Lawrence Livermore National Laboratory

LLNL-TR-810020

RUNIT PROJECT: DATA REPORT

Exterior Concrete Core Test Results

Terry Hamilton

March 2020

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LLNL-TR-810020

RUNIT PROJECT: DATA REPORT

Exterior Concrete Core Test Results

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March 2020

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1. PROLOGUE

The Cactus Crater containment structure (*Runit Dome*) on Enewetak Atoll consists of a mound of encapsulated radioactively contaminated soil and debris placed inside an unlined nuclear test crater on the north end of Runit Island. The waste pile is protected by a key wall surround designed to prevent scouring and undercutting of the containment structure, and a non-load-bearing concrete cap constructed of clean aggregate, devised to protect the mound of encapsulated material below from natural erosion by wind and water (Fig. 1) (Hamilton, 2013; DNA, 1981).

The concrete cap is comprised of 357 trapezoidal shaped panel or segments arranged in circular rows around the structure, and a top cap section at the apex. The individually poured concrete segments vary in size from around 6.2 x 6.5 meters along the bottom fringe of the structure to about 1.8 x 2.3 meters near the apex. The average thickness of the concrete cap is highly variable but averages around 43 ± 7 cm or very close to the design thickness of 45 cm (Hamilton 2020a). Segments around ring rows near the base and apex of the containment structure have typical readings greater than the average thickness. The thinnest concrete cap segments appear in the middle rows.

Visual surveys of exterior concrete covering the containment structure show that cracks and spalls in the exterior concrete have formed over the life history of the containment structure (Hamilton, 2020b; 2013). Variations in coloration of the external concrete have also been observed. The positioning of most cracks along the centerline of individual panel segments is thought to be indicative of effects of long-term drying shrinkage of the concrete rather than from concrete settlement (Fig 2.). Many concrete segments covering the containment structure also contain chipped edges with varying degrees of spalling. The individually constructed concrete panels covering the containment structure do not contain expansion joints except for the seam between the bottom ring row and the key wall. Under these circumstances, the chipped edges and spalling along the seams between panel segments were most likely caused by thermal movement of the concrete slabs with expansion and contraction of concrete under extremes in daily temperature (*Concrete Science Inc., Per comm*). It is also true to say that vertical movement of the concrete segments could also cause edges of cracks and joints to chip and spall.

The concrete cap is composed of crushed coarse and fine aggregate limestone and Portland cement. Petrographic examination of recovered exterior surfaces (*spalled pieces of concrete*) show that aggregate materials are well graded, properly shaped, uniformly distributed, and hard to fairly hard (Micro-Chem Inc., Per comm). The maximum observed size aggregate was around 2.5 cm. The concrete was not air entrained and contained no excessive fines or dirty aggregate particles. No fly ash or other types of supplementary cementitious materials were detected in the material. Based on petrographic examination and observed paste-aggregate bonding properties of the material, the overall strength properties of the concrete were viewed as excellent.

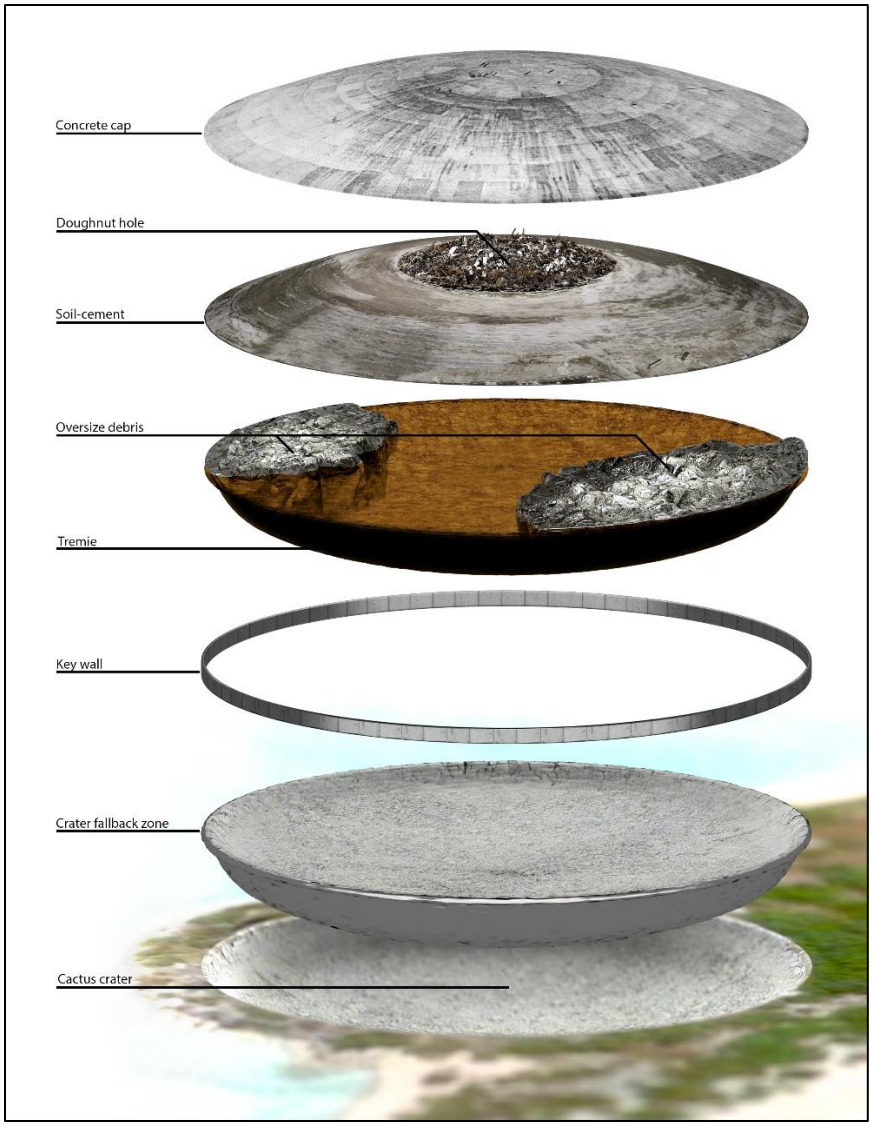


Fig. 1. Generalized schematic showing the layout and various design features of the Cactus crater containment structure (after Hamilton, 2013).

From a radiological viewpoint, cracks and spalls appearing in the concrete cap of the containment structure are not expected to form significant sites for elevated external or internal radiation exposure or lead to the spread of contamination that could potentially impact or endanger human health, the environment or wildlife.

Nonetheless some efforts have been made to perform cosmetic repair of exterior surfaces of the containment structure for the purposes of helping alleviate public perception that the overall effectiveness of the structure is compromised and potentially allowing harmful quantities of radioactive fallout contamination becoming available for human exposure (Hamilton 2020b). It was also expected that the repair of cracks and spalls would allow for a more careful assessment of future changes in the condition and rate of deterioration of the concrete. Repair will also help

reduce the potential for rainwater infiltrating down through the cracks and possibly influencing the solubilization potential and mass transport of the encapsulated material below.

Previous assessments of the containment structure based on Ground Penetrating Radar (GPR), Impact Echo (IE) and Spectral Analysis of Surface Waves (SAWP) nondestructive testing (NDT) show that the vast majority of the concrete is in a sound structural condition with very few voided or poorly supported regions (Hamilton, 2020a). *These findings support the view that the Cactus Crater containment structure on Runit Island is in no immediate danger of collapse or failure*.

The main risk posed by *the Cactus Crater containment structure*, or more specifically, the radioactive material encapsulated in the dome will be derived from the flow of contaminated groundwater from beneath the containment structure into the local marine environment, and the subsequent uptake of dome derived fallout contamination into the marine food chain. The flow of contaminated groundwater away from the site boundary into the marine environment will be controlled by the solubilization potential of radionuclides encapsulated in the waste pile and local groundwater hydrology. *It is only after drilling a suitable network of groundwater sampling wells that a work program can be devised and implemented to assess the potential impacts of any leakage of radioactive waste from the Cactus Crater containment structure on the wider marine environment*.

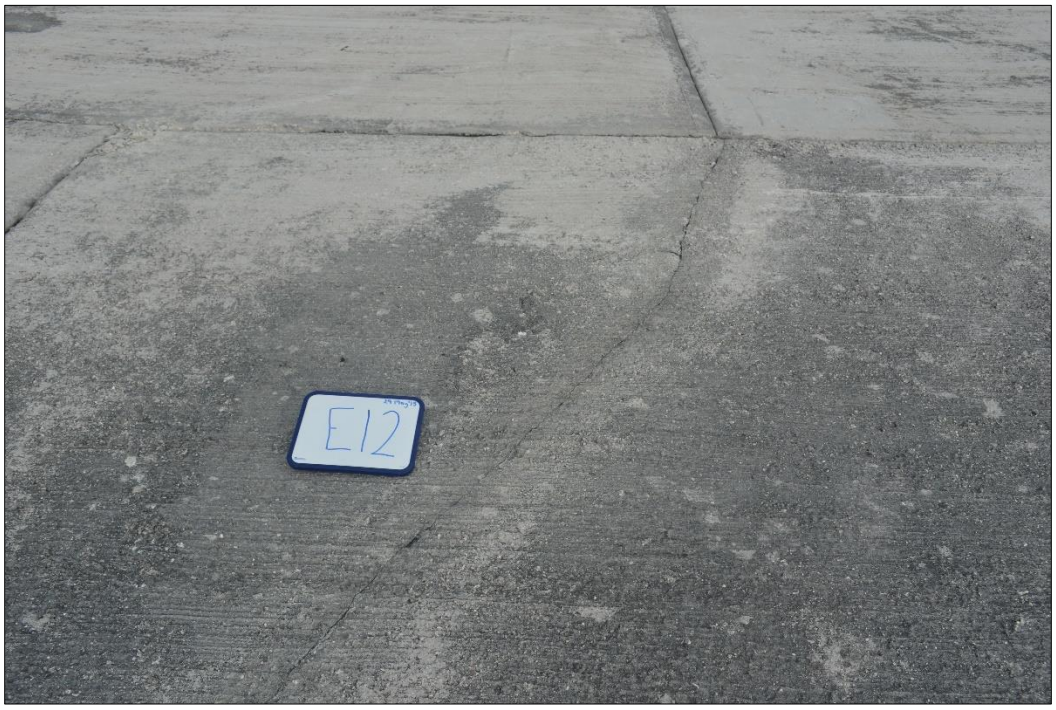


Fig 2. A visually defective concrete panel (E12) showing a minor to moderate size crack extending upwards across the centerline of a panel segment (after Hamilton, 2013).

FIELD INVESTIGATION AND LABORATORY ANALYSIS OVERVIEW

Full implementation of a proposed groundwater monitoring program under the *Insular Areas Act of 2011* will provide a scientific basis to assess the degree of leakage of radioactive waste from the Cactus Crater containment structure into the local marine environment. The overall goal of this program is to develop essential data and information to conduct a site-specific dose assessment and quantitative risk analysis that describes conditions that may affect the health status of people of Enewetak now and into the future. *To this end, it will be necessary to drill and install a network of groundwater monitoring wells on and around the containment structure.*

The current study was conducted as a preemptive step in support of the *Insular Areas Act of 2011* and involved the collection and analysis of a series of hardened concrete core test specimens from the concrete cap. The concrete cores were collected in August 2016 in accordance with ASTM C42 *Obtaining and Testing Drilled Cores and Sawed Beams of Concrete* under the supervision of a licensed engineer. Efforts were made to collect concrete cores along a path across the containment structure that would likely be followed by a drilling rig.

A total of 40 concrete core specimens were obtained from the site and shipped to Consolidated Engineering Laboratories, Oakland, CA. Thirty concrete core specimens from ten locations were subsequently prepared, conditioned, and tested for compressive strength according to Compression Testing per ASTM C42 *Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*. The compressive strength tests were conducted to provide added confidence that the drilling operation to establish groundwater monitoring wells could be conducted in a safe manner without fear of causing additional damage to the surrounding concrete or the integrity of the structure.

Ten concrete core specimens from ten locations were shipped to an independent licensed contractor (*Micro-Chem Laboratories*) for petrographic examination and chemical analysis. The objective was to evaluate the physical and mineralogical properties of the concrete by petrographic examination, determine sulfate (as SO_3) and acid-soluble chloride profiles within the concrete and, more generally, to assess the overall quality of the concrete specimens.

The petrographic examination was performed according to ASTM C856-14, "Standard Practice for Petrographic Examination of Hardened Concrete." The specimens were first longitudinally saw cut, lapped, and examined with a stereomicroscope to evaluate the physical properties of the concrete. Air contents were estimated based on comparison to reference concrete. Thin sections were prepared from the exterior and interior areas of all ten cores and examined with a petrographic microscope to evaluate the mineralogy of the paste and aggregates, assess the degree of Portland cement hydration, and detect the presence of any deleterious reactions or deposits in the concrete. Depth of paste carbonation was determined by thin section analysis.

For chemical analysis, concrete sections were transversely saw cut from four selected areas, crushed, and pulverized. The SO_3 content of each sample was determined by LECO Induction Furnace procedures based on ASTM C114-15, "Standard Test Methods for Chemical Analysis of

Hydraulic Cement." Chloride contents were determined according to ASTM C1152-04 (2012), "Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete."

3.0 SUMMARY FINDINGS

Results of the compressive strength testing, petrographic examination, and chemical analysis of concrete cap core specimens from the Cactus Crater containment structure are shown in Appendix A.

In general, analyses of concrete core specimens from the exterior concrete of the containment structure show that the exterior concrete remains well cemented, appears to be properly consolidated and cured, and has satisfactory strength and binding properties. Microcracks and small macrocracks observed along the exterior portion of concrete do not appear to be adversely affecting the strength properties or overall integrity of the concrete. The compressive strength of the concrete core specimens averaged 46,200 ± 7600 kPa (6704 ± 1100 psi) with a measured load capacity varying between 22,200 and 50,440 kg (49,000-111,000 lbs). Taken together with the NDT data as previously described (Hamilton, 2020a), these data indicate the exterior concrete cap is not significantly compromised and is still serving its intended purpose of providing an effective barrier to reduce natural erosion of the waste pile below. Moreover, work can proceed with installation of groundwater sampling boreholes knowing that the containment structure can support the weight of a drill rig.

This study was conducted to provide added confidence that the drilling and groundwater sampling borehole installation project, as proposed under Insular Areas Act of 2011, can be conducted in a safe and environmentally protective manner. Ultimately the implementation of a groundwater monitoring program on Runit Island is expected to lead to a scientifically defensible assessment of radiological conditions imposed by the site on the people of Enewetak with distribution of data and information under a rigorous peer review process.

4.0 REFERENCES

DNA (1981). *The Radiological Cleanup of Enewetak Atoll*, Defense Nuclear Agency (DNA), Washington D.C.

Hamilton T.F. (2020a). *Runit Project: Data Report – Non-Destructive Testing and Evaluation Investigation of Runit Island Containment Structure*, Lawrence Livermore National Laboratory, LLNL-TR-810290.

Hamilton T.F. (2020b). *Web based mosaic and interactive showing results of a drone visual survey of the exterior concrete of the Cactus Crater containment structure on Runit Island, Enewetak Atoll*. https://marshallislands.llnl.gov/, Lawrence Livermore National Laboratory (under construction).

Hamilton T.F. (2013). *A Visual Description of the Concrete Exterior of the Cactus Crater Containment Structure*, Lawrence Livermore National Laboratory, LLNL-TR-648143.

Appendix A

Concrete Core Test Report

(Consolidated Engineering Laboratories (CEL) in conjunction with Micro-Chem Laboratories)

Released with authorization CEL

CONSOLIDATED ENGINEERING
LABORATORIES

February 9, 2017

Terry Hamilton

Lawrence Livermore National Laboratory Sent via e -mail: hamilton18@llnl.gov

RE: Runit Dome Concrete Test
Report CEL #10 -01508 -
LAW

CONCRETE TEST REPORT

As requested, Consolidated Engineering Laboratories has performed testing of hardened concrete core test samples. Samples were obtained from the site on August 7-8, 2016. Samples were obtained in accordance with ASTM C42 *Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.* A total of forty samples were obtained and shipped to our Oakland laboratory for testing. The following tests were performed:

Compression Testing per ASTM C42 *Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*
Petrographic Analysis per ASTM C856 *Standard Practice for Petrographic Examination of Hardened Concrete*
Acid -Soluble Chloride per ASTM C1152 *Standard Test Method for Acid -Soluble Chloride in Mortar and Concrete*
Sulfate Content per ASTM C114 *Standard Test Methods for Chemical Ana lysis of Hydraulic Cement*

A total of thirty core samples from ten locations were prepared, conditioned, and tested for compressive strength. Refer to attached table for test results.

A total of ten samples from ten locations were tested for petrographic analysis, acid soluble chlorides and sulfate content. Samples were sent to Micro-Chem Laboratories. Refer to attached report for test results.

This concludes the test report. Please contact the undersigned if you have any questions.

REGISTERED PROFESSIONAL ENGINEER
JAMES M. POWERS
No. C41046
Exp. 03/31/17
CIVIL
STATE OF CALIFORNIA

James Powers, P.E.
Reviewing Engineer

Encl. (50)

2001 Crow Canyon Road, Suite 100, San Ramon, CA 94583 Tel. (925) 314-7100; FAX (925) 885-7140

CONSOLIDATED ENGINEERING
LABORATORIES

Project: Runit Dome
CEL # 50-53216-S
Sample Date: 8/7-8/16
Test Date: 1/13/2017

TABLE 1
CONCRETE CORE COMPRESSION TEST REPORT

Sample Number	Sample Location	Diameter (inches)	Prepared Length (inches)	Area (sq.in.)	L/D	Correction Factor	Ultimate Load (lbs.)	Compressive Strength(psi)	
A44-1	Segment A44	3.73	7.09	10.93	1.90	1.00	67,020	6,133	
A44-2	Segment A44	3.73	6.85	10.93	1.84	1.00	64,090	5,865	
A44-3	Segment A44	3.73	7.00	10.93	1.88	1.00	89,280	8,170	
B10-2	Segment B10	3.73	7.05	10.93	1.89	1.00	76,280	6,981	
B10-3	Segment B10	3.73	7.09	10.93	1.90	1.00	68,930	6,308	
B10-4	Segment B10	3.73	7.34	10.93	1.97	1.00	79,360	7,262	
B19-2	Segment B19	3.73	7.17	10.93	1.92	1.00	70,920	6,490	
B19-3	Segment B19	3.73	7.23	10.93	1.94	1.00	65,480	5,992	
B19-4	Segment B19	3.73	7.01	10.93	1.88	1.00	74,540	6,821	
B25-2	Segment B25	3.73	7.17	10.93	1.92	1.00	76,140	6,968	
B25-3	Segment B25	3.73	7.05	10.93	1.89	1.00	74,790	6,844	
B25-4	Segment B25	3.73	6.93	10.93	1.86	1.00	49,060	4,490	Note 1
B33-1	Segment B33	3.73	7.02	10.93	1.88	1.00	76,880	7,035	
B33-2	Segment B33	3.73	7.12	10.93	1.91	1.00	75,990	6,954	
B33-3	Segment B33	3.73	7.11	10.93	1.91	1.00	56,490	5,170	
B36-1	Segment B36	3.73	7.20	10.93	1.93	1.00	72,630	6,647	
B36-2	Segment B36	3.73	7.32	10.93	1.96	1.00	74,390	6,808	
B36-3	Segment B36	3.73	7.13	10.93	1.91	1.00	69,990	6,405	
B40-1	Segment B40	3.73	7.11	10.93	1.91	1.00	66,370	6,074	
B40-2	Segment B40	3.73	7.11	10.93	1.91	1.00	65,870	6,028	
B40-4	Segment B40	3.73	7.21	10.93	1.93	1.00	80,090	7,329	
C9-1	Segment C9	3.73	7.20	10.93	1.93	1.00	65,210	5,967	
C9-3	Segment C9	3.73	7.05	10.93	1.89	1.00	64,540	5,906	
C9-4	Segment C9	3.73	7.01	10.93	1.88	1.00	66,480	6,084	
C25-2	Segment C25	3.73	7.18	10.93	1.92	1.00	63,650	5,825	
C25-3	Segment C25	3.73	7.06	10.93	1.89	1.00	77,950	7,133	
C25-4	Segment C25	3.73	7.50	10.93	2.01	1.00	70,240	6,428	
C33-1	Segment C33	3.73	5.56	10.93	1.49	0.96	82,610	7,257	
C33-2	Segment C33	3.73	7.07	10.93	1.90	1.00	111,250	10,181	
C33-4	Segment C33	3.73	7.46	10.93	2.00	1.00	104,440	9,558	

Note 1 – Sample #B25-4 observed to have void in center of sample breaking

Average	6,704
STD DEV	1,100
COV	16.41%

ANALYSIS OF CONCRETE CORE SPECIMENS

Project: Runit Dome

Report Prepared for:

Consolidated Engineering Laboratories
534 23 Ave.
Oakland, CA 94606

January 30, 2017

Micro-Chem Laboratories Job No. C-6374-16

MICRO-CHEM LABORATORIES

635 Bret Harte Drive • P.O. Box 485 • Murphys, CA • 95247 • (209) 728-8200 • FAX 209-728-8251 • www.micro-chem.com

January 30, 2017

Consolidated Engineering Laboratories
534 23 Ave.
Oakland, CA 94606 Job No. C-6374-16

Attn: Mr. Jim Powers

Re: Analysis of Concrete Core Specimens

Project: Runit Dome

In response to your request, ten hardened concrete core specimens were received for petrographic examination and chemical analysis. The specimens were reportedly obtained from the above referenced project. The objectives of the analyses were to evaluate the physical and mineralogical properties by petrographic examination, chemically determine the sulfate (as SO_3) and acid-soluble chloride profiles of the concretes, and asses the overall quality of the concrete as represented by the supplied concrete core specimens.

Test Methods

Cores A44-4, B10-1, B19-1, B25-1, B33-4, B36-4, B40-3, C9-2, C25-01, and C33-3 were examined according to ASTM C856-14, "Standard Practice for Petrographic Examination of Hardened Concrete." The specimens were longitudinally saw cut, lapped, and examined with a stereomicroscope to evaluate the physical properties of the concrete. Air contents were estimated based on comparison to reference concretes. Thin sections were prepared from the exterior and interior areas of all ten cores and examined with a petrographic microscope to evaluate the mineralogy of the paste and aggregates, assess the degree of Portland cement hydration, and detect the presence of any deleterious reactions or deposits in the concrete. Depth of paste carbonation was determined by thin section analysis.

All ten concrete core specimens were chemically analyzed for SO_3 and acid-soluble chloride contents. Sections were transversely saw cut from four selected areas, crushed, and pulverized. The SO_3 contents were determined by LECO Induction Furnace procedures based on ASTM C114-15, "Standard Test Methods for Chemical Analysis of Hydraulic Cement." Chloride contents were determined according to ASTM C1152-04 (2012), "Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete."

Sample Descriptions

The descriptions of the ten concrete core specimens are presented in Table I.

Chemical Analysis

The results of the acid-soluble chloride and SO_3 contents of the ten concrete core specimens by chemical analysis are presented in Table II.

Petrographic Examination

1. The concrete from Cores A44-4, B10-1, B19-1, B25-1, B33-4, B36-4, B40-3, C9-2, C25-01, and C33-3 was composed of crushed carbonate coarse and fine aggregate materials and Portland cement. No fly ash or any other supplementary cementitious materials were detected. The concrete from all ten cores was not air entrained. The coarse and fine aggregate materials were composed of fossiliferous limestone. Maximum size aggregate was 1.0 in. in Cores A44-4, B10-1, B19-1, B36-4, B40-3, C9-2, C25-01, and C33-3 and 1.5 in. in Cores B25-1 and B33-4. The aggregate materials were well graded, properly shaped, uniformly distributed, and hard to fairly hard. No excessive fines or "dirty" aggregate particles were detected in the concrete core specimens.

2. The physical description, physical properties, mineralogical properties, and secondary deposits of the concrete from Cores A44-4, B10-1, B19-1, B25-1, B33-4, B36-4, B40-3, C9-2, C25-01, and C33-3 are presented in Tables III-XII.

Discussion and Conclusions

1. The determined acid-soluble contents of Cores A44-4, B10-1, B19-1, B25-1, B33-4, B36-4, B40-3, C9-2, C25-01, and C33-3 by chemical analysis from the exterior, middle areas, and interior locations of the concrete were all high and exceeded the chloride corrosion threshold value of 0.2%, calculated by mass of Portland cement. Generally, the chloride profile analysis revealed that chloride ions intruded into the exterior surface of the concrete as the chloride levels decreased with depth into the concrete.

2. The chemically determined sulfate contents (expressed as SO_3) ranged from 0.53% (Core C9-2 Middle 2) to 0.99% (Core B10-1 Middle 2). The SO_3 contents of all four locations from each of the ten concrete cores were elevated in comparison to the SO_3 content assignable to the Portland cement. The calculated SO_3 content was 0.38%, by mass of concrete, assuming a 15% Portland cement content of the concrete and a 2.5% SO_3 value of the Portland cement. The sulfate profile analysis generally did not indicate significant differences in sulfate levels among the exterior, middle 1, middle 2, and interior locations, except for Core A44-4.

3. The concrete from all ten core specimens was properly consolidated and cured by petrographic examination. Depth of paste carbonation along the exterior surface ranged from 0.0-3.0 mm (minor) in Core C9-2 to 25 mm (very deep) in Core B33-4. The buff colored areas along the exterior surfaces were carbonated. The Portland cement was sufficiently hydrated by thin section analysis. The un-hydrated Portland cement contents were lower in the buff colored carbonated regions along the exterior surface of the cores. The buff colored cement paste generally was weaker than the medium gray paste at depth. Overall, the strength properties of the concrete were satisfactory as indicated by the strength of the cement paste and paste-aggregate bonding properties by petrographic examination.

4. No large cracks were detected in the ten concrete cores. No small macrocracks were detected in Cores B25-1 and C9-2. Cores A44-4, B10-1, B19-1, B33-4, B36-4, and B40-3 contained minor amounts of small longitudinal cracking in the exterior portion of the concrete to a maximum depth of 37 mm in Core B36-4. Core 25-1 contained small longitudinal and transverse cracks in the exterior 15 mm of the concrete. No small macrocracks were detected below these exterior areas. Thin section analysis revealed a wide range in microcracking among the ten concrete cores. However, the microcracking and small macrocracks along the exterior portion of the concrete did not appear to have adversely affected the strength properties or integrity of the concrete based on the petrographic analysis. The exterior of the ten cores had a rough surface that ranged from intact (no scaling) to very light scaling (sand particles exposed) to moderate scaling (coarse aggregate particles exposed). The cause of the scaling, small macrocracks, and microcracks was not evident from the petrographic analysis. The scaling and cracks/microcracks were not caused by deleterious chemical reactions, weak strength properties, poor consolidation, or insufficient cement hydration.

5. Secondary ettringite (calcium sulfo-aluminate hydrate) deposits were present among the concrete cores except for Cores B33-4, B26-4, and C25-1. These deposits were caused by an innocuous reorganization of the cement paste due to cyclic wetting and drying of the concrete over time as opposed to chemical sulfate attack. Secondary patches of calcium carbonate were common along the exterior surfaces of the cores.

Should any questions arise concerning the findings of this report, please contact the undersigned.

Respectfully submitted,

MICRO-CHEM LABORATORIES

Robert C. O'Neill, P.G.
Senior Petrographer

RCON/jamc
C637416
Attachments

Sample Disposition: The samples will be stored for a period of one month and thereafter discarded. Charges for additional sample storage time and/or shipping of the samples will be billed to the client.

TABLE I

JOB NO. C-6374-16

SAMPLE DESCRIPTIONS

Core ID.	Diameter, in.	Length, in.	Reinforcing Steel
A44-4	3.7	8.0	None
B10-1	3.7	8.1	None
B19-1	3.7	7.8	None
B25-1	3.7	5.4	None
B33-4	3.7	8.0	None
B36-4	3.7	7.8	None
B40-3	3.7	7.4	None
C9-2	3.7	7.3	None
C25-1	3.7	7.8	None
C33-3	3.7	5.6	None

TABLE II

JOB NO. C-6374-16

CHEMICAL ANALYSIS OF CONCRETE SAMPLE
ASTM C1152-04 (2012) AND C114-15

Acid-Soluble Chloride and SO_3 Determinations

Core ID.	Location	Depth, in.	C1, %[1]	C1, %[2]	SO_3, %[2]
A44-4	Middle-1	2.5-3.0	0.369	2.46	0.68
A44-4	Middle-2	5.0-5.5	0.234	1.56	0.70
A44-4	Interior	7.4-7.9	0.210	1.40	0.70
B10-1	Exterior Surface	0.0-0.5	0.325	2.17	0.91
B10-1	Middle-1	2.4-2.9	0.340	2.27	0.84
B10-1	Middle-2	4.8-5.3	0.355	2.37	0.99
B10-1	Interior	7.3-7.8	0.323	2.15	0.86
B19-1	Exterior Surface	0.0-0.5	0.383	2.55	0.74
B19-1	Middle-1	2.3-2.8	0.390	2.60	0.56
B19-1	Middle-2	4.6-5.1	0.266	1.77	0.63
B19-1	Interior	7.0-7.5	0.373	2.49	0.83
B25-1	Exterior Surface	0.0-0.5	0.376	2.51	0.65
B25-1	Middle-1	1.6-2.1	0.419	2.79	0.67
B25-1	Middle-2	3.2-3.7	0.408	2.72	0.66
B25-1	Interior	4.7-5.2	0.258	1.72	0.65
B33-4	Exterior Surface	0.0-0.5	0.404	2.69	0.71
B33-4	Middle-1	2.4-2.9	0.451	3.01	0.65
B33-4	Middle-2	4.8-5.3	0.357	2.38	0.64
B33-4	Interior	7.2-7.7	0.348	2.32	0.64

TABLE II (con't.)
JOB NO. C-6374-16

CHEMICAL ANALYSIS OF CONCRETE SAMPLE
ASTM C1152-04 (2012) AND C114-15

Acid-Soluble Chloride and SO_3 Determinations

Core ID.	Location	Depth, in.	C1, %(1)	C1, %(2)	SO_3, %(2)
B36-4	Middle-1	2.4-2.9	0.508	3.39	0.64
B36-4	Middle-2	4.8-5.3	0.288	1.92	0.67
B36-4	Interior	7.1-7.6	0.273	1.82	0.79
B40-3	Exterior Surface	0.0-0.5	0.506	3.37	0.73
B40-3	Middle-1	2.2-2.7	0.439	2.93	0.67
B40-3	Middle-2	4.4-4.9	0.286	1.91	0.67
B40-3	Interior	6.6-7.1	0.219	1.46	0.62
C9-2	Exterior Surface	0.0-0.5	0.628	4.19	0.76
C9-2	Middle-1	2.1-2.6	0.436	2.91	0.56
C9-2	Middle-2	4.2-4.7	0.346	2.31	0.53
C9-2	Interior	6.4-6.9	0.290	1.93	0.63
C25-1	Exterior Surface	0.0-0.5	0.453	3.02	0.76
C25-1	Middle-1	2.4-2.9	0.386	2.57	0.62
C25-1	Middle-2	4.8-5.3	0.249	1.66	0.57
C25-1	Interior	7.2-7.7	0.269	1.79	0.60
C33-3	Exterior Surface	0.0-0.5	0.317	2.11	0.70
C33-3	Middle-1	1.6-2.1	0.428	2.85	0.75
C33-3	Middle-2	3.2-3.7	0.256	1.71	0.66
C33-3	Interior	4.7-5.2	0.256	1.71	0.72

TABLE III

JOB NO. C-6374-16

CORE ID. A44-4

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium brown gray, very hard to hard, and lightly scaled	Broken surface	Few patches of $CaCO_3$ on exterior surface. Air-voids lined with $CaCO_3$, and ettringite deposits on interior surface.	No large cracks. Very few small longitudinal cracks in exterior 14-21 mm.

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Hard to very hard. Fairly hard in buff colored area.	Patches of buff exterior 11 mm. Medium gray below.	Moderately low	Very strong	2-3	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-10 in carbonated layer along exterior. 10-20 below.	20-25	None	Trace longitudinal along exterior	Spotty to 9.0 mm from exterior surface
Interior 35 mm	15-22	20-25	None	Very few random	1.5-5.0 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Few air-voids lined with ettringite deposits mostly in interior 12 mm	None	Few air-voids lining/fillings with ettringite deposits above carbonated layer

TABLE IV

JOB NO. C-6374-16

CORE ID. B10-1

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Dark gray to buff, very hard, and moderately scaled	Broken surface	Patches of $CaCO_3$ on exterior surface. Air-voids lined with $CaCO_3$ and ettringite deposits on interior surface.	No large cracks. Very few small longitudinal cracks in exterior 30 mm.

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content %	Consolidation
Very hard with few hard areas. Fairly hard to soft in buff colored areas.	Patches of buff to 17 mm. Medium gray below.	Moderately low	Very strong	3-4. Some large entrapped air-voids	Good to fair

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-10 in carbonated layer along exterior. 15-22 below.	20-30	None	Very few transverse and longitudinal in exterior 2 mm	1.0-18.0 mm from exterior surface
Interior 35 mm	15-22	25-30	None	Some mostly transverse throughout section	0.25-0.5 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Ettringite deposits lining/filling air-voids throughout core	Ettringite deposits lining/filling air-voids below carbonated layer	Low amount of ettringite deposits lining a few air-voids

TABLE V

JOB NO. C-6374-16

CORE ID. B19-1

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray to medium brown gray, very hard, and lightly scaled with rough intact areas.	Broken surface	Small patches of $CaCO_3$ on exterior surface. Very low amount of $CaCO_3$ in air-voids on interior surface.	No large cracks. Some small cracks on exterior surface. Very few small longitudinal cracks in exterior 15 mm.

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content %	Consolidation
Hard to very hard	Patches of buff exterior 12 mm. Medium gray below.	Moderately low	Very strong	1-2	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-5 in carbonated layer along exterior. 5-12 below.	15-25	None	Trace longitudinal along exterior 2 mm	0.00-0.5 mm from exterior surface and along cracks
Interior 35 mm	7-15	20-30	None	Some transverse in middle of thin section	0.25-0.75 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Very low amount of ettringite deposits lining air-voids in interior half of concrete	None	Very low amount of ettringite deposits lining/filling air-voids throughout section

TABLE VI

JOB NO. C-6374-16

CORE ID. B25-1

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray to buff, very hard, and rough intact surface to very light to lightly scaled	Broken surface	Small patches of $CaCO_3$ on exterior surface. Patches of $CaCO_3$ on interior surface	None

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Very hard to hard. Fairly hard to soft in buff colored areas.	Patches of buff exterior 9 mm. Medium gray below.	Moderate	Very strong	2-3. Few large air-voids in interior half.	Good to fair in interior half of core.

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-7 in carbonated layer along exterior. 10-15 below.	25-30	None	Some transverse along exterior. Few random below.	1.0-6.0 from exterior surface
Interior 35 mm	7-20	25-30	None	Few to some random throughout section	Spotty to 10.0 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Very low amount of ettringite deposits lining air-voids in interior 1/3 concrete	None	None

TABLE VII

JOB NO. C-6374-16

CORE ID. B33-4

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray to light brown gray, very hard, and light to very light scaled	Broken surface	Small patches of $CaCO_3$ on exterior surface. Thin layer of $CaCO_3$ covering interior surface	No large cracks. Very few small longitudinal cracks in exterior 6-13 mm.

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Hard with few fairly hard areas. Fairly hard to fairly soft in buff colored areas.	Patches of buff exterior 13mm. Medium gray below.	Moderate	Very strong	1-2.	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-7 in carbonated layer along exterior. 7-15 below.	15-20	None	Very few random throughout section.	Spotty to 25.0 mm from exterior surface
Interior 35 mm	10-15	15-20	None	None	0.5-8.0 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
None	None	None

TABLE VIII

JOB NO. C-6374-16

CORE ID. B36-4

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray to light gray, and very light to lightly scaled to rough intact surface	Broken surface	Small patches of $CaCO_3$ on exterior surface. Medium brown to dark brown soil debris and air-voids lined with $CaCO_3$ and ettringite deposits on interior surface	No large cracks. One small longitudinal crack in exterior 37 mm

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Very hard to hard. Fairly hard to fairly soft in buff colored areas.	Patches of buff exterior 15 mm. Medium gray below.	Moderately low	Very strong	2-3.	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-10 in carbonated layer along exterior. 7-15 below.	15-22	None	Very few random throughout section.	0.0-6.0 mm from exterior surface
Interior 35 mm	15-20	20-25	None	Very few random throughout section	0.0-0.5 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
None	None	Some air-voids with calcium hydroxide deposits through section

TABLE IX

JOB NO. C-6374-16

CORE ID. B40-3

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray, very hard, and rough intact surface	Broken surface	Patches of $CaCO_3$ and in air-voids on interior surface	No large cracks. One small longitudinal crack in exterior 15 mm.

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Very hard with few areas. Hard to fairly soft in buff colored areas.	Patches of buff exterior 11 mm. Medium gray below.	Moderately low	Very strong	3-4	Good to fair

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-10 in carbonated layer along exterior. 10-20 below.	20-25	None	Few longitudinal in exterior 5 mm.	0.5-4.0 mm from exterior surface and along small longitudinal crack
Interior 35 mm	15-20	20-25	None	Very few random throughout section	0.0-0.5 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Very low amount of ettringite deposits in air-voids in interior 1/3 of concrete	None	Very low amount of ettringite deposits in air-voids throughout section

TABLE X

JOB NO. C-6374-16

CORE ID. C9-2

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Mottled medium gray to dark gray to medium brown gray, very hard to hard, and moderately scaled	Broken surface	Exterior surface covered with $CaCO_3$ Patch of rust colored deposit	None

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Hard to very hard	Patches of buff exterior 16 mm. Medium gray below.	Moderately low	Very strong	2-3	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-5 in carbonated layer along exterior. 7-15 below.	20-25	None	Few mostly longitudinal throughout section	0.0-3.0 mm from exterior surface
Interior 35 mm	10-20	15-20	None	None	0.0 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Very low amount of ettringite and calcium hydroxide deposits in air voids in exterior and interior areas	Very low amount of ettringite and calcium hydroxide deposits in air-voids below carbonated layer	None

TABLE XI

JOB NO. C-6374-16

CORE ID. C25-1

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray to buff, very hard to hard, and rough intact surface to very lightly scaled	Broken surface	Small patch of rust deposits on side of core at exterior surface. Patch of $CaCO_3$ along edge of core at interior surface.	No large cracks. One small longitudinal crack and transverse cracks in exterior 15 mm.

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Very hard with few hard areas. Fairly soft areas in buff colored areas	Patches of buff exterior 13 mm. Medium gray below.	Moderate	Very strong	2-4	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-10 in carbonated layer along exterior. 10-20 below.	15-25	None	Few longitudinal exterior 1.5-4 mm	0.0-6.0 mm from exterior surface
Interior 35 mm	10-20	20-25	None	Trace random throughout section	0.5-4.0 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
None	None	None

TABLE XII

JOB NO. C-6374-16

CORE ID. C33-3

PETROGRAPHIC EXAMINATION OF CONCRETE CORE SPECIMEN
ASTM C856-14

Physical Description of Concrete

Exterior Surface	Interior Surface	Surface Deposits/Coatings	Cracks
Medium gray with buff, very hard, and lightly with spalled area on edge of core to rough intact surface	Broken surface	Few patches of $CaCO_3$ on exterior surface	No large cracks. Trace of small longitudinal cracks in exterior 5 mm

Physical Properties of Concrete

Paste Hardness	Paste Color	Paste Volume	Paste-Aggregate Bond	Air Content%	Consolidation
Very hard. Few soft areas in buff colored areas	Patches of buff exterior 9 mm. Medium gray below.	Moderately low	Very strong	2-3	Good

Mineralogical Properties of Cementitious Paste

Location	Unhydrated Cement, %	Calcium Hydroxide, %	Fly Ash. %	Microcracks	Depth of Carbonation
Exterior 25 mm	<1-15 in carbonated layer along exterior. 10-20 below.	20-25	None	Trace longitudinal along exterior	2.0-9.0 mm from exterior surface
Interior 35 mm	15-20	20-25	None	Trace random throughout section	0.0 mm from interior surface

Secondary Deposits

Concrete Sections	Exterior Thin Section	Interior Thin Section
Ettringite deposits lining/filling air-voids throughout core	Low amount of ttringite deposits in air-'oids below carbonated layer	Low amount of ettringite deposits in air-voids throughout section

PHOTOGRAPHS OF AS-RECEIVED SAMPLE

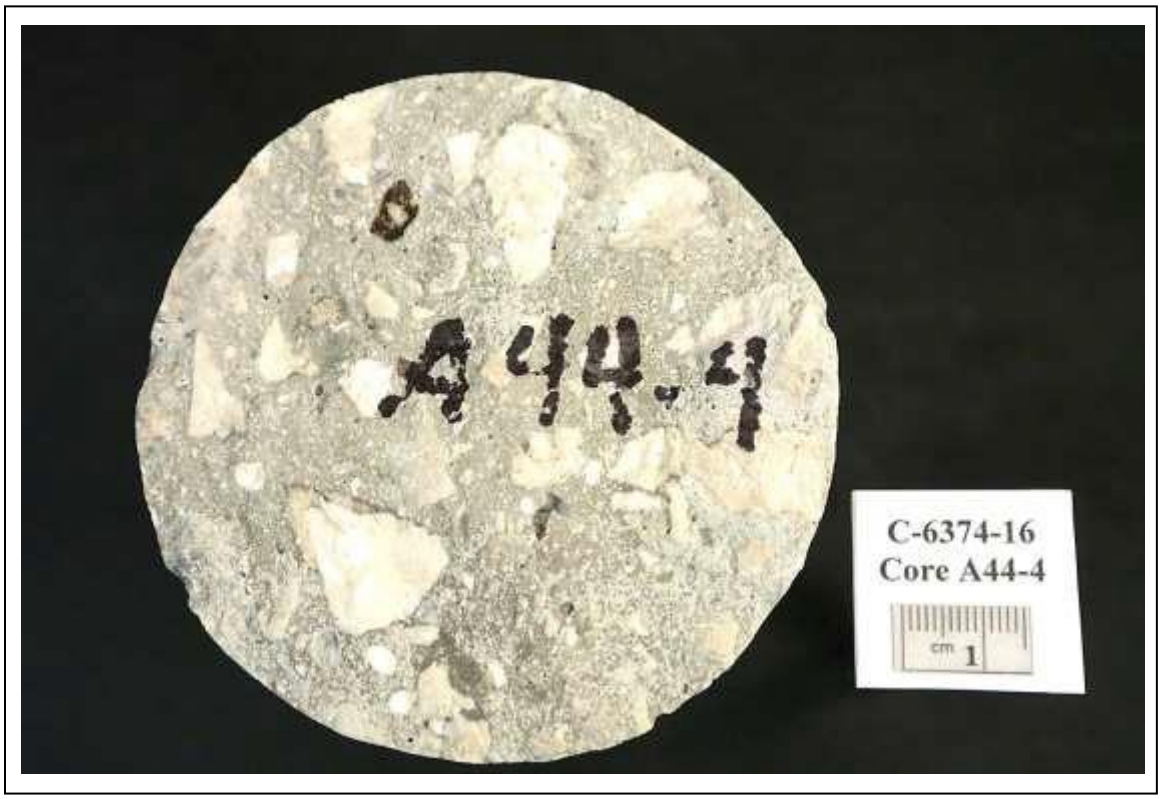
CORE A44-4 (scale in cm)

PHOTO NO. 1 – Exterior surface of core

PHOTO NO. 2 – Side of core. Exterior surface at left of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE A44-4 (scale in cm)

PHOTO NO. 3 – Interior surface of core



PHOTOGRAPH OF LAPPED SECTION
CORE A44-4 (scale in cm)

PHOTO NO. 4 – Exterior surface at left of photo

PHOTOGRAPH OF LAPPED SECTION
CORE A44-4 (scale in cm)

PHOTO NO. 4 – Exterior surface at left of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE B10-1 (scale in cm)

PHOTO NO. 5 – Exterior surface of core

PHOTO NO. 6 – Side of core. Exterior surface at left of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE B10-1 (scale in cm)

PHOTO NO. 7 – Interior surface of core

PHOTOGRAPH OF LAPPED SECTION
CORE B10-1 (scale in cm)

PHOTO NO. 8 – Exterior surface at left of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE B19-1 (scale in cm)

PHOTO NO. 9 – Exterior surface of core

PHOTO NO. 10 – Side of core. Exterior surface at right of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE B19-1 (scale in cm)

PHOTO NO. 11 – Interior surface of core

PHOTOGRAPH OF LAPPED SECTION
CORE B19-1 (scale in cm)

PHOTO NO. 12 – Exterior surface at right of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE B25-1 (scale in cm)

PHOTO NO. 13 – Exterior surface of core

PHOTO NO. 14 – Side of core. Exterior surface at right of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE B25-1 (scale in cm)

PHOTO NO. 15 – Interior surface of core

PHOTOGRAPH OF LAPPED SECTION
CORE B25-1 (scale in cm)

PHOTO NO. 16 – Exterior surface at right of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE B33-4 (scale in cm)

PHOTO NO. 17 – Exterior surface of core

PHOTO NO. 18 – Side of core. Exterior surface at left of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE B33-4 (scale in cm)

PHOTO NO. 19 – Interior surface of core

PHOTOGRAPH OF LAPPED SECTION
CORE B33-4 (scale in cm)

PHOTO NO. 20 – Exterior surface at left of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE B36-4 (scale in cm)

PHOTO NO. 21 – Exterior surface of core

PHOTO NO. 22 – Side of core. Exterior surface at left of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE B36-4 (scale in cm)

PHOTO NO. 23 – Interior surface of core

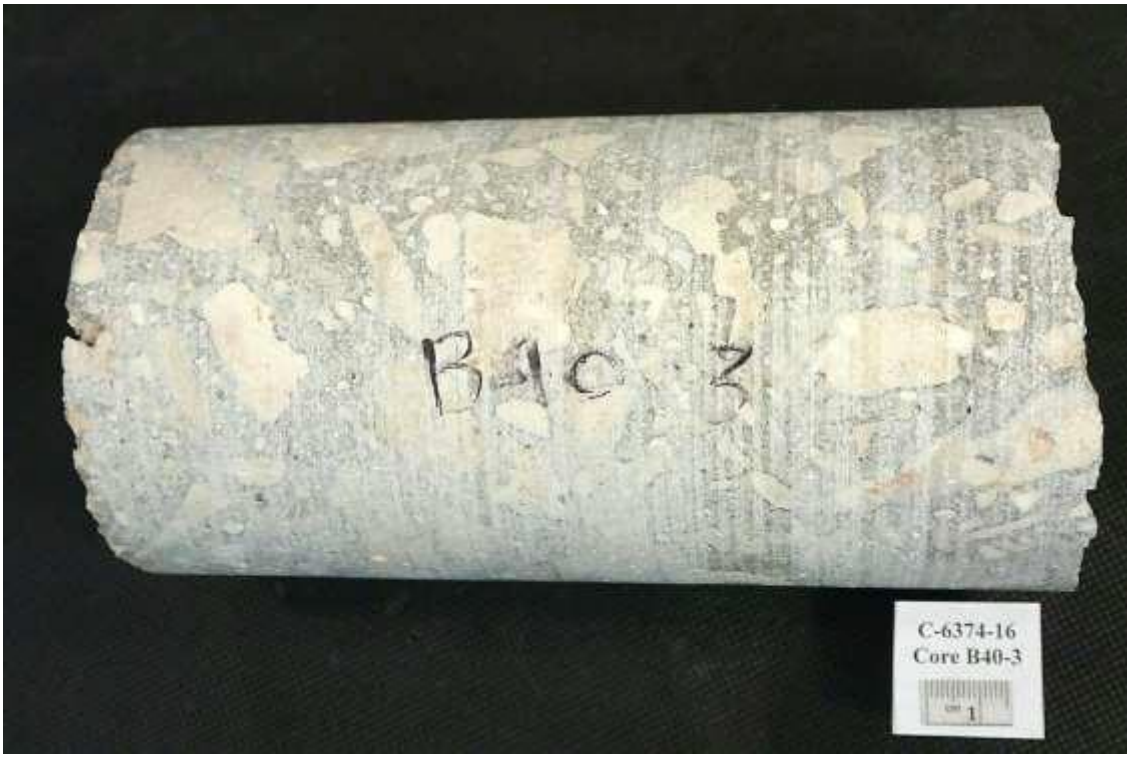
PHOTOGRAPH OF LAPPED SECTION
CORE B36-4 (scale in cm)

PHOTO NO. 24 – Exterior surface at left of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE B40-3 (scale in cm)

PHOTO NO. 25 – Exterior surface of core

PHOTO NO. 26 – Side of core. Exterior surface at left of photo.



PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE B40-3 (scale in cm)

PHOTO NO. 27– Interior surface of core

PHOTOGRAPH OF LAPPED SECTION
CORE B40-3 (scale in cm)

PHOTO NO. 28 – Exterior surface at left of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE C9-2 (scale in cm)

PHOTO NO. 29 – Exterior surface of core

PHOTO NO. 30 – Side of core. Exterior surface at right of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE 9-2 (scale in cm)

PHOTO NO. 31 – Interior surface of core

PHOTOGRAPH OF LAPPED SECTION
CORE C9-2 (scale in cm)

PHOTO NO. 32 – Exterior surface at right of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE C25-1 (scale in cm)

PHOTO NO. 33 – Exterior surface of core

PHOTO NO. 34 – Side of core. Exterior surface at left of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE C25-1 (scale in cm)

PHOTO NO. 35 – Interior of core

PHOTOGRAPH OF LAPPED SECTION
CORE C25-1 (scale in cm)

PHOTO NO. 36 – Exterior surface at left of photo

PHOTOGRAPHS OF AS-RECEIVED SAMPLE
CORE C33-3 (scale in cm)

PHOTO NO. 37 – Exterior surface of core

PHOTO NO. 38 – Side of core. Exterior surface at left of photo.

PHOTOGRAPH OF AS-RECEIVED SAMPLE
CORE C33-3 (scale in cm)

PHOTO NO. 39 – Interior of core

PHOTOGRAPH OF LAPPED SECTION
CORE C33-3 (scale in cm)

PHOTO NO. 40 – Exterior surface at left of photo

C-6374-16
Core C33-3
cm 1