals to estimate w/c.

Depth and pattern of paste carbonation was initially determined by application of a pH indicator solution (phenolphthalein) to freshly cut and original fractured concrete surfaces. The solution imparts a deep magenta stain to high pH, non-carbonated paste. Carbonated paste does not change color. The extent of paste carbonation was confirmed in thin-section.

Derek Brown

Derek Brown
Senior Microscopist
Microscopy Group

DB/DB

Notes:
1. Results refer specifically to the sample submitted.
2. This report may not be reproduced except in its entirety.
3. The sample will be retained for 30 days, after which it will be discarded unless we hear otherwise from you.

to 0.4 in.). Somewhat uneven distribution of voids. Marginally air entrained based on the very low volume of moderate to small sized spherical air voids in the hardened cement paste.

Depth of Carbonation: 4 to 5 mm (0.16 to 0.20 in.) as measured from the outer surface. Negligible when measured from the inner fractured core surface.

Calcium Hydroxide*: Estimated 6 to 12% of small to medium sized crystals evenly distributed throughout the paste, and around aggregate to paste interfaces. Estimation of the volume is difficult due to the presence of calcite fines in the cement paste.

Residual Portland Cement Clinker Particles*: Estimated 4 to 8%. Some large cement particles, particularly belite clusters, of up to 0.15 mm in size suggest a portland cement as produced more than 30 years ago.

Supplementary Cementitious Materials*: None observed by the core supplied.

Secondary Deposits: None observed either in the body of the core and or near the fracture surface.

MICROCRACKING: A small number of medium length (5 to 10 mm), randomly orientated microcracks are evenly distributed throughout the body of the core. At the fractured end of the core there was no observed increase in microcracking relative to the body of the core.

ESTIMATED WATER-CEMENT RATIO: Moderate to moderately high (0.50 to 0.60) but estimation may be biased upwards due to the well advanced degree of hydration / apparent old age of the concrete.

MISCELLANEOUS:

1. Water droplets applied to freshly fractured surfaces were somewhat slowly absorbed by the hardened cement paste.
2. Some small areas of the inner fractured surface of the core, as received, exhibit a thin white haze of efflorescence-like substance suggesting leaching of lime in solution from within the core, or alternatively, moisture on or flowing past the fractured surface at the delamination position within the wall.
3. A moderate volume of fine calcite particles is present within the hardened cement paste, most likely from coarse aggregate crusher fines.

---

*percent by volume of paste