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Chloride Diffusivity and Resistivity of Cured and Mature Binary/Ternary Concrete
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Units Conversion Page

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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16. Abstract

This investigation was performed to gain additional insight into the long-term durability of reinforced concrete structures. The chloride diffusion of concrete with supplementary cementitious materials is known to decrease with time, eventually reaching a stable value. This study aims to better understand when the chloride diffusion rate transitions from decreasing values to a stable minimum. The bulk diffusion tests and the rapid migration tests were carried out on concrete specimens that have been curing for several years (and that were characterized also at an earlier age). There are several reasons why the apparent diffusion (D_{app}) values do not match with D_{nssd}, including the fact that D_{nssd} specimens are immersed all the time and exposed indoors to lab room temperature, whereas the field structures are exposed to temperature and humidity changes depending on time of the day, seasonal changes, and the elevation within the structure, which results in moisture variations within the concrete.

The chloride diffusion coefficients (D_{nssm} and D_{nssd}) of mature concrete were obtained. For some concrete compositions, D_{app} values were calculated from chloride profiles obtained on cored specimens exposed to simulated field conditions for approximately 4 years. The D_{app} values were obtained only on a subset of the concrete mixtures investigated. Matured high performance concrete cylinders were available that were prepared as part of earlier projects. Most of these concrete cylinders have been curing for more than 4 years. The D_{nssd} were obtained after exposure for 10 to 12 months in 16.5% NaCl solution (i.e., bulk diffusion test). The D_{nssm} values were obtained from rapid migration tests per the Nordtest NT Build 492 method. The D_{nssd} and D_{nssm} values were correlated to the resistivity values measured on companion cylinders (if available) or to the resistivity values measured on the cylinders before starting the diffusion tests. Four concrete compositions were prepared in 2016 as part of this project. The sorptivity, resistivity, porosity, D_{nssd}, and D_{nssm} were characterized several times over the duration of the project.

17. Key Word	18. Distribution Statement		
Apparent diffusion coefficient (D_{app}), non-steady state diffusion (D_{nssd}), non-steady state migration (D_{nssm}), resistivity, sorptivity, binary and ternary mixes			
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 273	22. Price

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Executive Summary

The apparent diffusion coefficient (D_{app}) that is calculated from profiles obtained from field cores – e.g., from structures partially immersed – depends on the elevation from where the cores are obtained, the structure location, and the environment surrounding the structure. These D_{app} values are usually compared to the non-steady-state migration coefficient (D_{nssm}) usually obtained by rapid migration test or are compared to the non-steady-state diffusion coefficient (D_{nssd}) obtained from bulk diffusion tests. Up to one order of magnitude difference is often observed, with D_{app} typically being the smaller reported value. For concrete with supplementary cementitious materials, these three diffusion values are known to decrease with time. The difference between these coefficients could be partially explained by the age at which the concrete is tested. Moreover, as concrete ages (matures), the diffusion rate of change gradually slows down significantly. This study aims to better understand when the rate of change of the diffusion coefficient transitions from a significant reduction to negligible reduction. Bulk diffusion tests and rapid migration tests were performed on concrete specimens that have been curing for several years (and that were characterized also at an earlier age). The recently obtained values will be compared to the previous results.

There are several reasons why the D_{app} values do not match with D_{nssd}. One factor has to do with the fact that D_{nssd} values are obtained from bulk diffusion specimens that are immersed all the time exposed indoors to lab room temperature in a given chloride concentration (e.g., 16.5%). The D_{app} values from cores obtained from the field, the structures are exposed to temperature and humidity changes depending on time of the day, the season and the elevation within the structure. The environment in the field affects both the moisture within the concrete and also the chloride surface concentration.

As part of this project, tests that generated diffusion coefficients (D_{nssm} and D_{nssd}) were measured on mature concrete. For some concrete compositions, D_{app} values were calculated from chloride profiles obtained from cored specimens exposed to simulated tidal or splash for approximately 4 years. The D_{app} values were obtained only on a subset of the concrete mixtures investigated (DCL mixes). Mature high-performance concrete cylinders were available that were prepared as part of completed projects for FDOT. D_{nssd} was obtained after exposure for 10 to 12 months in the solution of interest (i.e., bulk diffusion test). The D_{nssm} value was obtained from rapid migration tests as per the Nordtest NT Build 492 method. The D_{nssd} and D_{nssm} values were correlated to the resistivity values measured on companion cylinders (if available) or to the resistivity values measured on the cylinders before starting the diffusion tests.

The diffusion coefficient of chloride into concrete is one of the main factors that determines how long it would take before chloride reaches the rebar depth at concentrations exceeding the chloride threshold. The time-dependency of chloride diffusion coefficients is still not well understood. The conducted research addressed this knowledge gap. A better understanding of the time-dependency of chloride diffusion has been gained. This knowledge can then be included in future versions of FDOT models used for estimating the time to corrosion. The updated models would provide guidance as to when a more careful inspection becomes necessary (under ideal conditions). A better correlation between lab test methods (D_{nssm} and D_{nssd}) and D_{app} from field-collected values (in this project by obtaining D_{app} from simulated field specimen) could assist in predicting future performance from early characterization.

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Chapter 1 – Introduction

The motivation for this study was to better understand and compare apparent diffusion coefficients (D_{app}) vs. non-steady-state diffusion (D_{nssd}) and D_{app} vs. non-steady-state migration (D_{nssm}). The D_{nssd} and D_{nssm} values were obtained by testing samples that are mature and recently cast. Samples exposed to field simulated conditions were used to determine the D_{app}. The following paragraphs briefly describe the approach implemented, and a later section describes the test methods used in this study.

Samples exposed to field-simulated conditions were cored, the cores sliced, and the chloride profiles obtained. The samples were cored after 54 months of exposure. These samples had been cored previously, and the results up to 24 months were reported [1]. Profiles after approximately 30 months of exposure were available (not previously reported) and are included in this report. The samples have been exposed to tidal and splash environments using seawater. The partially immersed samples were placed on a barge located at the Intracoastal Waterway.

The other samples' geometry was concrete cylinders. A portion of the tests was performed on mature concrete cylinders; there are three sets of samples. (1) Concrete cylinders prepared between October 2010 and February 2011 (12 compositions [2]) were immersed in calcium hydroxide all the time or immersed for at least one year in calcium hydroxide and then immersed in tap water. (2) Concrete cylinders prepared between September 2011 and February 2012 (11 compositions [1]) were exposed to high humidity for at least four and a half years prior to the start of this project. (3) Concrete slices obtained from cores (coring took place in 2012) at fender piles of the Key Royale bridge [3]. Concrete cylinders were prepared during April 2016 and during August 2016 (four additional concrete compositions).

A number of concrete cylinders were subjected to bulk-diffusion testing, concrete surface resistivity, rapid migration tests, and water absorption (sorptivity test), and a few cylinder slices were subjected to porosity testing. Correlations between some of these tests were obtained, and the results are presented in the discussion chapter. A brief description is included below for each of these tests. A more detailed description of the water absorption (sorptivity) test is included in Appendix A.

A recent report for FDOT [1], titled "Diffusion vs. Concentration of Chloride Ions in Concrete", included a literature review that introduces many of concepts related to diffusion of chloride into concrete. Rather than reproducing these concepts, the reader is referred to Chapter 2 [1] for a review of related topics.

This project used older samples (that were left over) from projects BDK79-977-02 [2] and BDK79-977-03 [1]. Additional concrete cylinders (or slices of cylinders) that were part of a resistivity round robin were also used for rapid migration testing. Sorptivity testing as per ASTM C1585-04 [4] was not performed in the studies listed above. Sorptivity testing was performed on a large number of mature concrete samples, at concrete ages significantly older than is customary. Sorptivity testing was also performed over time on selected concrete cylinders of the recently prepared concrete compositions.

In BDV79-977-03, the diffusion coefficient obtained after a bulk diffusion test was named apparent diffusivity (D_{app}). In this study, the nomenclature has been changed to non-steady-state diffusion (D_{nssd}). In this report, the term D_{app} is used for the chloride diffusivities obtained from samples exposed to field-simulated conditions.

1.1 Test methods used in this project

The following test methods and standards were performed as prescribed. However, in some instances they were slightly modified. For example, the duration for bulk diffusion test ranged from 6 to 12 months. For porosity and sorptivity testing the oven temperature was set to 70°C (and lasted longer) instead of the usual 105 °C. This was done to minimize microstructure changes to the concrete.

1.1.1 Surface resistivity measurement

Florida Department of Transportation (FDOT), Florida method of test for concrete resistivity as an electrical indicator of its permeability, FM5-578; January 27, 2004 [5].

American Association of State Highway Transportation Officials, Standard test method for surface resistivity indication of concrete's ability to resist chloride ion penetration. ASSHTO Designation: TP95-11, AASHTO Provisional Standards, Washington D.C.; June 2010[6].

1.1.2 Density, absorption, and voids in hardened concrete

American Society for Testing of Materials, Standard test method for density, absorption, and voids in hardened concrete, ASTM C 642-06, Annual Book of ASTM Standards, 2006[7]. This test was used to determine the concrete porosity.

1.1.3 Rapid migration test (RMT)

Nordtest Method, Chloride migration coefficient from non-steady-state migration experiment, NT Build 492, Nordtest, Espoo, Finland, Proj. 1388-98, 1999 [8].

1.1.4 Bulk diffusion

Concrete, Hardened: Accelerated Chloride Penetration (Nordtest Method NT Build 443) [9]

Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixture by Bulk Diffusion (ASTM C1556-04) [10]

The Nordtest bulk diffusion test is a modification of another test developed to address the deficiencies of the ASTM C1556 [10] salt ponding test to measure diffusion. The test was established as the Nordtest bulk diffusion test (NT Build 443) [9] and consists of calculating the diffusion without taking into account the effects of absorptions and wicking. The test consists of having cylindrical specimens cured for 28 days (sometimes the curing time is longer), cut in half and coated in a polymer/epoxy; then only one face is exposed to a 16.5% NaCl by wt% solution for a period of time of at least 35 days. This exposure is done in order to allow natural transport of the chloride ions through one saturated surface. The projects performed by FDOT-SMO/FAU have a typical duration in the chloride solution of one year immersed; also, the chloride concentration varies, e.g., 16.5% or 3% NaCl. The duration that samples were immersed as part of this project ranged from 6 months to one year. After this exposure period is completed, the specimens are removed, and the epoxy coating cut off. The concrete sample is then sliced and pulverized. The chloride concentration analyses are performed with the powder obtained at different depths of the specimens. The chloride profile can be obtained and the D_{nssd} calculated.

1.1.5 Chloride content analysis

The chloride content of both concrete powder and atmospheric chloride deposition are obtained in accordance with FDOT method with a slight modification: “Florida Method of Test for Determining Low-Level of Chloride in Concrete and Raw Materials, FM5-516” [11].

1.1.6 Sorptivity

Sorptivity is a term used for water ingress into concrete pores under unsaturated conditions (50 to 70% internal relative humidity), which is similar to the RH found near the surface in some field structures according to ASTM C1585-04 [4].

Chapter 2 – Experimental

2.1 Older specimens

The concrete compositions used to prepare the mature concrete cylinders are presented in Table 1 and Table 2. Both tables include the casting date. The cylinders are 10 cm diameter by 20 cm long (i.e., 4” × 8”).

Table 1. Mixture design of A-L specimens. A-L mixes. Cementitious component is 390 kg/m^3. W/cm is 0.41. Specimens prepared between Oct. 2010 and Feb. 2011.

Mix	Cast date	Coarse agg.	Cement kg/m^3	Fly Ash kg/m^3	Slag kg/m^3	Fine agg. kg/m3	Coarse agg. kg/m^3	FA %	Slag %
A	Nov. 8, 2010	Limestone	312	78	-	777	930	20	-
Ai	Oct. 13, 2010	Limestone	312	78	-	777	930	20	
J	Jan. 20, 2011	Limestone	273	117	-	739	951	30	-
B	Nov. 8, 2010	Limestone	234	156	-	712	916	40	-
Bi	Oct. 13, 2010	Limestone	234	156	-	712	916	40	
D	Dec. 7, 2010	Limestone	195	195	-	720	927	50	-
E	Dec. 7, 2010	Limestone	195	-	195	739	951	-	50
F	Dec. 20, 2010	Limestone	117	-	273	736	947	-	70
I	Dec. 20, 2010	Limestone	117	39	234	732	943	10	60
H	Jan. 20, 2011	Limestone	117	78	156	732	942	20	50
C	Jan. 26, 2011	Granite	312	78	-	736	1,061	20	-
K	Feb. 24, 2011	Granite	273	117	-	720	1,038	30	-
L	Feb. 24, 2011	Granite	195	195	-	709	1,023	50	-
G	Jan. 26, 2011	Granite	195	-	195	739	1,067	-	50

Table 2. DCL specimens concrete mix detail

Mix	Cast Date	Cementitious Content (kg/m^3)	Cement Content (kg/m^3)	20% FA (kg/m^3)	8%SF (kg/m^3)	50% Slag (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)	w/cm ratio
DCL1	Dec. 7, 2011	390	312	78	0	0	653	1,062	0.35
DCL2	Sep. 22, 2011	390	312	78	0	0	721	949	0.41
DCL3	Oct. 19, 2011	390	312	78	0	0	697	918	0.47
DCL4	Dec. 21, 2011	390	312	78	31	0	653	1,062	0.35
DCL5	Dec. 21, 2011	390	312	78	31	0	721	949	0.41
DCL6	Oct. 26, 2011	390	312	78	31	0	697	918	0.47
DCL7	Dec. 14, 2011	390	195	0	0	195	653	1,062	0.35
DCL8	Nov. 22, 2011	390	195	0	0	195	721	949	0.41
DCL9	Nov. 2, 2011	390	195	0	0	195	697	918	0.47
DCL10	Sep. 28, 2011	335	268	67	0	0	765	1,007	0.41
DCL10a	Oct. 12, 2011	335	268	67	0	0	765	1,007	0.41
DCL10b	Nov. 16, 2011	335	268	67	0	0	765	1,007	0.41
DCL11	Nov. 9, 2011	279	223	56	0	0	765	1,009	0.41
FA10	May 15, 2012	390	351	39	0	0	720	950	0.41

At the beginning of this project, there were seven concrete cylinders per mix for mixes A to L listed in Table 1. Three cylinders were being exposed at room temperature (RT) at SMO immersed in limewater, two cylinders immersed in RT tap water at FAU (these specimens spent some time in the elevated temperature room at an early age), and two cylinders were immersed in tap water while in an elevated temperature (ET) room (35 to 40 °C). However, one cylinder per mix in the ET had a thermocouple embedded in it. The top half of each cylinder was cut into two 5 cm slices and these were used for RMT and sorptivity tests, respectively. One of the cylinders per mix immersed in water at RT was cut into four slices 5 cm long each. The top slice was used for water absorption, the two middle slices for RMT and the bottom was planned for porosity, but not always performed.

For DCL mixes, the number of cylinders available per mix varied per mix. There were 11 concrete cylinders for mixes DCL4 to DCL9; and there were 8 concrete cylinders for mixes DCL1, 10a, 10b and 11. A smaller number of cylinders were available for mix DCL2 (4 concrete cylinders), and there were 7 cylinders for mixes DCL3 and DCL10. All DCL concrete cylinders were being exposed to high humidity and RT, but some had spent a short time in ET shortly after casting. One of the cylinders per mix was cut into four slices 5 cm long each and tested as described in the above paragraph.

2.2 Concrete mixes prepared during 2016

Four different compositions were prepared during 2016. Two compositions were prepared on April 2016 and two compositions were prepared on August 2016. Two batches per concrete mix design were prepared for each composition prepared on April 2016. Concrete with slag (50% cement replacement) was prepared on 4/4/2016; concrete with Fly Ash F (20% cement replacement) was prepared on 4/18/2016. The specimens for this project were 10 cm diameter by 20 cm long (i.e., 4”×8”) cylinders. 66 concrete cylinders were prepared per mix design. The reason for preparing the two batches per mix is that other reinforced concrete specimens were prepared as a part of a parallel project to study corrosion propagation. 12 cylinders per mix were prepared for each mix prepared on August 2016.

Table 3 shows the compositions for the concrete prepared during the spring and summer 2016. (Appendix B contains the detail concrete mix composition and early concrete properties for each mix). The slump was somewhat low on the SL samples, and it is attributed to the aggregates being left over the weekend for use on Monday when the concrete was prepared. The aggregate might have lost some of its moisture even if the bucket covers were in place. Cylinders 1 to 16 for each batch remained at FDOT-SMO, the remaining cylinders were transported to FAU-SeaTech for the indicated testing.

Table 3. Concrete mix detail for specimens prepared spring and summer 2016.

Mix	Cast Date	Cementititous Content	Cement Content	20% FA	8%SF	50% Slag	Fine agg.	Coarse agg.	w/cm ratio
		(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	
SL	Apr. 4, 2016	390	195		0	195	782	1009	0.41
FAM	Apr. 18, 2016	390	312	78	0	0	967	833	0.41
T1	Aug. 19, 2016	390	117.5	78.3	0	195.18	761	1009	0.41
T2	Aug. 19, 2016	390	289	70	31	0	790	1046	0.37

Table 4 contains the compression strength results at 28 days and Table 5 shows the initial chloride amounts determined via FDOT method on the concrete mixes prepared during 2016.

Table 4. Compressive strength

		Compressive Strength (psi)			
Mix ID	Cast ID	Specimen 1	Specimen 2	Specimen 3	Avg Comp
SL1	2016-04-003	9453	9691	9441	9528.3
SL2	2016-04-002	8866	9169	9069	9034.7
FA1	2016-04-017	6385	5959	6212	6185.3
FA2	2016-04-018	5381	5060	5031	5157.3
T1	2016-08-009	4240	4448	4335	4340
T2	2016-08-010	3720	3689	3522	3640

Table 5. Initial Chloride Concentration on concrete prepared in 2016

	Average	
	ppm	lb/yd^3
Sample: Mix SL1, Cast Date: Apr. 4, 2016. Slump: 1", Air:	37.4	0.141
4.2%, Mix Temp: 66 Degrees F. Slag in mix.		
Sample: Mix SL2, Cast Date: Apr. 4, 2016. Slump: 0.75",	34.1	0.130
Air: 3.1%, Mix Temp: 65 degrees F. Slag in mix.		
Sample: Mix FA1, Cast Date: Apr. 18, 2016. Slump: 1.75",	29.6	0.109
Air: 8.5%, Mix Temp: 65 Degrees F. No Slag in Mix.		
Sample: Mix FA2, Cast Date: Apr. 18, 2016. Slump: 5",	36.0	0.126
Air: 10%, Mix Temp: 65 Degrees F. No Slag in Mix.		
Sample: Mix T1, Cast Date: Aug. 16, 2016. Slump: 6.5",	26.2	0.092
Air: 12.4%, Mix Temp: 74 Degrees F.		
Sample: Mix T2, Cast Date: Aug. 16, 2016. Slump: 8",	44.7	0.157
Air: 20%, Mix Temp:77 Degrees F.		

2.3 Testing on mature concrete cylinders

A number of concrete cylinders (cured for several years) were selected for bulk diffusion test, but only the bottom half was used for bulk diffusion. The top half of the concrete cylinder was cut in half, the top slice was used for the sorptivity test. The second 5 cm tall slice was used for rapid migration test (RMT) as per NT Build 492 [8] to determine D_{nssm}. Figure 1 shows a diagram describing the cuts (a wet concrete diamond saw was used).

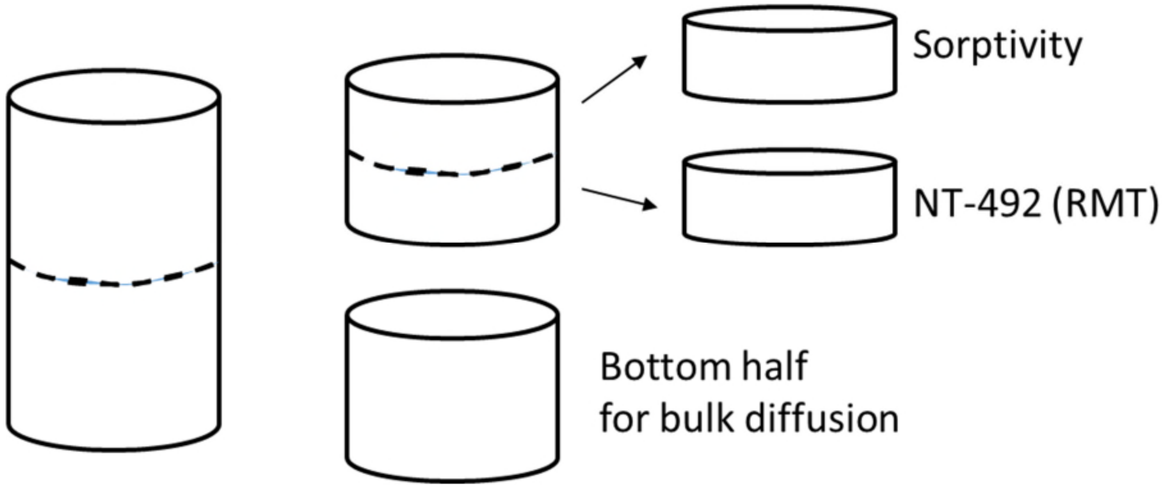


Figure 1. Diagram showing how a concrete cylinder was cut.

2.4 Testing on concrete cylinders prepared in 2016.

A number of concrete cylinders were selected for bulk diffusion, a similar procedure to that described above was performed. The bottom half was used for bulk diffusion and the top half was cut in half. The top slice was used for the sorptivity test. The second 5 cm tall slice was used for rapid migration test (RMT) as per NT Build 492 [8].

2.5 Tests performed on mature and recently prepared concrete cylinders

2.5.1 Bulk diffusion

Samples selected for bulk diffusion were immersed in 16.5% NaCl, the duration of the exposure varied and ranged from 6 months to one year. The exposure duration for each sample tested for bulk diffusion is presented in this section.

Table 6. SL samples subjected to bulk diffusion

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
SL 1-4	56	Feb. 10, 2017	8.5
SL 1-5	56	May 30, 2017	12.0
SL 1-6	56	May 30, 2017	12.0
SL 1-7	56	Feb. 10, 2017	8.5
SL 1-8	150	Aug. 7, 2017	11.2
SL 1-9	150	Aug. 7, 2017	11.2
SL 2-4	56	Dec. 15, 2016	6.5
SL 2-5	56	Feb. 10, 2017	8.5
SL 2-6	56	Feb. 10, 2017	8.5
SL 2-7	56	Dec. 15, 2016	6.5
SL 2-8	150	Aug. 7, 2017	11.2
SL 2-9	150	Aug. 7, 2017	11.2

The bulk diffusion test started as early as 56 days of age on SL and FA specimens. Twelve cylinders per mix were tested for SL and FA samples. Table 6 and Table 7 lists the cylinder labels, the age at which the samples were immersed, the removal date and the exposure duration for SL and FA specimens, respectively. Table 8 lists similar information for T1 and T2 specimens selected for bulk diffusion testing. Five cylinders per mix were tested for T1 and T2 groups.

Table 7. FA samples subjected to bulk diffusion

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
FA 1-4	56	Feb. 10, 2017	8.0
FA 1-5	56	Jun. 6, 2017	11.8
FA 1-6	56	Feb. 10, 2017	8.0
FA 1-7	56	Dec. 15, 2016	6.1
FA 1-8	150	Sep. 15, 2017	12.0
FA 1-9	150	Sep. 15, 2017	12.0
FA 2-4	56	Dec. 15, 2016	6.1
FA 2-5	56	Feb. 10, 2017	8.0
FA 2-6	56	Jun. 6, 2017	11.8
FA 2-7	56	Feb. 10, 2017	8.0
FA 2-8	150	Sep. 15, 2017	12.0
FA 2-9	150	Sep. 15, 2017	12.0

Table 8. T1 and T2 samples subjected to bulk diffusion

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
T1-A	28	Sep. 14, 2017	12.0
T1-B	28	Sep. 14, 2017	12.0
T1-C	28	Sep. 14, 2017	12.0
T 1-4	180	Nov. 16, 2017	9
T 1-5	180	Nov. 16, 2017	9
T2-A	28	Sep. 14, 2017	12.0
T2-B	28	Sep. 14, 2017	12.0
T2-C	28	Sep. 14, 2017	12.0
T 2-4	180	Nov. 16, 2017	9
T 2-5	180	Nov. 16, 2017	9

The bottom half of four or five cylinders per mix (for mixes A to L) were used for bulk diffusion testing. Three cylinders corresponded to those exposed all the time at SMO immersed in calcium hydroxide and one or two of the cylinders were exposed immersed in tap water while in the elevated temperature room at FAU SeaTech. Table 9 lists the samples tested for bulk diffusion, the age at immersion, removal date and for how long the samples were immersed. The samples at immersion were at least 1950 days of age.

Table 9. A and L half-cylinder samples subjected to bulk diffusion

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
Ai 1	2,156	Aug 7, 2017	11.0
Ai 2	2,156	Aug 7, 2017	11.0
Ai 3	2,156	Aug 7, 2017	11.0
FAA 23	2,142	Jun 19, 2017	9.8
FAA 28	2,142	Oct 2, 2017	13.3
A 1	2,115	Jun 19, 2017	9.8
A 2	2,115	Jun 19, 2017	9.8
A 3	2,115	Jun 19, 2017	9.8
FA 28	2,116	Jun 19, 2017	9.8
FA 23	2,116	Jun 19, 2017	9.8
Bi 1	2,086	Feb 10, 2017	7.5
Bi 2	2,086	Feb 10, 2017	7.5
Bi 3	2,086	Feb 10, 2017	7.5
FBB 22	2,230	Oct. 2, 2017	10.4
FBB 23	2,146	Jul. 24, 2017	10.8
FBB 28	2,230	Oct. 2, 2017	10.4
B 1	2,073	Jun 12, 2017	11.0
B 2	2,073	Jun 12, 2017	11.0
B 3	2,073	Jun 12, 2017	11.0
FB 23	2,120	Jul. 24, 2017	10.8
FB 29	2,120	Jul. 24, 2017	10.8
C 1	2,036	Jun 27, 2017	10.1
C 2	2,036	Jun 27, 2017	10.1
C 3	2,036	Jun 27, 2017	10.1
FC 22	2,056	Sep. 13, 2017	12.0
FC 23	2,056	Sep. 5, 2017	11.8
FC 28	2,056	Sep. 13, 2017	12.0
D 1	2,086	Jun 27, 2017	10.1
D 2	2,086	Jun 27, 2017	10.1
D 3	2,086	Jun 27, 2017	10.1
FD 22	2,091	Jul. 24, 2017	10.8
FD 23	2,260	Nov. 14, 2017	9.0

Table 9. Continues

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
E 1	2,101	Aug. 7, 2017	11.0
E 2	2,101	Aug. 7, 2017	11.0
E 3	2,101	Aug. 7, 2017	11.0
FE 23	2,106	Sep. 5, 2017	11.8
FE 22	2,106	Sep. 5, 2017	11.8
FE 28	2,106	Sep. 5, 2017	11.8
F 1	2,073	Jul. 10, 2017	10.5
F 2	2,073	Jul. 10, 2017	10.5
F 3	2,073	Jul. 10, 2017	10.5
FF 23	2,162	Oct. 2, 2017	10.4
G 1	2,051	Aug. 7, 2017	11.0
G 2	2,051	Aug. 7, 2017	11.0
G 3	2,051	Aug. 7, 2017	11.0
FG 22	2,125	Oct. 2, 2017	10.4
FG 23	2,125	Oct. 2, 2017	10.4
FG 28	2,125	Oct. 2, 2017	10.4
H 1	2,057	Aug. 21, 2017	11.4
H 2	2,057	Aug. 21, 2017	11.4
H 3	2,057	Aug. 21, 2017	11.4
FH 23	2,062	Sep. 13, 2017	12.0
FH 28	2,062	Sep. 13, 2017	12.0
I 1	2,088	Aug. 21, 2017	11.4
I 2	2,088	Aug. 21, 2017	11.4
I 3	2,088	Aug. 21, 2017	11.4
FI 23	2,095	Sep. 14, 2017	12.0
FI 28	2,095	Sep. 14, 2017	12.0
J1	1,987	Feb 10, 2017	7.5
J2	1,987	Feb 10, 2017	7.5
J3	1,987	Feb 10, 2017	7.5
FJ 23	2,064	Sep. 14, 2017	12.0
FJ 28	2,064	Sep. 14, 2017	12.0

Table 9. Continues

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
K1	2,097	Oct. 2, 2017	10.4
K2	2,097	Oct. 2, 2017	10.4
K3	2,097	Oct. 2, 2017	10.4
FK 23	2,096	Oct. 2, 2017	10.4
FK 28	2,096	Oct. 2, 2017	10.4
L 1	2,181	Nov. 14, 2017	9.0
L 2	2,181	Nov. 14, 2017	9.0
L 3	2,181	Nov. 14, 2017	9.0
FL 28	2,181	Nov. 14, 2017	9.0
FL 23	2,181	Nov. 14, 2017	9.0

For most DCL mixes, three cylinders were used for bulk diffusion test. However, in some cases, four cylinders were tested (recall that only the cylinder bottom half is used for bulk diffusion). Table 10 lists the concrete cylinders from DCL mixes subjected to bulk diffusion test, the age at immersion and the exposure duration.

Table 10: Sample age, casting, and immersing date

Sample name	Exposure duration (Month)	Casting date	Immersion date	Removal date	Age at immersing (Year)	Samples
DCL 1	11	12/07/2011	11/22/2016	10/22/2017	5	1, 7, 24
DCL 2	9.4	09/22/2011	2/27/2017	12/11/2017	5.4	2, 7, 23
DCL 3	9.4	10/19/2011	2/28/2017	12/12/2017	5.4	1, 7, 23
DCL 4	11	12/21/2011	11/22/2016	10/22/2017	4.9	1, 7, 27
DCL 5	9.4	12/21/2011	2/20/2017	12/04/2017	5.2	1, 7, 26, 27
DCL 6	9.4	10/26/2011	2/20/2017	12/04/2017	5.3	1, 7, 26, 27
DCL 7	9.4	12/14/2011	2/27/2017	12/11/2017	5.2	1, 7, 26, 27
DCL 8	9.4	11/22/2011	2/27/2017	12/11/2017	5.3	1, 7, 26, 27
DCL 9	9.4	11/02/2011	2/28/2017	12/12/2017	5.3	1, 7, 24
DCL 10b	9	11/16/2011	2/12/2017	11/14/2017	5.2	1, 7, 24
DCL 11	9.4	11/09/2011	2/28/2017	12/12/2017	5.3	1, 7, 24

Additionally (for mixes DC1 to DCL9), half cylinders (bulk diffusion test) had been exposed immersed to low chloride concentration for over 4.5 years. These samples were immersed at an age of 200 days. For these half cylinders, initially, an aqueous NaCl solution was prepared with 6.1 grams of NaCl per liter (i.e., 0.6% NaCl or approx. 0.1 M NaCl). The solution was replaced once a week during the first three months. After that, the NaCl liquid was replaced once every two weeks due to the concentration remaining almost constant within those two weeks for the next 20 months. However, the chloride concentration was not maintained well in between projects, which might then affect to some extent the chloride profiles obtained.

Bulk diffusion testing was done on cylinders at an intermediate age for specimens prepared with A to L mixes and DCL mixes. Appendix C contains tables that describe the age at which the cylinders were immersed and for how long each sample was immersed in either 16.5% NaCl or 3% NaCl. The discussion section contains the D_{nssd} values for these specimens. Additional D_{nssd} values for samples immersed 28 to 56 days after casting after normal cure (i.e., fog room curing) are also included in the discussion chapter; the D_{nssd} values have been reported previously [2].

Upon completion of the exposure period, the samples subjected to bulk diffusion were removed, vertical cuts were made to remove the epoxy, then, the sample was sliced (see the following paragraph), and seven or eight layers were obtained. Each concrete slice was pulverized, and then, chloride titrations per FDOT method were performed. The chloride profiles were obtained for each of these samples. The chloride profiles were plotted, and then, the D_{nssd} calculated using all layers and with one layer removed.

For the A to L specimens and DCL specimens tested for bulk diffusion at 28 or 56 days of age and immersed for a year, the nominal slice thickness was 0.635 cm. For the samples immersed at intermediate age (i.e., after 700 for DCL samples and more than 1,600 days for A to L samples), 0.152 cm was milled off the first layer, the second slice was 0.483 cm thick, and subsequent slices were 0.635 cm. The samples subjected to bulk diffusion testing as part of this project were sliced using a lapidary blade. The thickness of each slice was 0.4 cm.

2.5.2 Rapid migration test (RMT)

The RMT test was performed according to NT Build 492. In this experiment, the concrete was preconditioned in a water vacuum. As indicated above, only one slice was available for cylinders from which the bottom half was used for bulk diffusion. Additional cylinders were available for testing, and these selected whole cylinders were sliced. Three cuts were made using a wet concrete saw (diamond blade). Slice A and slice B from each cylinder were subjected to an RMT test, as illustrated in Figure 2. D_{nssm} of these cylinders was the average value of the two slices when two slices were available. In the results section, the D_{nssm} for each slice is shown. A picture of a specimen being sliced with a wet concrete saw is shown in Figure 3a. Figure 3b shows a slice being placed inside of the rubber casing prior to the RMT test. Figure 3c shows the setup with four samples on a fish tank. Three power supplies are shown on the right of this picture, one for each tank.

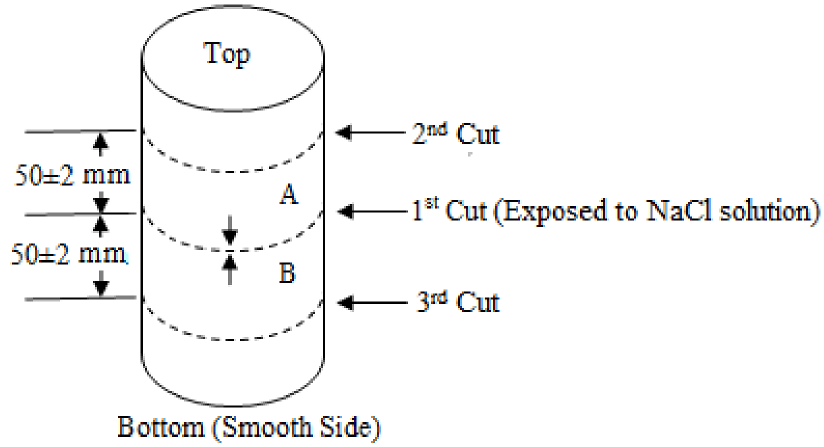


Figure 2. The procedure for slicing specimens.

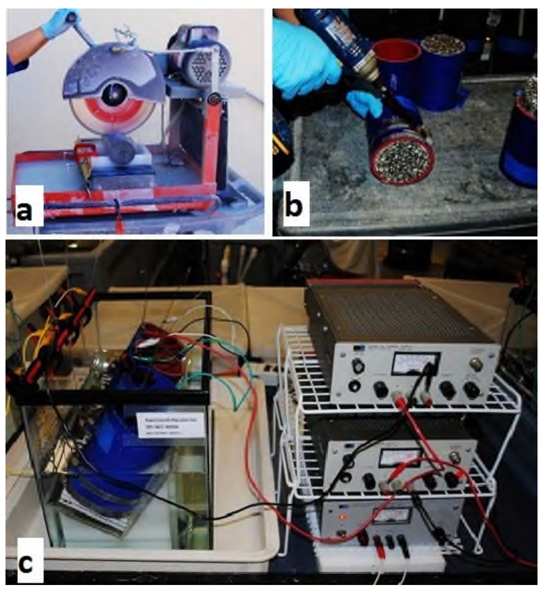


Figure 3. Illustration of (a) specimen slicing and (b, c) setup of RMT test.

After the exposure period, the tested slices were split into halves and 0.1N $AgNO_3$ was sprayed on the cross-section. This provided an indication of chloride ion penetration depth. After a few minutes, a caliper was used to measure the penetration depth, as shown in Figure 4 and Figure 5. D_{nssm} was then calculated according to the procedure indicated in NT Build 492.

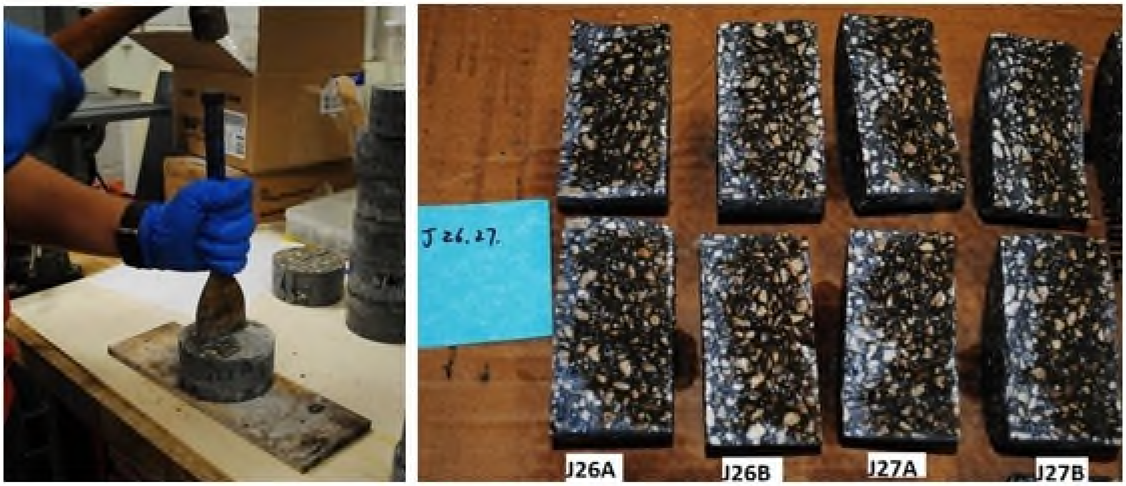


Figure 4. Illustration of splitting slices and spraying 0.1N $AgNO_3$ at the cross-section as an indication of chloride ion penetration depth.

Figure 5. Measurement of chloride ion penetration depth.

RMT tests on mature concrete specimens were performed at least twice per concrete mix. RMT tests were carried out shortly after the half cylinder arrived at FAU-SeaTech. At least one additional cylinder per mix (DCL mixes when available) was tested for RMT test. The target schedule for RMT test on recently prepared specimens was at 2, 4, 6, 12 months after casting the specimens. Two slices from concrete cylinders per mix (SL and FA) were tested after accelerated curing: 2 days cured at room temperature followed by 26 days at elevated temperature, followed by 28 days at room temperature (plus additional time passed between slicing and testing). The RMT test on these latter samples took place several weeks later once these samples arrived at FAU-SeaTech.

2.5.3 Surface resistivity

The surface resistivity monitoring was performed on selected concrete cylinders prepared during spring and summer of 2016 (SL, FA, T1, and T2). The readings took place during the duration of this project. No geometric correction (nor temperature correction) was applied to the values reported in here (whereas in previous reports and journal publications from our group this has been done). Geometric correction to convert to resistivity values was done on values used to correlate resistivity vs. D_{nssd} or resistivity vs. D_{nssm}.

Cylinders selected for bulk diffusion stored at FAU-Seatech (older mature mixes) were transported to SMO-Gainesville during spring 2016. Cylinders of Mixes FA10 (CRA label), Ai, Bi, A, B, C, D, E, F, G, H, I, J, K, and L were measured at SMO using both Resipod and Farnell SR meters. Three cylinders per mix have been monitored for resistivity at SMO per each mix since casting. Surface Resistivity measurements were performed on cylinders that remained at FAU for specimens from the DCL series.

2.5.4 The rate of water absorption (sorptivity test)

The rate of water absorption (sorptivity) testing was conducted on concrete slices. It was determined in accordance with ASTM C1585–04. The top 5 cm thick slice for the selected concrete cylinders was used for this test.

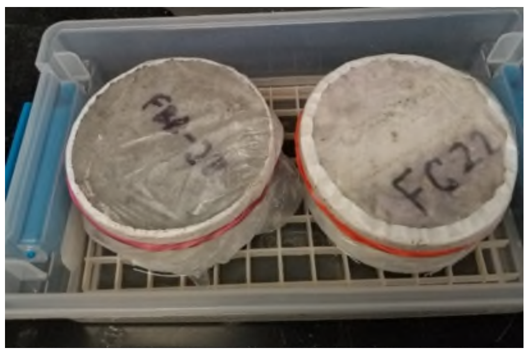


Figure 6. Laboratory water sorptivity test setup (top surfaces were covered with plastic sheets).

The sliced specimens were placed in an environmental chamber at a temperature of 50 ± 2°C and RH of 80 ± 3 % for three days. After 3 days, each specimen was placed inside a sealable container or the specimen remained in the environmental chamber for 15 days at 21 °C temperature and 80% RH. For the samples placed into plastic containers, precautions were taken to allow free flow of air around the specimen by ensuring minimal contact of the specimen with the walls of the container. The containers were stored at 23 ± 2°C for at least 15 days before the start of the absorption procedure. A few samples were exposed in separate plastic containers. Most of the samples remained in the environmental chamber at a temperature of 20 ± 2°C and RH of 80 ± 3 % for fifteen days (sometimes for a longer period of time).

Once the samples completed the 15 days at room temperature, the sample side surface (i.e. outer/round circumference) was sealed with duct tape. The top end of each specimen was sealed with a loosely attached plastic sheet to avoid/minimize evaporation from the sample during testing. The plastic cover remained in place using a rubber band. Each specimen was placed in a plastic container. A mesh was placed in the bottom of the container. Each container was filled with tap water solutions to 3 mm above the top of the supporting mesh for the duration of the test (Figure 6). After the samples were prepared, testing occurred in accordance with ASTM C1585-04.

The mass of the specimens was recorded at the specific interval after the first contact of the specimen's surface. For each measurement, after removing the sample from the pan, the exposed surface was wiped off with a dampened cloth so as to remove excess water. The first point was 60 ± 2 s and the second point was 5 min ± 10 s. Subsequent measurements were within ± 2 min of 10 min, 20 min, 30 min, and 60 min. The mass measurements continued every hour, ± 5 min, up to 6 hours, from the first contact of the specimen with the solution. After the initial 6h, the measurement was taken once a day for up to 3 days followed by 3 measurements at least 24 h apart during days 4 to 7. Typically a final measurement was taken 24 h after the measurement at 9 days. For some specimens, additional mass measurements were performed up to 15 days.

The absorption, *I*, is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of the solution. For the purpose of this test, the temperature dependence of the density of water is neglected and a value of 0.001 g/mm^3 is used. There were two rates of absorption calculated, the initial rate of absorption, which was obtained from 1 min to 6 h readings, and the secondary rate of absorption, which was between 1 day and 7 days (as indicated in the standard).

The absorption was calculated as follow (Equation 1):

$$I = \frac{m_t}{a \times d} \qquad \text{Equation 1}$$

Where:
I is the absorption, m_t is the change in specimen mass in grams at the time t, *a* is the exposed area of the specimen, in mm^2, and *d* is the density of the water in g/mm^3.

2.5.5 Bulk diffusion and RMT on slices at Key Royale Bridge

There were a few slices remaining from cores obtained from the Key Royale Bridge (KRB) fender piles [3]. There were at least two slices per fender pile (each one has a different composition). Table 11 shows the nominal concrete composition used at each pile (reported in lb/yd^3 in reference[12,13]). Each fender pile is identified by its id and the cementitious material used in the concrete composition. CEM only Portland cement, UFA: contains fly ash and ultrafine fly ash, FA id piles that contains fly ash, SF the pile that contains fly ash and silica fume, MET the pile that contains fly ash and metakaolin, and BFS the pile prepared with the mix that contains fly ash and blast furnace slag. A slice was used for the bulk diffusion test. Table 12 lists the sample ID, the approximate age of the concrete counted from the day the piles were driven, the date the samples were removed from the solution and the exposure duration. A second sliced was used to test for RMT (as per NT492 to determine D_{nssm}). These concrete slices have been immersed in tap water for over four years. Recall that these slices were obtained from 4-inch diameter cores drilled from the top of selected fender piles (during December 2011 (cores from five fender piles) and (one core from one fender) in April 2012) [3].

Table 11. Mixture designs used in the piles (units in kg/m^3)

Material	**Type**	Key Royale Bridge fender piles					
		KRB1	KRB2	KRB3	KRB4	KRB6	KRB5
		CEM	UFA	FA	SF	MET	BFS
Coarse Aggregate	#67	1092.0	1092.0	1092.0	1092.0	1092.0	1092.0
Fine Aggregate	Silica	478.3	478.3	478.3	478.3	478.3	478.3
Cement	Type II	575.7	397.6	471.8	424.3	412.5	397.6
Fly Ash	Type F	0	103.9	103.9	103.9	103.9	103.9
GGBFS	Grade 100	0	0	0.0	0.0	0.0	178.0
Ultrafine Fly Ash	Type F	0	74.2	0.0	0.0	0.0	0.0
Metakaolin	Type N	0	0	0.0	0.0	59.3	0.0
Silica Fume	Densified	0	0	0.0	47.5	0.0	0.0
Water	Local	197.6	197.6	197.6	197.6	197.6	197.6
Air Entr. Admixture	AEA	3.0	3.0	3.0	3.0	3.0	3.0

Note: Row one indicates the fender pile id, and the second row the supplementary cementitious material that identifies each fender pile.

Table 12. Sample ID, age of concrete, and exposure duration.

Sample	Age at exposure (days)	Removal Date	Exposure Time (months)
KRB1-1	3608	July 5, 2017	11.4
KRB2-2	3608	July 5, 2017	11.4
KRB3-1	3608	July 5, 2017	11.4
KRB4-2	3843	July 5, 2017	11.4
KRB5-1	3843	July 5, 2017	11.4
KRB6-1	3843	July 5, 2017	11.4

2.6 Apparent diffusion coefficient – simulated field

Concrete specimens prepared as part of a previous study continued to be exposed to three different environments simulating bridge substructure components exposed to the marine environment. Details of the samples and initial exposure can be found in [1]. The concrete specimens were 22" × 7" × 4.75” and prepared with DCL concrete compositions. Tidal exposure took place in a tank with two sides filled with seawater, in which the seawater was transferred from one side to the other side to simulate the tidal region every six hours. A second field simulation was a splash simulation with seawater and a splash simulation with 10% seawater. The simulated splash was achieved by a sprinkler system that was activated for 5 minutes every day, where the cover of the tanks was in place and prevented evaporation. The third environment was exposure in a barge in the intracoastal waters (a portion of the specimens was permanently immersed) and the portion above was subjected to ocean spray particulates as well as the splash from boat traffic. Selected specimens were cored at about 4.5 years (54 months) of exposure on specimens exposed to each of these environments as part of this project. The samples had also been cored at 6, 10, 18 and 30 months. Not all samples exposed to the tidal conditions were cored at 30 months.

Specimens exposed to the tidal conditions were cored at four elevations (below water, low tide, below high tide and above high tide – specimens from mixes DC1, DC4 and DC7). The block from the other mixes were cored at three (all other samples) elevations (below water, middle of tide zone and just above high tide). The samples cored at four elevations were cored at an elevation of 2, 8.3, 12 and 18" (with respect to the core center, and correspond to the same elevations as that of 6 or 10 months of exposure). The samples exposed to the splash simulation were cored at two elevations. The samples exposed at the barge were cored at two elevations. Table 13 shows the elevation at which the cores were obtained with respect to the cores' centers for samples cored at two or three locations at 54 months of exposure. The cores were obtained using a 6 cm drill bit. The cores obtained from samples exposed at the tidal tank and the barge were sliced from both sides. The cores obtained from samples exposed in the splash simulation tank were sliced only from the surface that was sprayed. The slices were sent to SMO and the samples were pulverized and the chloride concentration was obtained.

The slicing of the cores obtained at 54 months was as follow: 0.3 cm for the first layer and all other layers were 0.4 nominal thickness. The samples cored at 30 months were milled at SMO. The first two layers were 0.15 cm, the third layer was 0.2 cm and the next four layers were 0.3 cm, layer 7 was 0.35 cm, and layer 8 was 0.5 cm. Those milled at FAU for samples cored at 30 months were as follows: layer 1:0.2 cm, layers 2 to 5: 0.3 cm, and layers 6 to 8 were 0.4 cm (the actual layer thickness was recorded and used when preparing the profiles as well as the diffusivity values).

It is important to note that over the year before the project started, the seawater in the tidal tank was not changed as often as would have been desired and the chloride concentration likely increased due to evaporation. However, the tank was filled periodically up to the required levels to compensate for evaporation. Also, when filling or refreshing the seawater of the tanks on occasion some spill/splash took place to regions above the high tide. These events might in part explain the higher chloride concentration observed at higher elevations in a few specimens. The specimens exposed in the barge were cored and sliced during the early summer/2016. The chloride concentration was converted to %cm and plotted together with the profiles obtained at 6, 10, 18 and 30 months.

Table 13. Elevation of the core centers for samples cored at 54 months

Condition	**A**	**C**	**D**
Barge	5.1"	-	19"
Tidal	5.5"	10.6"	15"
Splash	4.7"	-	15"

The D_{app} values were calculated and an attempt was made to determine the m value (aging factor) for the different compositions and elevations. The m values are presented as part of the discussion chapter.

Chapter 3 – Results

3.1 Resistivity mature results

Table 13 shows the surface resistivity values as reported by each device (i.e., geometric correction not applied). When comparing the readings with both devices, the surface resistivity values were identical in very few cases. In other cases, a small percent difference: with respect to the value measured using the Farnell meter (Equation 2),

$$100\% \times (SR_{Farnell} - SR_{Resipod})/SR_{Farnell} \qquad \text{Equation 2}$$

Two instances were observed in which the difference was greater than 10% (13 and 15%), but for most specimens, the percent difference was less than 6.25 percent. The set of surface resistivity measurements was performed shortly prior to cutting the concrete cylinders for bulk diffusion specimen preparation.

In general, the surface resistivity measured on specimens XX27 and XX28 (XX indicates mixes A to L) should had been somewhat larger but have similar values to the surface resistivity values measured on XX1, XX2, and XX3 specimens (in Table 14 the average is shown, and Table 15 shows the detail for the comparison set of measurements). Specimens XX1, XX2 and XX3 were immersed in calcium hydroxide all the time (with the calcium hydroxide replaced every 6 months). Cylinders XX27 and XX28 were subjected to 2 days at room temperature, followed by 26 days at elevated temperature (ET) immersed in calcium hydroxide followed by room temperature exposure until these were transported to FDOT/SMO in 2016. The samples during the latter room temperature period were immersed in water with little or no calcium hydroxide, and a solution change about once a year. Specimens XX22 or XX23 were exposed in the ET immersed in calcium hydroxide for about a year, and later, the solution was tap water. For some of these specimens, this latter immersion appears to have allowed leaching to take place and the resistivity to decrease (when measured at RT and compared to the other concrete cylinders of the same mix). However, for the most part, the SR measured was the largest on those cylinders that were in the ET for a prolonged period of time (e.g., AA, B, E, F, H, J, and G mixes).

Table 14. Comparison of Surface Resistivity measured at SMO.

					Farnell	Farnell	Resipod	Resipod
Mix name FAU cured	Cast date	Test date	Age (days)	Samples	SR results (kΩ·cm)	SR avg (kΩ·cm)	SR results (kΩ·cm)	SR avg (kΩ·cm)
Ai(AA)	10/13/2010	4/25/2016	2021	AA28	190.7	123.6	187.0	123.3
				AA23	56.5		59.6	
				Ai (1-3)	78.3		81.0	
Bi(BB)	10/13/2010	4/14/2016	2010	BB22	232.0	225.6	201.6	210.4
				BB28	219.1		219.1	
A	11/8/2010	4/25/2016	1995	A23	47.8	61.7	46.0	60.3
				A28	75.5		74.5	
				A(1-3)	74.3		76.3	
B	11/8/2010	4/14/2016	1984	B22	228.3	207.6	221.8	201.8
				B23	222.1		222.1	
				B29	172.3		161.6	
				B(1-3)	194.3		196.0	
D	12/7/2010	4/18/2016	1959	D23	208.4	244.8	208.4	246.4
				D27	281.2		284.3	
				D(1-3)	414.0		413.0	
E	12/7/2010	4/14/2016	1955	E22	100.2	89.5	100.5	89.5
				E23	104.7		104.7	
				E28	63.5		63.2	
				E(1-3)	54.7		55.0	
F	12/20/2010	4/14/2016	1942	F23	208.8	152.0	208.8	149.5
				F27	95.1		90.2	
				F(1-3)	77.7		78.7	
I	12/20/2010	4/14/2016	1942	I22	194.8	203.6	195.0	204.3
				I23	214.1		216.0	
				I28	201.8		201.8	
				I(1-3)	122.0		123.0	
H	1/20/2011	4/14/2016	1911	H23	329.4	245.9	329.4	245.6
				H28	162.3		161.8	
				H(1-3)	157.0		152.7	
J	1/20/2011	4/18/2016	1915	J23	171.4	153.1	171.1	150.6
				J28	134.7		130.0	
				J(1-3)	124.0		121.3	
C	1/26/2011	4/18/2016	1909	C22	113.6	129.0	113.6	
				C23	122.6		123.4	130.3
				C28	150.8		153.8	
				C(1-3)	116.3		116.0	

Table 14 continues

G	1/26/2011	4/14/2016	1905	G22	99.6		99.6	88.1
				G23	106.6		106.6	
				G28	55.3	87.2	58.2	
				G(1-3)	38.3		37.0	
K	2/24/2011	4/14/2016	1876	K23	177.1		150.4	193.3
				K28	236.1	206.6	236.1	
				K(1-3)	195.3		197.7	
L	2/24/2011	4/25/2016	1887	L22	415.7		401.5	
				L23	234.8	277.7	240.0	272.0
				L28	182.7		174.6	
				L(1-3)	507.7		507.7	
CRA	5/15/2012	4/25/2016	1441	10	18.7		18.5	19.7
				11	20.0	19.3	20.7	
				12	19.2		19.8	

NOTE: The date format is mm/dd/yyyy

Table 15. Comparison of surface resistivity for specimens FX-1, 2, and 3 using two devices

	Ai	Bi	A	B	D	E	F	I	H	J	C	G	K	L
Resipod Surface Resistivity kΩ·cm	4/27/2016	4/27/2016	5/4/16	5/4/16	5/4/2016	5/4/16	4/27/16	4/27/16	5/5/16	5/5/16	5/5/16	5/5/16	4/28/2016	5/5/2016
	2023		2003	2003	2003	1974	1967	1955	1931	1931	1925	1925	1896	1895
	80	N/A	78	199	422	55	78	120	148	122	113	37	201	496
	80	N/A	73	194	417	54	77	131	151	121	116	36	200	520
	83	N/A	78	195	400	56	81	118	159	121	119	38	192	507
AVG	81	N/A	76	196	413	55	79	123	153	121	116	37	198	508
	Ai	Bi	A	B	D	E	F	I	H	J	C	G	K	L
Farnell Surface Resistivity kΩ·cm	4/27/2016	4/27/16	5/4/16	5/4/16	5/4/2016	5/4/16	4/27/16	4/27/16	5/5/16	5/5/16	5/5/16	5/5/16	4/28/2016	5/5/2016
	2023	2023	2003	2003	2003	1974	1967	1955	1931	1931	1925	1925	1896	1895
	76	210	74	192	420	55	76	120	155	122	114	37	197	496
	78	222	76	196	415	54	77	130	159	123	117	37	200	520
	81	214	73	195	407	55	80	116	157	127	118	41	189	507
AVG	78	215	74	194	414	55	78	122	157	124	116	38	195	508

NOTE: The date format is mm/dd/yyyy

NOTE: The values shown on Table 14 and Table 15 are surface resistivity values as measured, no geometric correction applied. Readings on samples stored at SMO

3.2 Resistivity vs. time on recently prepared specimens.

3.2.1 SL specimens

Figure 7, Figure 8 and Figure 9 show the surface resistivity measured vs. time on selected cylinders prepared with slag cement (50% replacement). Figure 7 and Figure 8 show surface resistivity values measured on selected cylinders kept at FAU and Figure 9 shows the surface resistivity values measured on cylinders at SMO. The specimens at FAU currently have values between 40 and 50 kΩ·cm and those at SMO between 42 and 50 kΩ·cm. The small difference might be in part due to a slight temperature difference in the solution at SMO compared to the solution at FAU, or by the concrete heterogeneity. Cylinders 39, 40, 55 and 56 were placed in the elevated temperature room immersed in water for two weeks when they reached 50 days of age, after which these cylinders were immersed in RT water. While in the ET, the measured resistivity values were lower (as expected before temperature correction and not waiting for the cylinder to reach RT), but upon placing them in the RT solution, the measured values were comparable to those measured on cylinders that remained in the RT solution all the time. The third set of samples corresponds to cylinders that were exposed in a high humidity environment all the time (some samples experienced an increase in SR values when the moisture was not kept as high). Figure 10 shows surface resistivity vs. time measured on the cylinders that were exposed to high humidity. Over time some of the cylinders originally exposed in the high humidity exposure were transferred to the immersed condition. Surface resistivity values after immersion are shown in Figure 7 (cylinders 41 to 44) and Figure 8 (cylinders 57 to 59). This was done prior to using these samples for RMT or sorptivity testing.

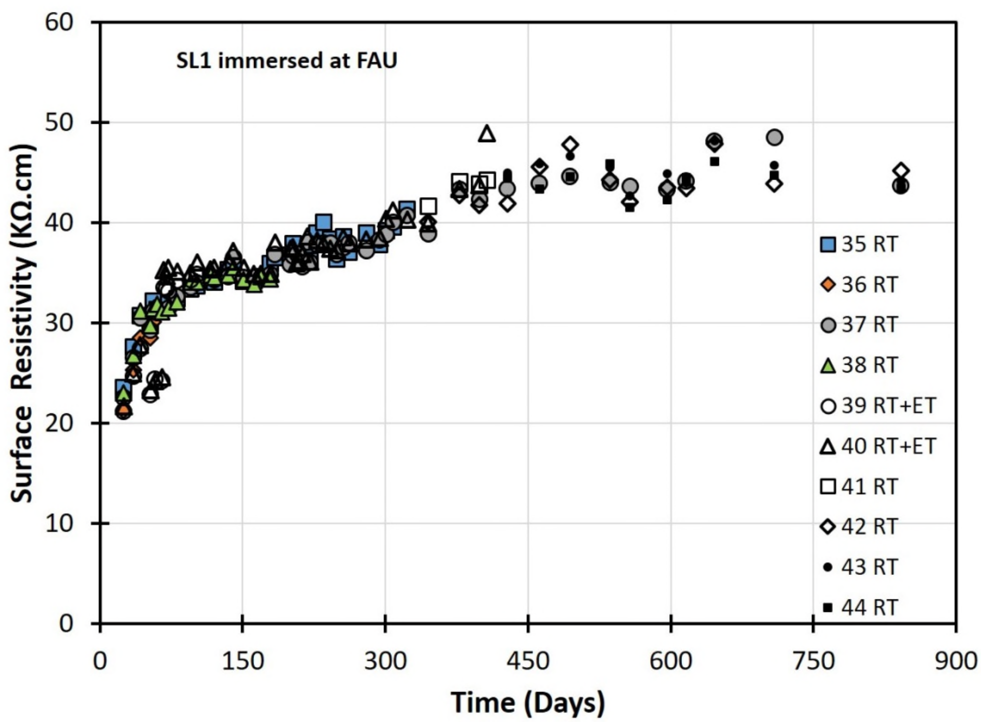


Figure 7. Surface resistivity vs. time measured on selected SL1 concrete cylinders

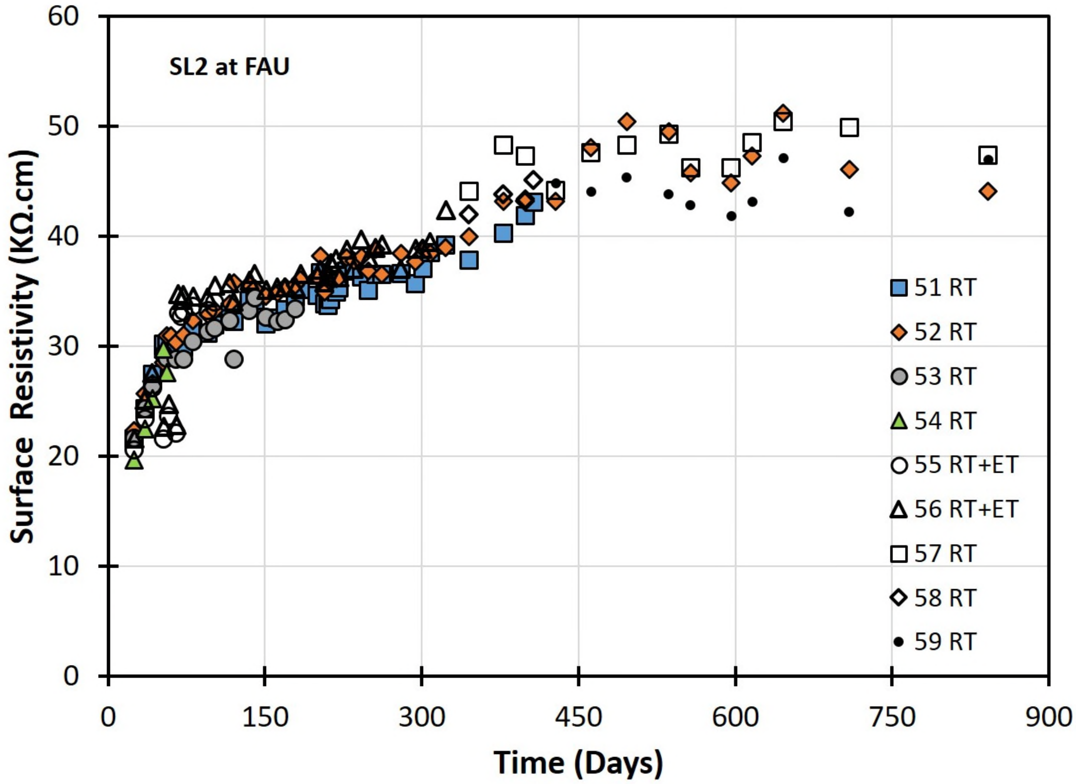


Figure 8. Surface resistivity vs. time measured on selected SL2 concrete cylinders.

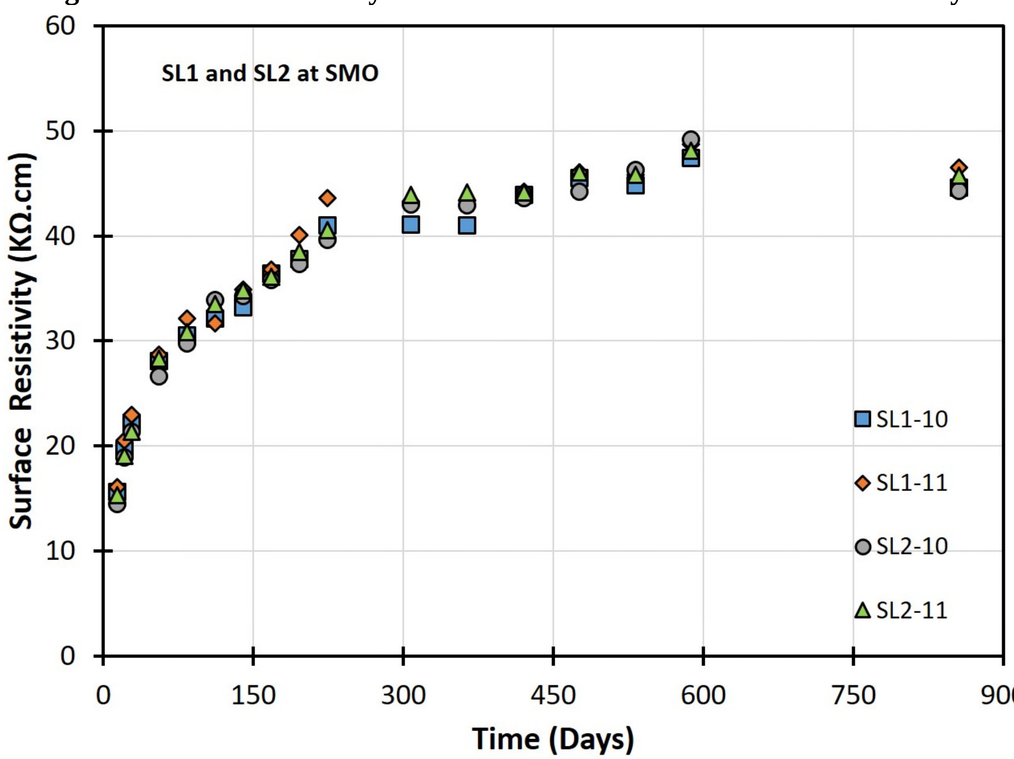


Figure 9. Surface resistivity vs. time measured on selected SL1 and SL2 cylinders at SMO.

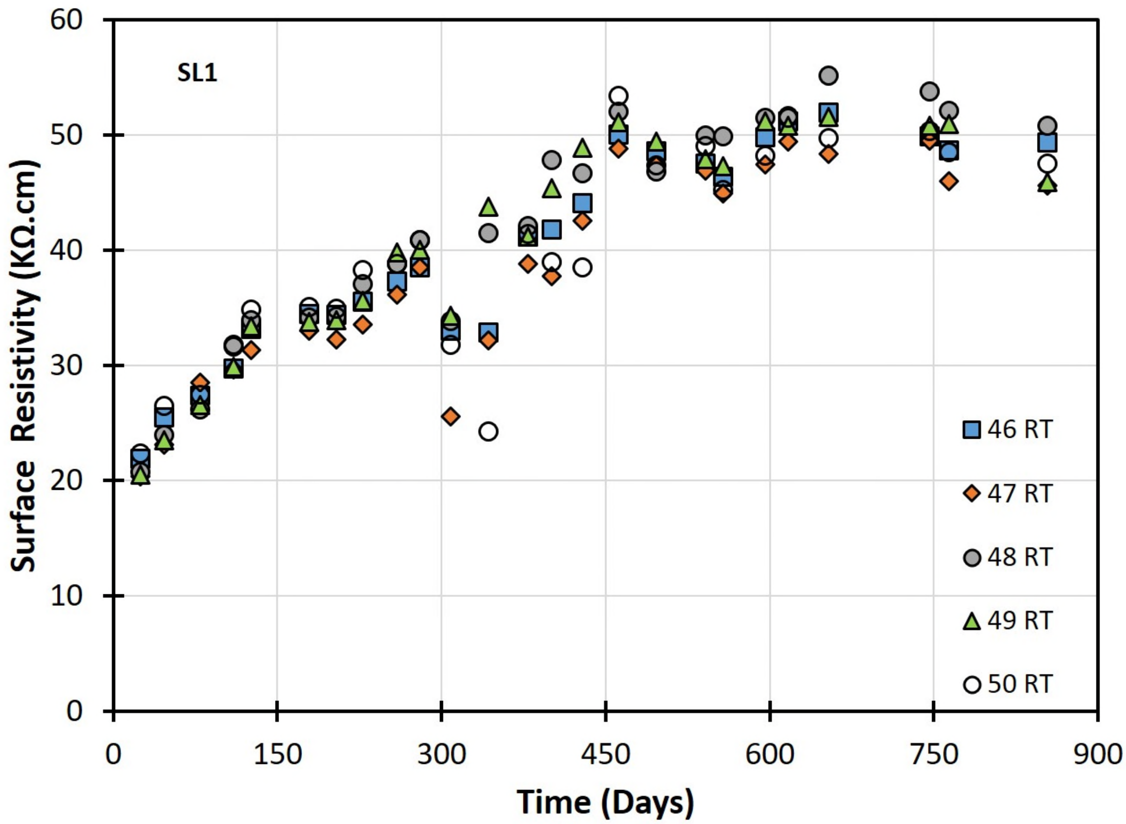


Figure 10. Surface resistivity vs. time measured on selected SL1 concrete cylinders exposed to high humidity.

3.2.2 FA specimens

Figure 11, Figure 12, Figure 13 and Figure 14 show the surface resistivity evolution for the specimens prepared with Fly ash (binary mixes). Four cylinders were placed in the elevated temperature (ET) room for two weeks (two of which have been terminated to measure migration, porosity, and water absorption), see Figure 11 and Figure 12. While in the ET room, the surface resistivity measured was larger than that measured on specimens immersed in RT water (no temperature correction), and upon moving them to RT immersion, an additional increase in surface resistivity value was observed. The resistivity on the two remaining cylinders exposed in the ET room is slightly greater than that measured on those at SMO and the other cylinders at FAU immersed in water. The resistivity of the cylinders at SMO is about 5 kΩ·cm larger than that of the cylinders at FAU that have been immersed in room temperature solution (water with calcium hydroxide) all the time. After 200 days the surface resistivity values range between 35 and 45 kΩ·cm. By day 750 the surface resistivity reached a value between 50 and 60 kΩ·cm. Some cylinders that initially were exposed to high humidity were transfer to immersed conditions, these cylinders reached surface resistivity values between 60 and 65 kΩ·cm by day 800.

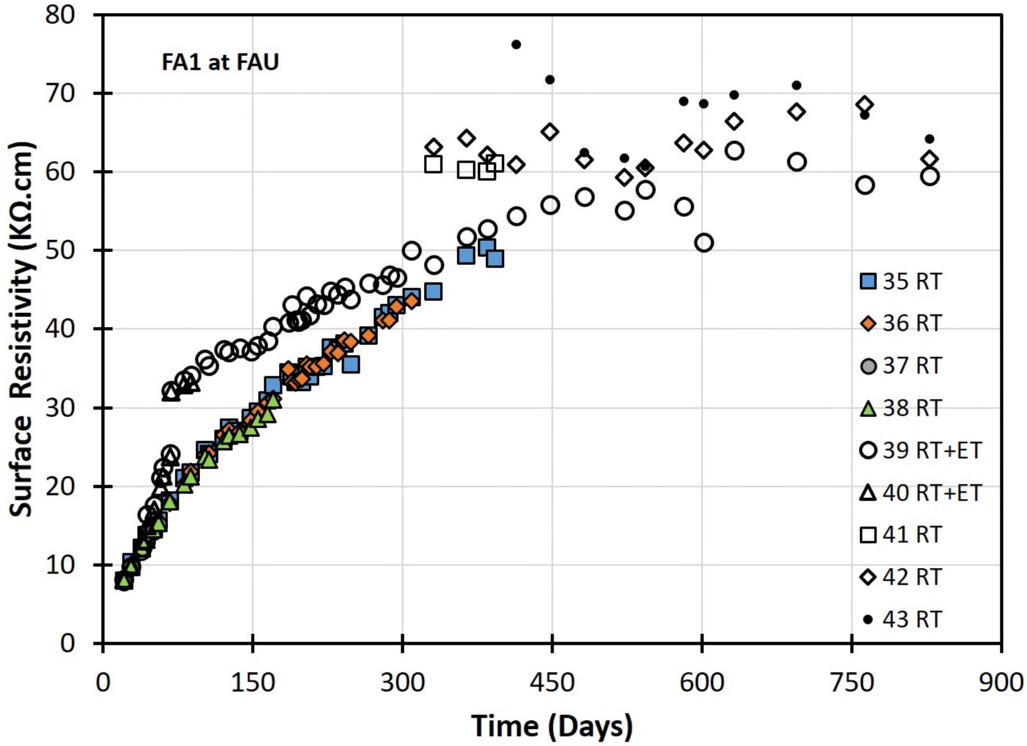


Figure 11. Surface resistivity vs. time measured on selected FA1 concrete cylinders at FAU.

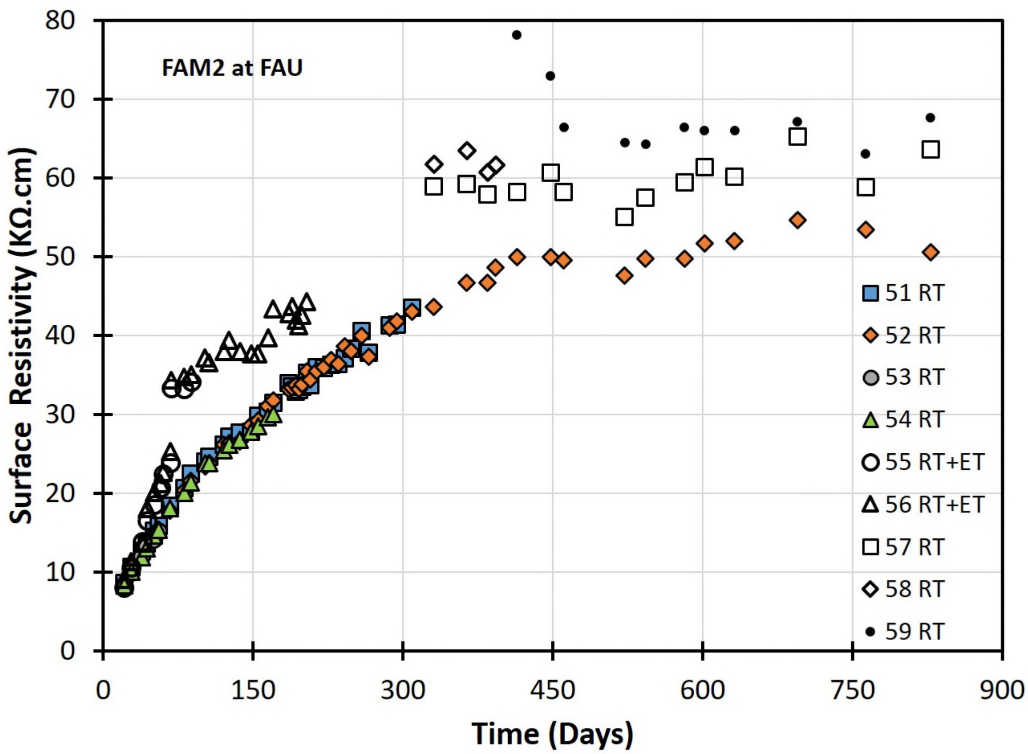


Figure 12. Surface resistivity vs. time measured on selected FA2 concrete cylinders at FAU.

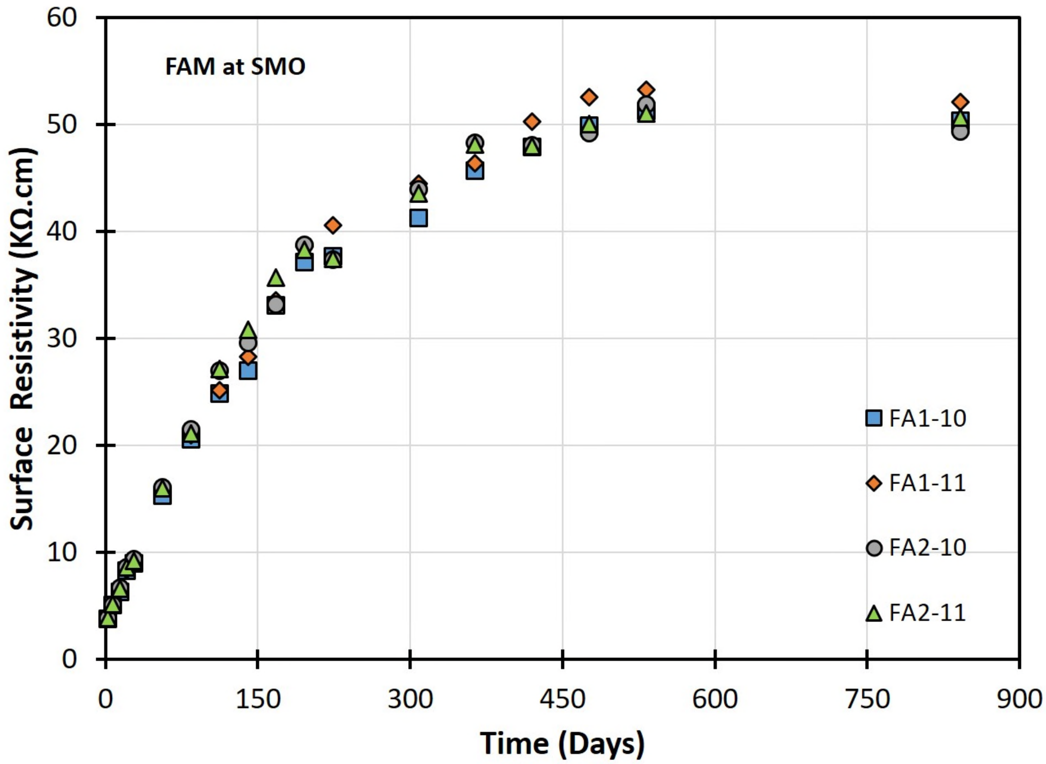


Figure 13. Surface resistivity vs. time measured on selected FA1 and FA2 cylinders at SMO.

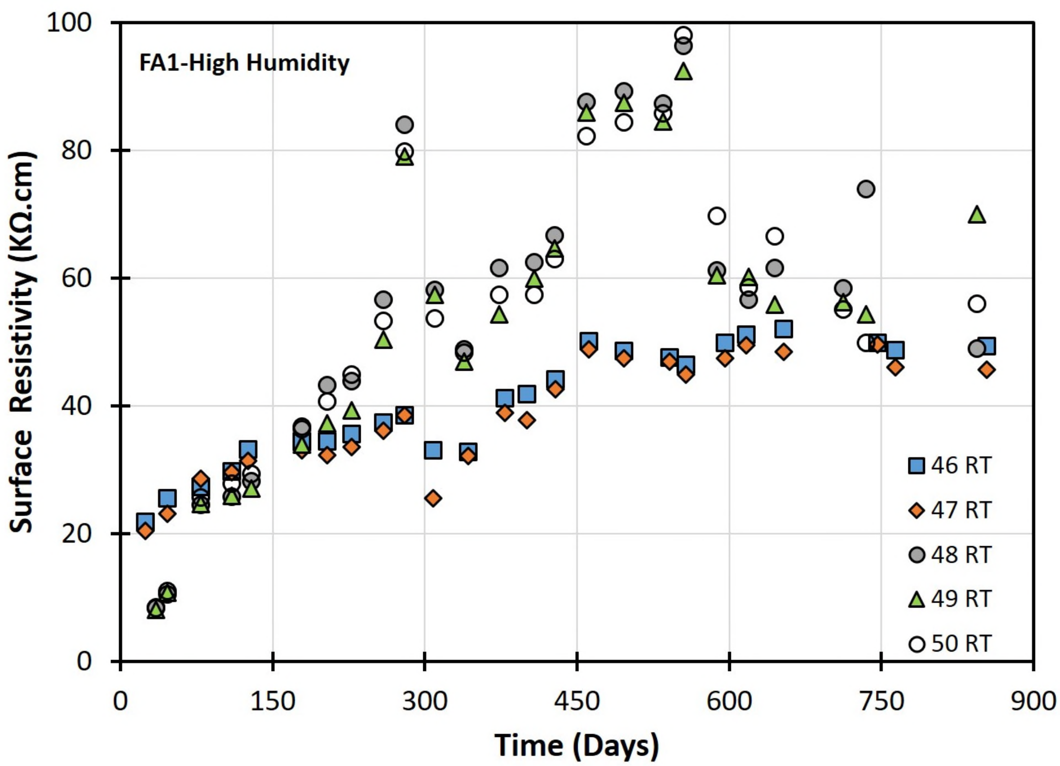
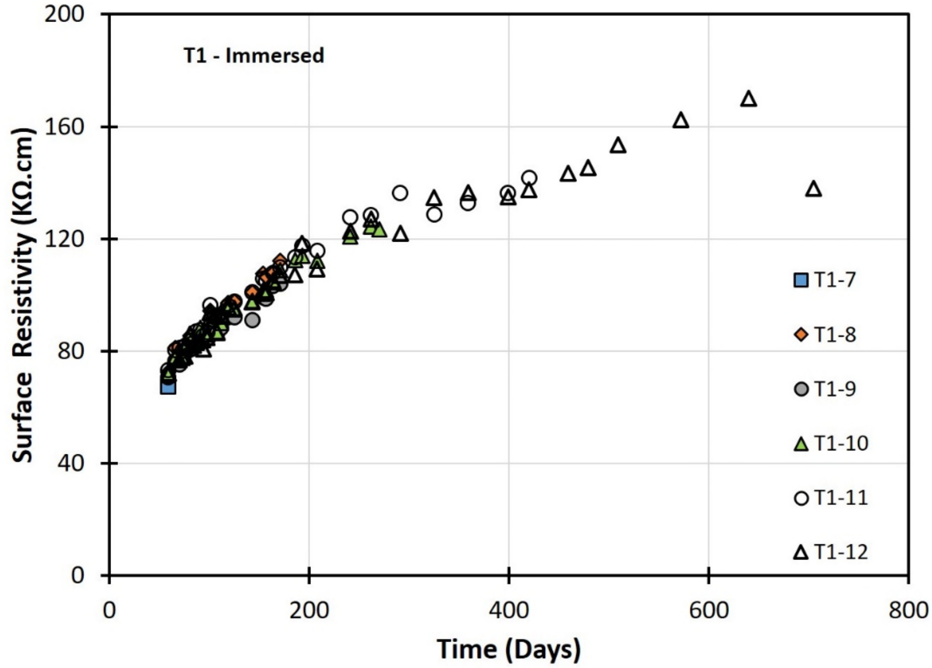


Figure 14. Surface resistivity vs. time measured on selected FA1 concrete cylinders exposed to high humidity.

3.2.3 T1 and T2 specimens

Figure 15 shows the surface resistivity measured on specimens at FAU prepared with Ternary mixes. T1 cylinders contain fly ash and slag, and T2 cylinders contain fly ash and silica fume. At 80 days of age the surface resistivity for T1 cylinders is approximately 160 kΩ·cm and for T2 cylinders is about 170 kΩ·cm.



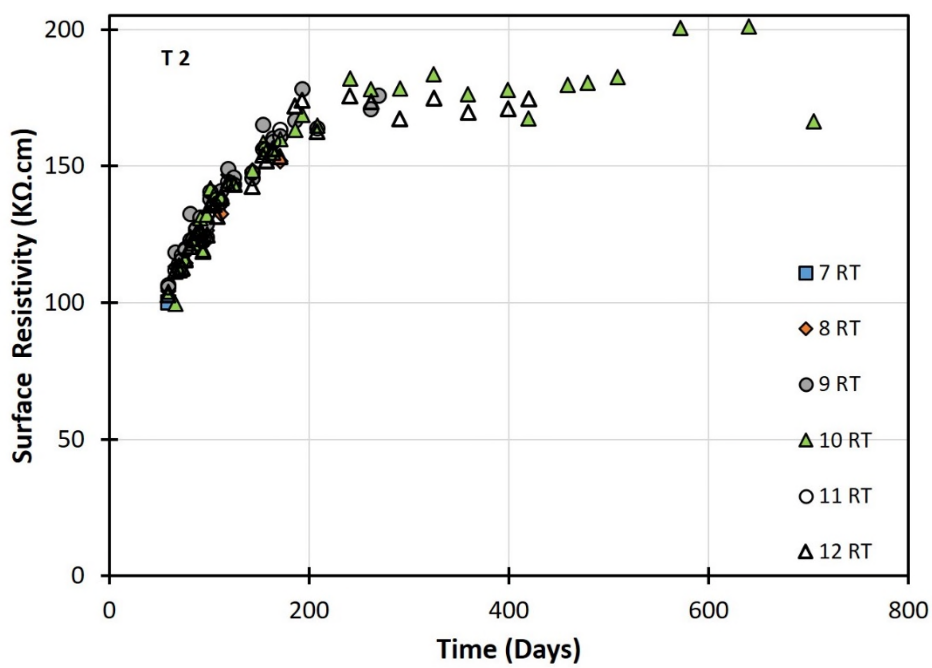


Figure 15. Surface resistivity vs. time measured on selected T1 and T2 concrete cylinders at FAU.

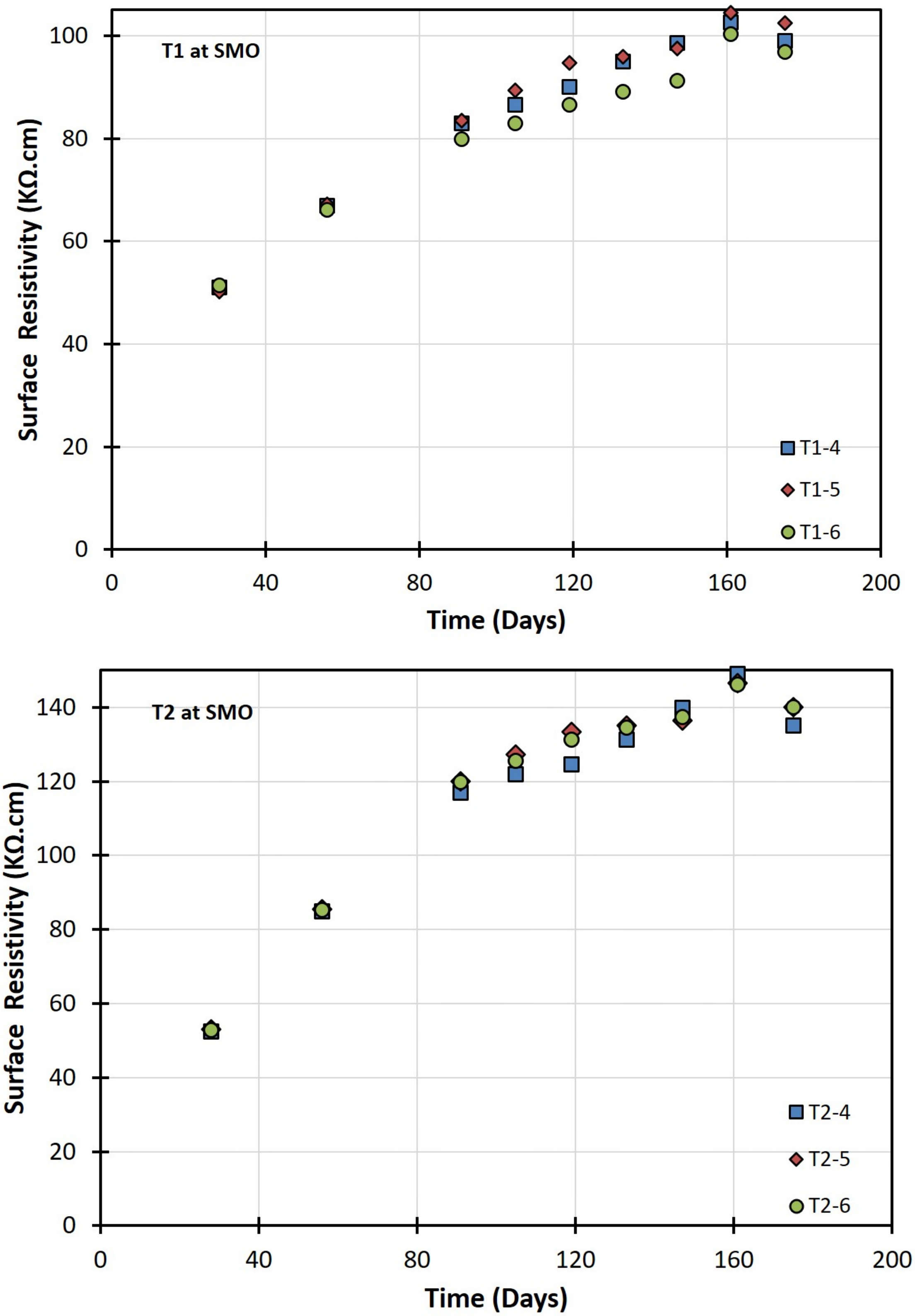


Figure 16. Surface resistivity vs. time measured on selected T1 and T2 concrete cylinders at SMO.

Figure 16 shows the surface resistivity values measured on T1 and T2 cylinders that were monitored at SMO until day 170. The average surface resistivity on T1 cylinders was 100 kΩ·cm, and for T2 cylinders, the average surface resistivity was close to 140 kΩ·cm. Appendix D contains surface resistivity vs. time plots measured on other SL and FA specimens. It also contains surface resistivity vs. time plots measured on selected DCL specimens stored in high humidity.

3.3 Porosity

This section presents the porosity values measured on selected specimens for which the bottom 5-cm slice was available. For some specimens for mixes A to L, the porosity test was not performed. Table 16 shows the values measured on DCL specimens and the cylinders with 10 percent fly ash. Most tested specimens from series DC1 to DC11 had a porosity between 6% and 7%. The exception was DC3-22, which had a porosity of 8.6%. The porosity measured on specimen DC10-22 was 9.2%. The porosity measured on FA10 cylinders was slightly lower and ranged between 5.2% and 5.7%.

Table 16. Porosity of DCL specimens and FA10 specimens.

Specimen	%
DC1-24	6.5
DC2-22	6.9
DC3-22	8.6
DC4-22	6.9
DC5-22	6.8
DC6-22	6.2
DC7-22	6.6
DC8-25	6.6
DC9-25	6.6
DC10-22	9.2
DC10a-23	6.9
DC10b-23	6.0
DC11-23	7.0
FA10-13	5.7
FA10-15	5.2

Table 17 presents the porosity measured on SL and FA specimens. There are a few values that appear to be out-layers. It is more evident on specimens with the lower porosity; these were the last set of specimens measured, but it is not likely that the porosity decreased that much (2.1 percent on SL and 3.8 on FA specimens). Not including the lower range out-layers, the porosity on FA specimens ranged between 12 and 7 percent and that obtained on SL cylinders ranged between 10.8 and 5.3 percent.

Table 17. Porosity measured on FA and SL specimens

Specimen	% Porosity	Specimen	% Porosity
FA1-35	9.0	SL1-35	10.8
FA1-36	11.8	SL1-36	7.2
FA1-37	9.7	SL1-38	6.3
FA1-38	9.9	SL1-39	5.5
FA1-40	7.0	SL1-40	5.3
FA1-41	7.2	SL1-41	5.4
Specimen	% Porosity	Specimen	% Porosity
FA1-45	3.7	SL1-45	2.1
FA2-51	12.7	SL2-51	5.4
FA2-53	10.8	SL2-53	5.8
FA2-54	11.2	SL2-54	7.3
FA2-55	8.6	SL2-55	5.7
FA2-56	9.2	SL2-56	5.7
FA2-58	10.4	SL2-58	6.3
FA2-60	3.9	SL2-60	2.0

Table 18 shows the porosity measured in T1 and T2 specimens. The porosity measured on T1 cylinders ranged between 6 and 8.5 percent (not including T1-7 nor T1-11 values). The porosity measured on T2 specimens ranged between 11.9 and 5.5 (not including the max value of 24.7 measured on T2-7 nor the minimum value of 4.8% measured on T2-12)

Table 18. Porosity measured in T1 and T2 specimens

Specimen	% Porosity	Specimen	% Porosity
T1-6	8.5	T2-7	24.7
T1-7	15.3	T2-6	8.6
T1-8	7.0	T2-8	11.9
T1-9	8.5	T2-9	8.5
T1-10	6.0	T2-11	5.5
T1-11	3.8	T2-12	4.8

Table 19 shows the porosity measured on A to L cylinders number 27 or 22 (for 4 different mixes), the porosity ranged between 8.6 and 10%. Specimens from cylinders numbered 12 that were sliced and immersed to water for a few years (after slicing) had porosity that ranged between 13.2 and 14%, the latter porosity values corresponded to early samples measured by the student, so there is the possibility of a higher human error, but it is also possible that these samples had a somewhat higher porosity.

Table 19. Porosity range for other species.

Specimen	%
D-27	9.98
F-27	9.44
I-22	8.61
L-22	8.63
H12	13.21
I12	13.33
J12	13.22
K12	14.25
L10	14.10

3.4 Sorptivity

The mass measurements obtained on each specimen as per the standard were used to calculate the rate of absorption of the 5 cm tall slice specimens selected for sorptivity. Typically, the readings were extended beyond the number of days indicated in the standard. The primary and secondary water absorption values reported for these specimens were obtained by using the least-square linear regression analysis. Selected plots of water absorption vs. time for samples are presented in here and are plotted as a function of the square root of time. Figures 17 plots for some of the SL specimens tested. Figure 18 show plots for FA specimens. Figure 19 and Figure 20 show plots for the ternary mixture T1 and T2, respectively. Figure 21 and Figure 22 present selected water absorption plots for samples prepared with DCL mixtures.

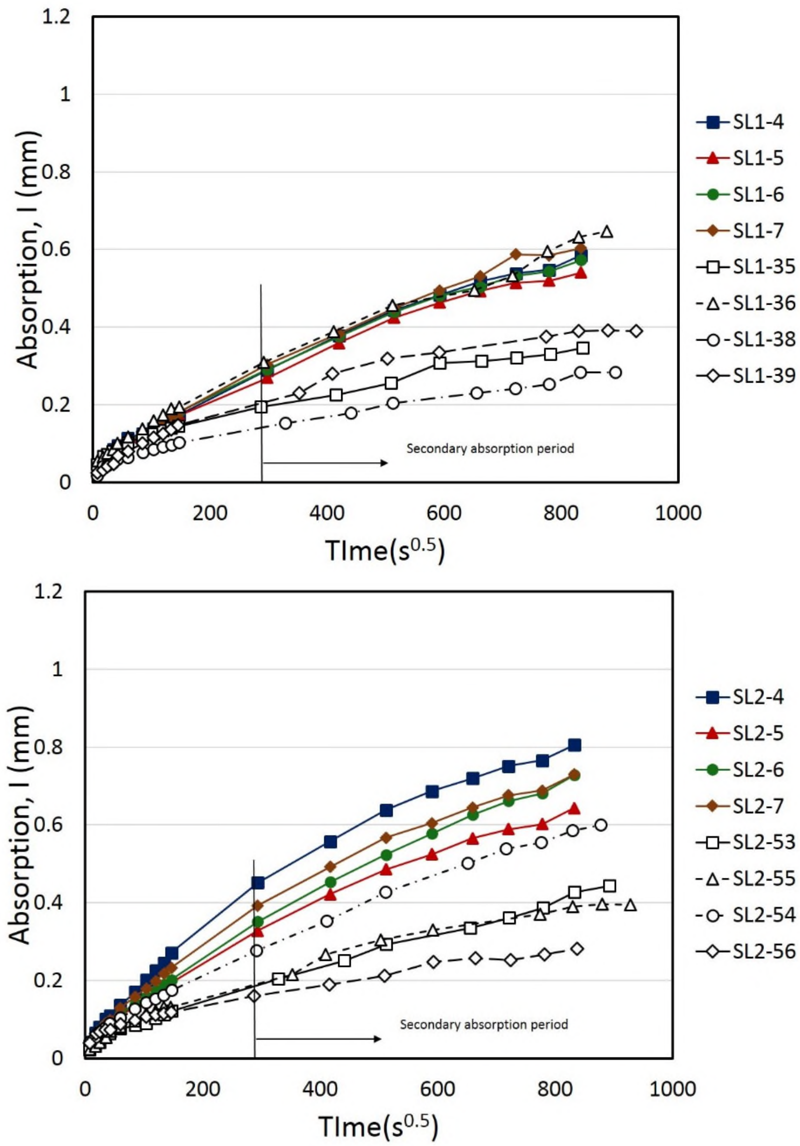


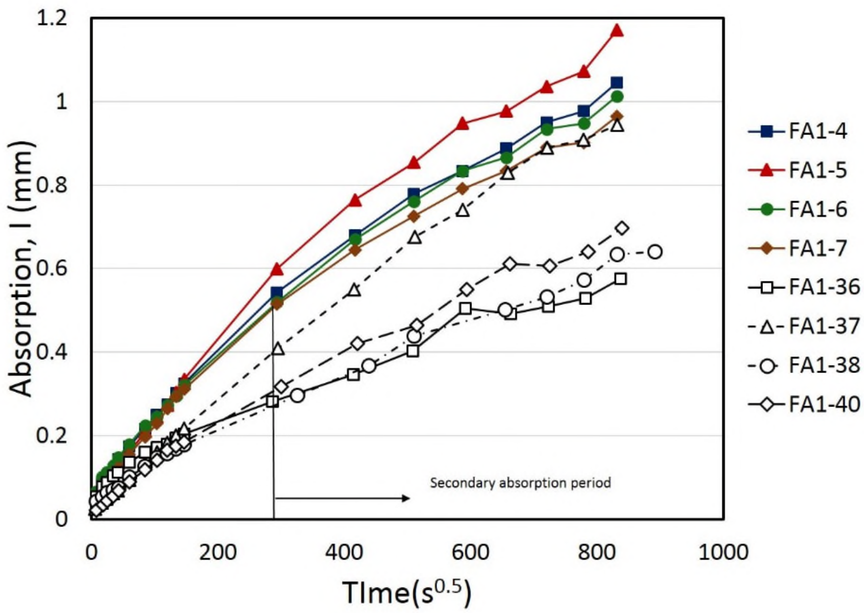
Figure 17. Water absorption vs. time (SL specimens).

Figure 17 presents typical sorptivity results of tests performed on SL-1 cylinder slices during the absorption period as a function of square time. Recall that the top slice of each cylinder was used. The horizontal axis represents the square root of time in seconds and the vertical axis represents water absorption penetration in mm. It can also be observed that each series contains three main regions: 1) the region of short-term water absorption, 2) transition region, and 3) the region of long-term water absorption.

The slopes of the curve in region 1 and 3 describe the rate of cumulative water absorption per unit area at short and long terms respectively. As an overall primary absorption trend, it is clear that the depth of penetration of all the specimens increased gradually with time. The penetration reached deeper on some specimens (e.g., SL1-6, SL1-37) than others (e.g., SL1-35, 39). It is noticeable that specimens SL1-38 and SL1-39 exhibited very similar secondary absorption: initially, the water penetrated mildly, continued rising and finally plateaued. At the end of the secondary regime, the final penetration ranged from 0.6 mm to 0.27 mm on these samples.

Figure 18 shows examples of the absorption behavior on slices from the FA groups (i.e., mixes FA1 and FA2). The various series graphs compare the penetration and the trends observed on several selected specimens from the FA mixes. The data shown includes up to 8/9 days. As an overall trend, it is clear that a monotonic increase is observed during both primary and secondary absorption.

Regarding the initial absorption, the final penetrations were 0.35, 0.23, 0.30 and 0.22 mm depths for specimens FA1-5, FA1-37, FA2-53, and FA2-55, respectively. At the end of the secondary regime, the penetrations obtained were 1.18, 0.96, 1.02 and 0.68 mm for specimens FA1-5, FA1-37, FA2-53, and FA2-55, respectively. From the figure, it is also noticeable that FA1-36, FA1-38, FA1-40, FA2-51, FA2-54, and FA2-55 exhibited more moderate primary and secondary absorptions.



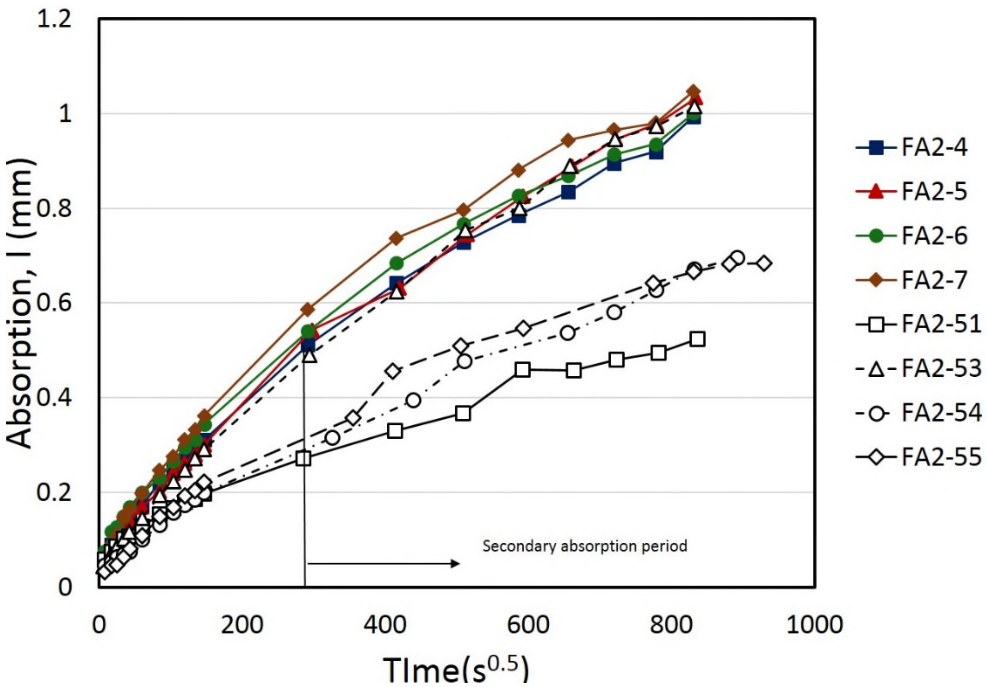


Figure 18. Water absorption vs. time (FA).

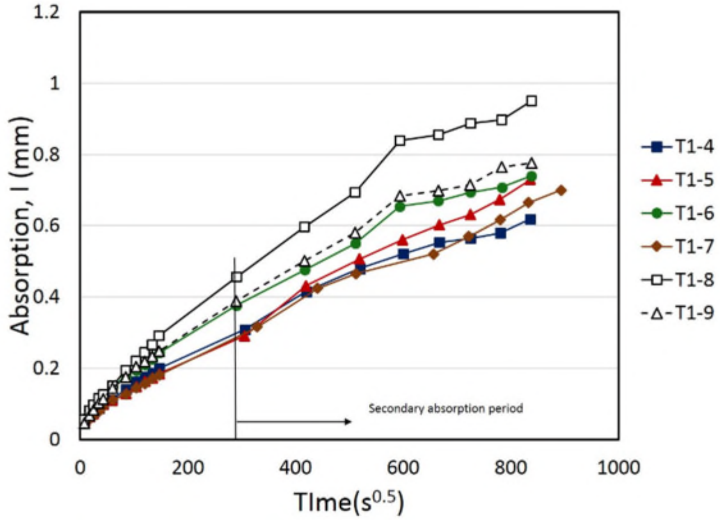


Figure 19. Water absorption vs. time (T1).

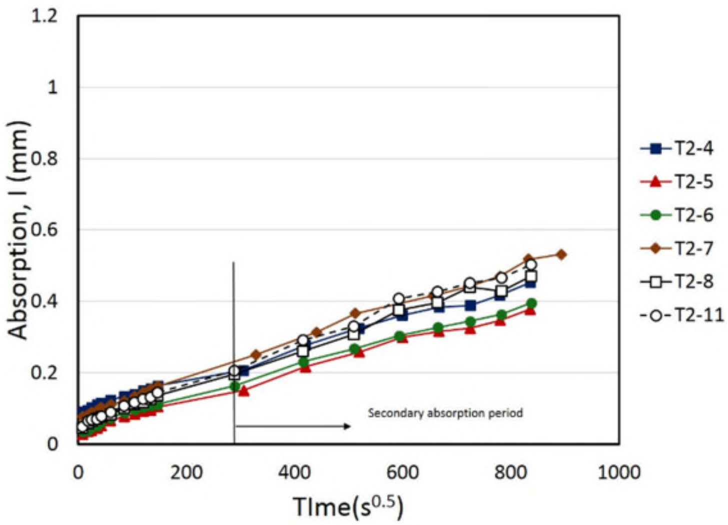


Figure 20. Water absorption vs. time (T2).

Figure 19 displays the water absorption behavior of the concrete mixtures from the ternary group T1 and Figure 20 displays the sorptivity for T2 samples. It can be clearly seen that for T1-8 the water penetrated up to 0.9 mm, while T2-7 penetrated steadily to 0.17 mm by the sixth hour and then gradually reached 0.56 mm penetration depth, at the end of the secondary regime.

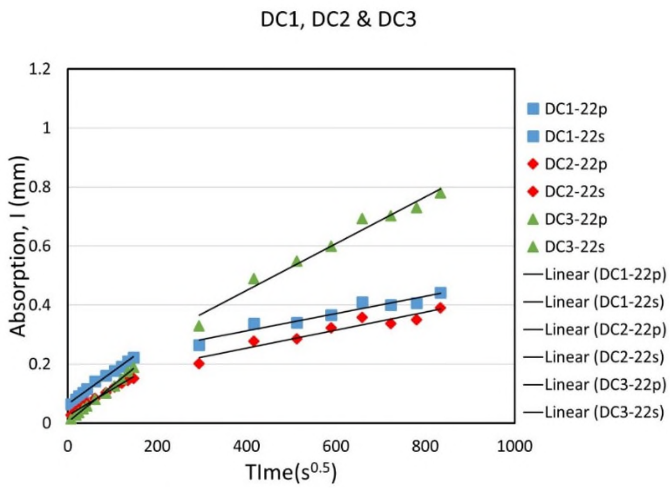


Figure 21. Water absorption vs. time (DC 1, 2, 3).

Figure 21 depicts the sorptivity of the sliced specimens during the absorption period as a function of the square root of time (for selected DCL1, DC2, and DC3 samples). The depth of penetration of the specimens increased until the sixth hour. At the end of the initial regime, the penetrations of 0.22, 0.18 and 0.19 mm were recorded for DCL1-22, DCL2-22, and DCL3-22, respectively. During the secondary regime, a monotonic increase in penetration was observed for DCL3-22, whereas a plateau state was observed for the latter portion of the secondary regime on DCL1-22 and DCL2-22 specimens. The final penetration values of DCL1-22, DCL2-22, and DCL3-22 were 0.39, 0.43, and 0.79 mm, respectively.

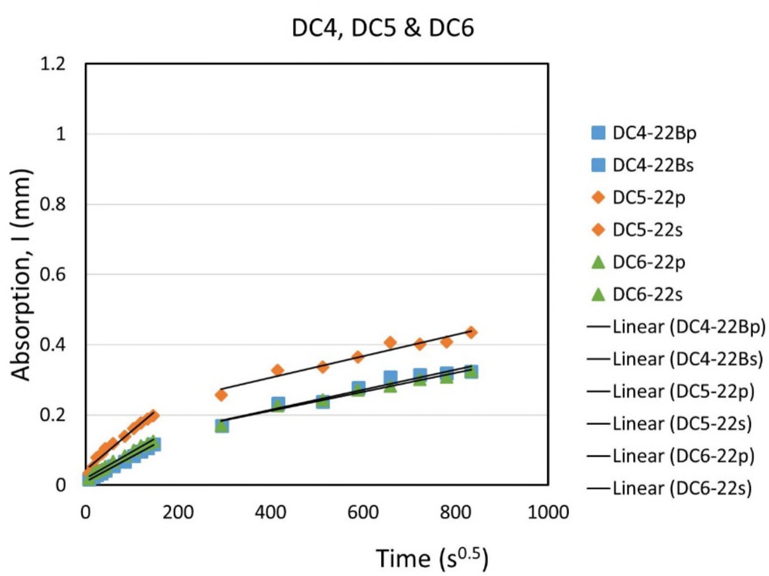
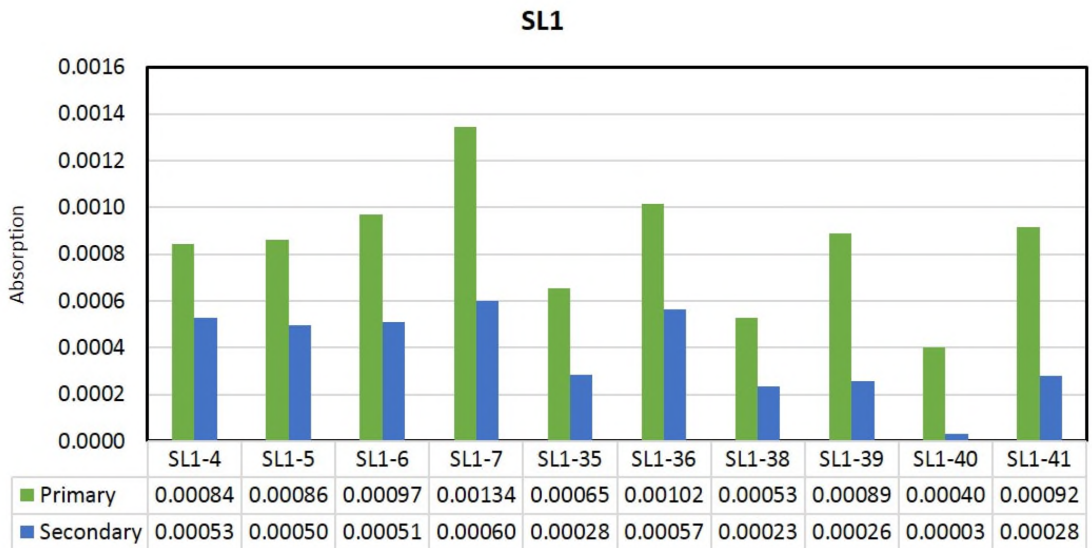


Figure 22. Water absorption vs time (DC 4, 5, 6).

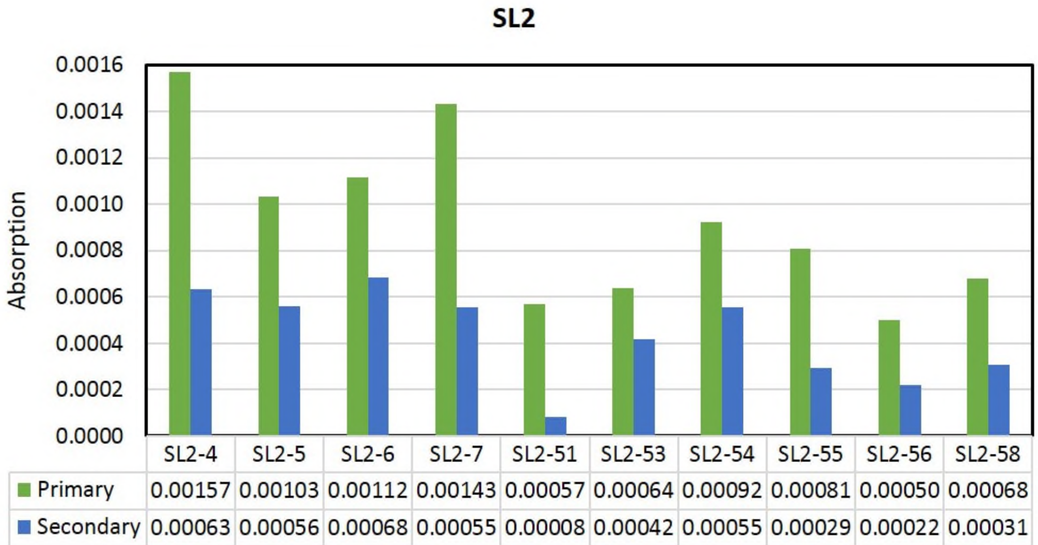
Figure 22 illustrates the absorption behavior on selected samples for the concrete mixtures DC4, DC5, and DC6 group(s). The graph compares the depth of penetrations and its tendency in DCL4-22B, DCL5-22 and DCL6-22 mixtures from 1 min to 7 days. As an overall trend, it is evident that a gradual increase is noticeable during the primary absorption and a more moderate penetration occurs during the secondary absorption regime. At the end of primary absorption, the upward trends were exhibited at 0.09, 0.2 and 0.1 mm penetration by DCL4-22B, DCL5-22 and DCL6-22, respectively. At the end of the secondary regime, the depths obtained were 0.33, 0.42 and 0.32 mm by DCL4-22B, DCL5-22 and DCL6-22, respectively. From the figure, it is also noticeable that during the secondary absorption regime the three samples experienced a gradual penetration followed by a plateau during the last three readings. Appendix E shows additional water absorption vs. time$^{1/2}$ plots for DC samples and Appendix F presents similar plots for the samples from mixes A to L.

In the following pages, the fitted water absorption rate (initial and secondary absorption rates) values are shown in bar plots with the tabulated values (rates are in mm/sec^{½}) grouped per mix type for most samples tested. It can be observed from Figure 23 and Figure 24 that specimen SL2-4 from mixtures SL exhibited the greater primary absorption compared with all the other SL specimens shown. Specimen SL2-6 exhibited the largest secondary absorption rate.



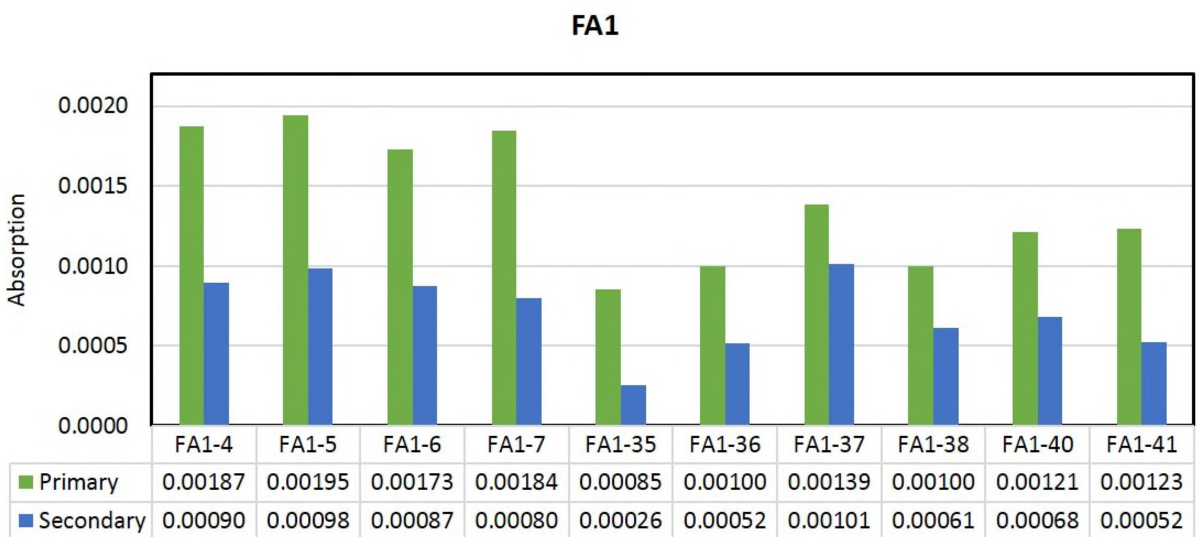
	SL1-4	SL1-5	SL1-6	SL1-7	SL1-35	SL1-36	SL1-38	SL1-39	SL1-40	SL1-41
Primary	0.00084	0.00086	0.00097	0.00134	0.00065	0.00102	0.00053	0.00089	0.00040	0.00092
Secondary	0.00053	0.00050	0.00051	0.00060	0.00028	0.00057	0.00023	0.00026	0.00003	0.00028

Figure 23. Primary and secondary absorption rate for SL1 specimens.



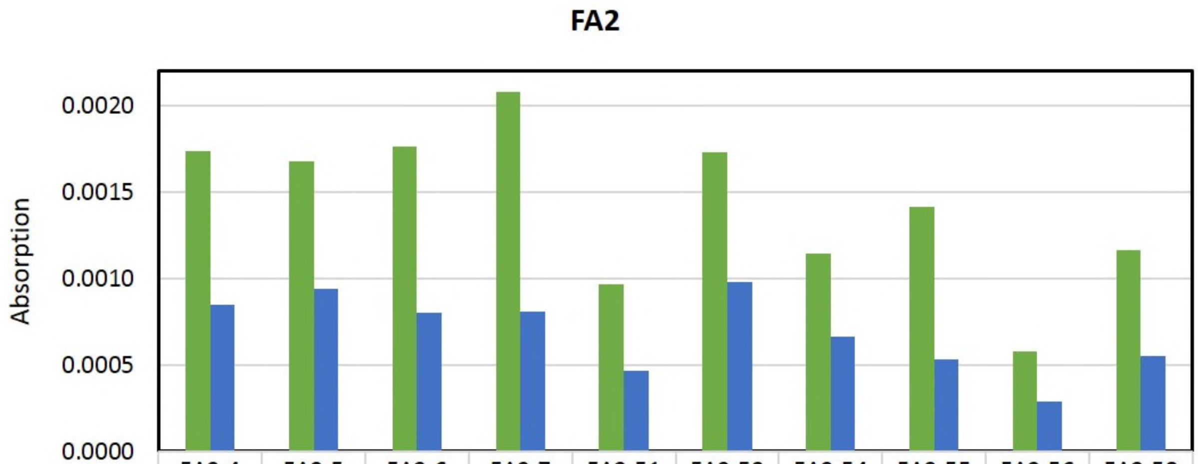
	SL2-4	SL2-5	SL2-6	SL2-7	SL2-51	SL2-53	SL2-54	SL2-55	SL2-56	SL2-58
Primary	0.00157	0.00103	0.00112	0.00143	0.00057	0.00064	0.00092	0.00081	0.00050	0.00068
Secondary	0.00063	0.00056	0.00068	0.00055	0.00008	0.00042	0.00055	0.00029	0.00022	0.00031

Figure 24. Primary and secondary absorption rate for SL2 specimens.



	FA1-4	FA1-5	FA1-6	FA1-7	FA1-35	FA1-36	FA1-37	FA1-38	FA1-40	FA1-41
Primary	0.00187	0.00195	0.00173	0.00184	0.00085	0.00100	0.00139	0.00100	0.00121	0.00123
Secondary	0.00090	0.00098	0.00087	0.00080	0.00026	0.00052	0.00101	0.00061	0.00068	0.00052

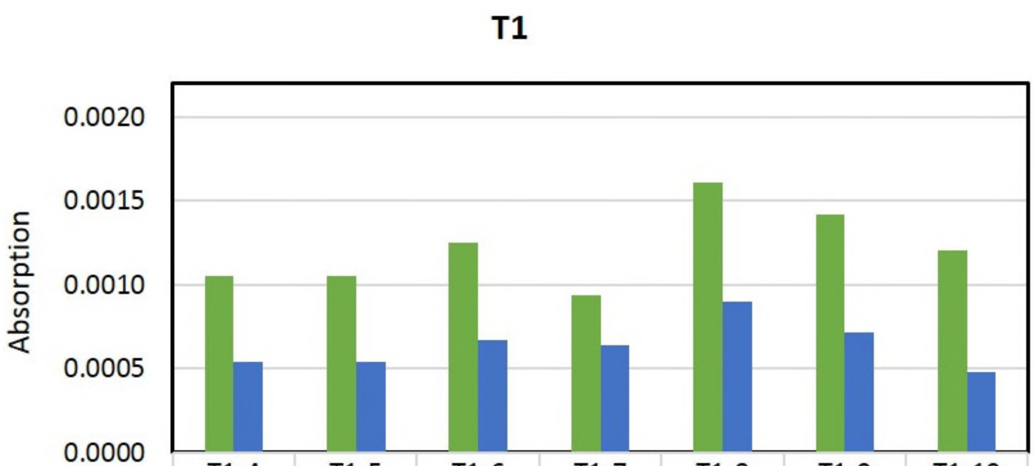
Figure 25. Primary and secondary absorption rate for FA1 specimens.



	FA2-4	FA2-5	FA2-6	FA2-7	FA2-51	FA2-53	FA2-54	FA2-55	FA2-56	FA2-58
Primary	0.00174	0.00168	0.00176	0.00208	0.00097	0.00173	0.00114	0.00142	0.00058	0.00117
Secondary	0.00085	0.00094	0.00080	0.00081	0.00047	0.00098	0.00066	0.00053	0.00029	0.00055

Figure 26. Primary and secondary absorption rate for FA2 specimens.

Figure 25 and Figure 26 show the primary and secondary rate of absorption for FA specimens. The specimens that absorbed the least during the primary regime were specimens FA1-35 and FA2-56, whereas the greatest were for specimens FA1-5 and FA2-7. Specimens FA1-4 to FA1-7, FA1-37, FA2-4 to FA2-7 and FA2-53 had final secondary absorption between 0.8 and 1.2 mm, whereas FA1-35 and FA2-56 had the lowest two secondary values of around <0.3 mm. Figure 27 and 28 show the primary and secondary absorption rates measured on specimens T1 and T2, respectively. As shown in Figure 23 and Figure 24, concrete mixes containing slag (SL mixes) had lower water sorptivity values than fly ash mix specimens (Figure 25 and Figure 26) and ternary (fly ash and 50% slag) concrete mixes at all times. Concrete mixtures with 50% slag (SL1-7, SL1-39, SL2-4, SL2-55) showed lower sorptivity values than T1-7 and all FAs.



	T1-4	T1-5	T1-6	T1-7	T1-8	T1-9	T1-10
Primary	0.00105	0.00105	0.00125	0.00094	0.00161	0.00142	0.00120
Secondary	0.00054	0.00054	0.00067	0.00064	0.00090	0.00071	0.00048

Figure 27. Primary and secondary absorption rate for T1 specimens.

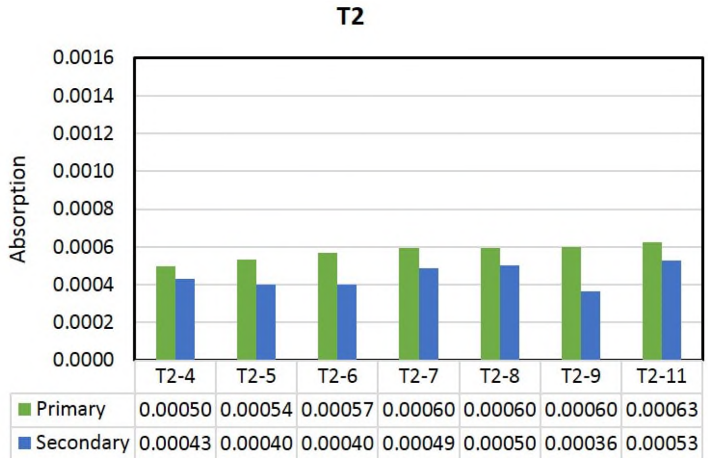


Figure 28. Primary and secondary absorption rate for T2 specimens.

In general, the initial and secondary absorption behavior varied from one group of mixtures to the other. In some cases, the variation in the rate of absorption was observed even within a given mix, due to different curing regimes. The water absorption rates were observed to decrease as the concrete aged on SL and FA specimens. It is speculated that high-performance mature concrete tends to have a more discontinuous pore system (and lower porosity), thus the water absorption rate due to the capillary pores suction is reduced, when compared to OPC concrete. Figure 29 to Figure 40 show that the secondary sorptivity values of DC's specimens. The rates of absorption on DCL8 samples were comparable or larger than the corresponding values measured on SL1, and SL2 specimens. DCL2 compares in composition to FA1, FA2 samples. Finally, DCL4 samples have similar composition than T2 specimens. Primary and secondary rate of absorption tended to be smaller on T2 specimens than on DCL4 specimens.

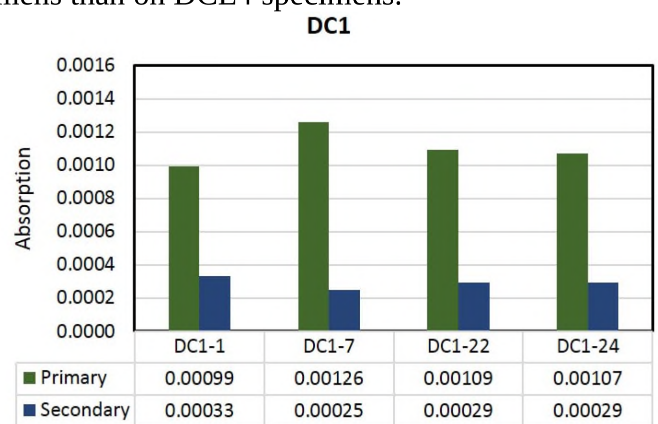


Figure 29. Primary and secondary absorption rate for DC1 specimens.

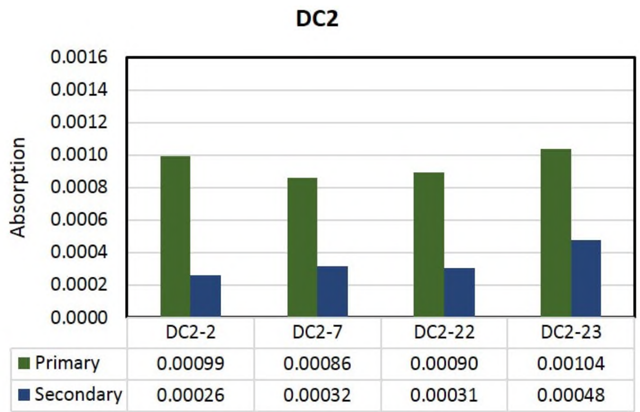


Figure 30. Primary and secondary absorption rate for DC2 specimens.

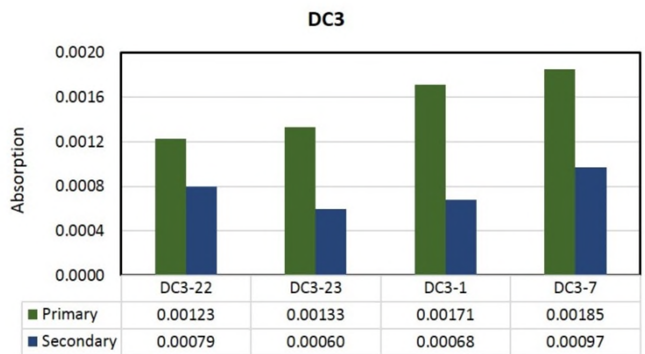


Figure 31. Primary and secondary absorption rate for DC3 specimens.

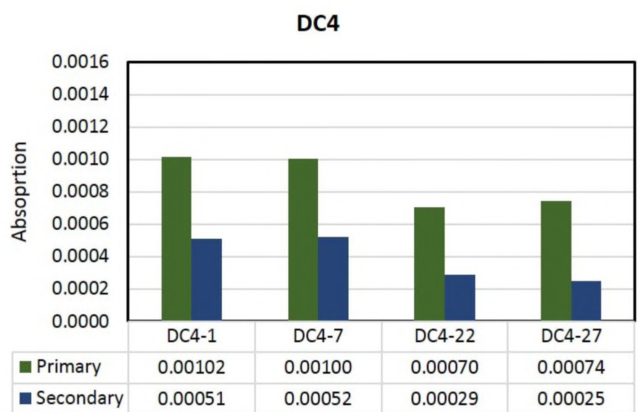


Figure 32. Primary and secondary absorption rate for DC4 specimens.

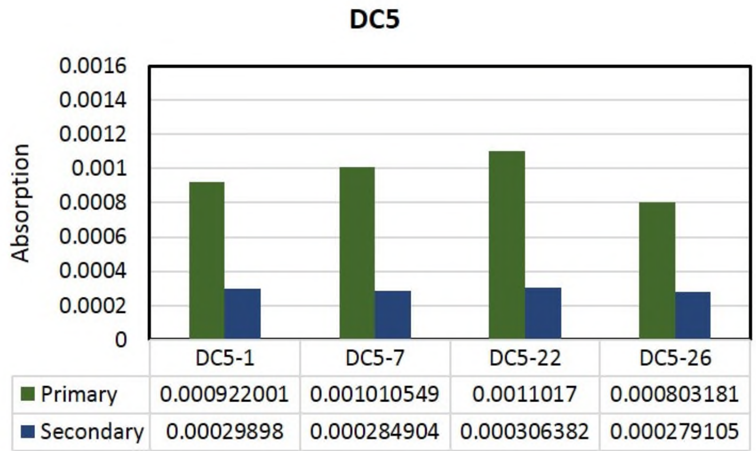


Figure 33. Primary and secondary absorption rate for DC5 specimens.

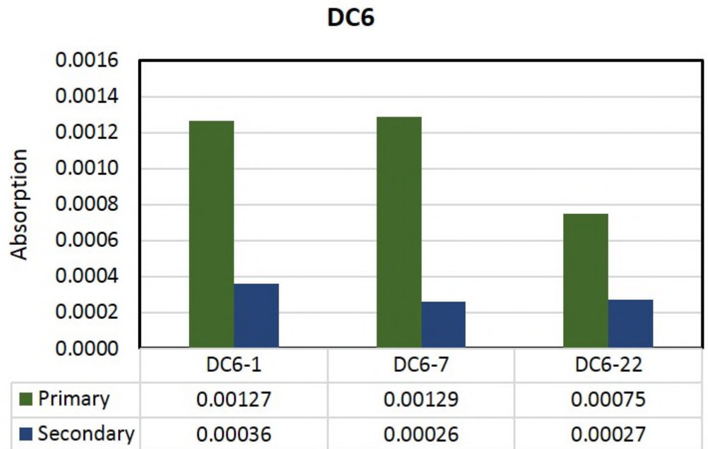


Figure 34. Primary and secondary absorption rate for DC6 specimens.

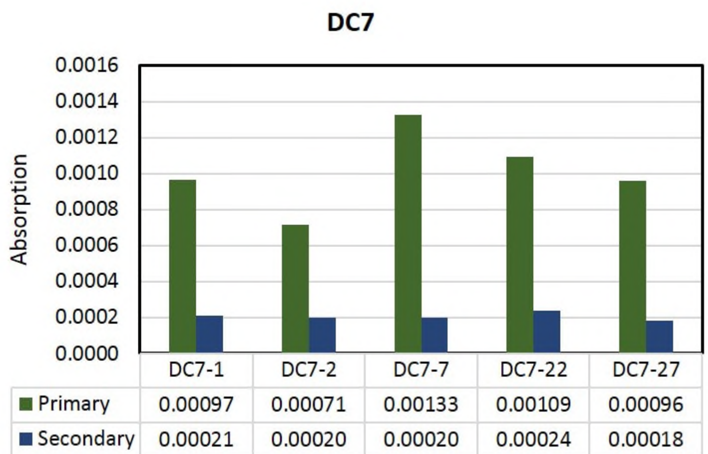


Figure 35. Primary and secondary absorption rate for DC7 specimens.

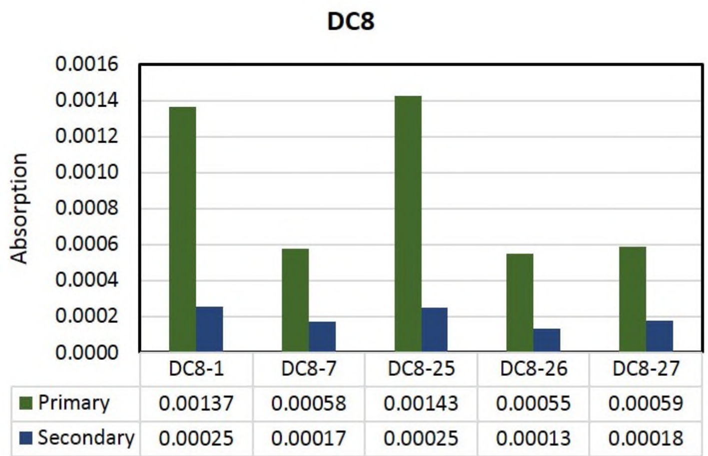


Figure 36. Primary and secondary absorption rate for DC8 specimens.

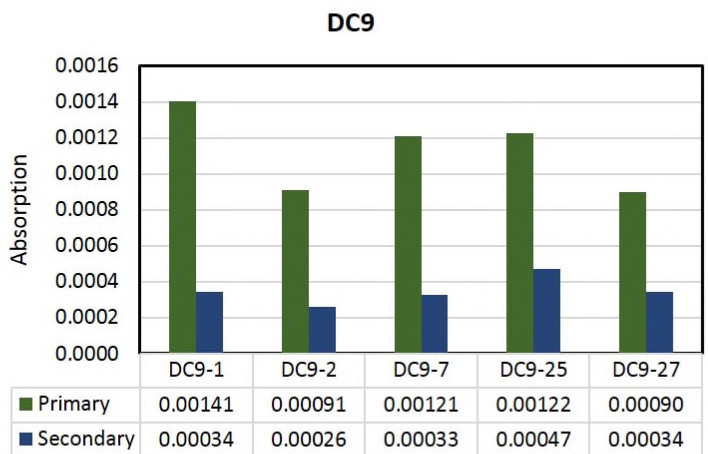


Figure 37. Primary and secondary absorption rate for DC9 specimens.

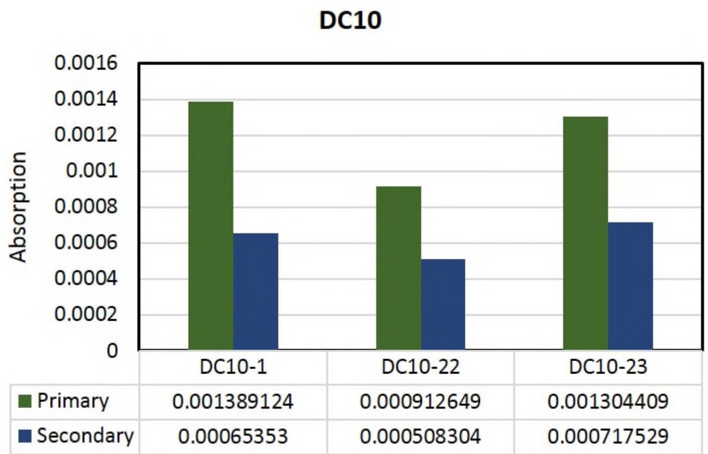


Figure 38. Primary and secondary absorption rate for DC10 specimens.

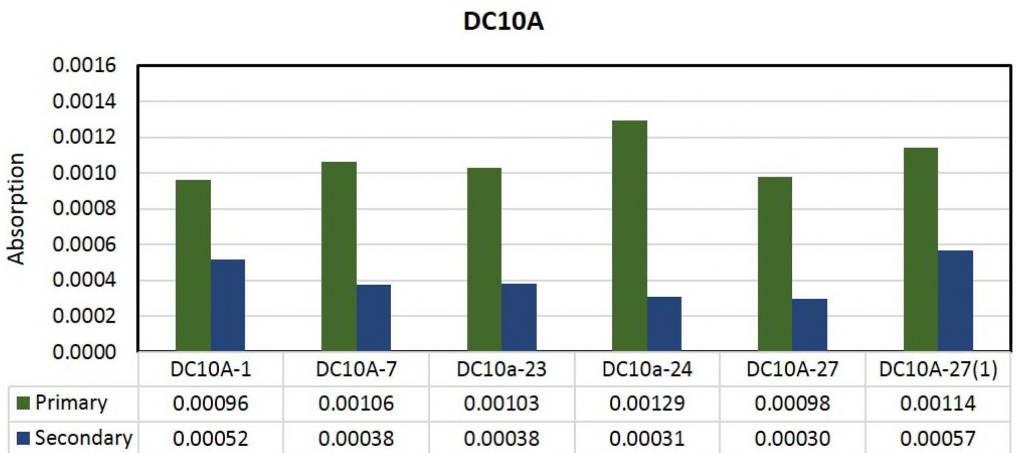


Figure 39. Primary and secondary absorption rate for DC10a specimens.

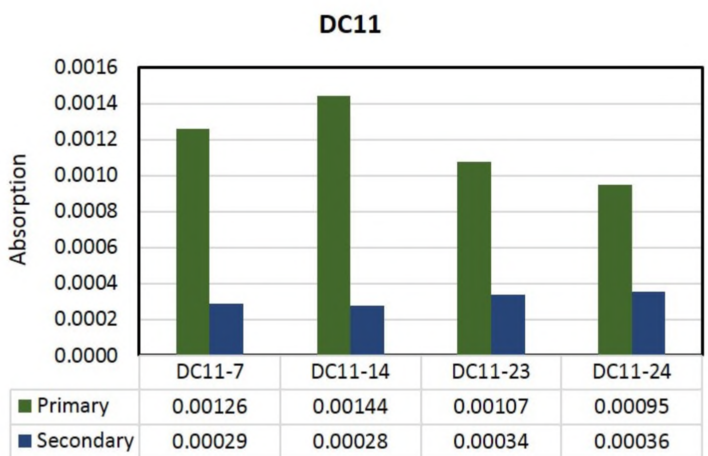


Figure 40. Primary and secondary absorption rate for DC11 specimens.

One of the specimens that experienced the greatest primary and secondary absorption, was prepared with a 0.47 w/cm ratio (20% FA DCL 3-22). The specimens that absorbed the least were from DCL4-22B and DCL 6-22, both with fly ash and silica fume and w/cm of 0.37 and 0.47, respectively. The specimens from DCL 4-22B, DCL 5-22, and DCL 6-22 experienced low secondary absorption rates and reached penetrations of 0.4 ~ 0.5 mm at the end of the monitoring period. Silica fume is an ultrafine material. It tends to strengthen the interfacial transition zone (ITZ) by better particle packing and providing nucleation for the pozzolanic reaction with portlandite. Concrete mixes containing fly ash and silica fume had lower initial water sorptivity values because of the combined effects of fly ash and silica fume effects on concrete pore structure. For example, specimens T2-7, DCL 4-22B & DCL 6-22 experienced some of the lowest primary absorption values (20% fly ash and 8% silica fume).

Since the ability of concrete to resist water penetration is influenced by the connectivity of its capillary pore structure, lower w/cm ratio mixes had lower sorptivity values as shown in Figure 29 and Figure 32 (DCL 1, DCL 4). Concrete mixes with low w/cm ratio tend to have lower porosity and the pore system is less continuous. These mixes typically result in a lower amount of water absorbed by the capillary suction. Here lower w/cm ratios of 0.35 (DCL 1, DCL4, DCL7, and T2) experienced the lowest sorptivity values. Since higher w/cm ratios result in higher porosity and high continuity of the pore structure, the water sorptivity of the DCL (3, 6, 9) 0.47 mix exhibited the highest sorptivity value.

It is important to mention that the mixes containing fly ash+silica fume (DCL4, DCL5, DCL6) and slag DCL (DCL7, DCL8, DCL9) had relatively fast initial sorptivity due to their finer pore structure, but sorptivity likely decreased rapidly in part due to a more tortuous pore structure. (These samples were several years old by the time of the sorptivity tests took place.)

It can be concluded that the water sorptivity is influenced by factors affecting the capillary pore system and its continuity such as the w/cm ratio and the addition of SCMs. Although the relative humidity of the specimens used for laboratory sorptivity test was constant, it has been discussed by other researchers (e.g., Nokken [14]) that concrete sorptivity decreases with an increasing degree of saturation and also a decreasing w/cm ratio.

Appendix G presents figures (as those shown above e.g., Figure 40) for the primary and secondary rate of absorption for samples prepared with A to L mixes. Appendix H contains tables with the primary and secondary absorption rate measured on all specimens and includes the sample name and the date/age at which a given specimen was tested.

3.5 D_{nssm} results

The following pages will present the results of the RMT tests. D_{nssm} measured on DCL concrete cylinders is presented in Table 20, followed by D_{nssm} measured on cylinders with compositions A to L (Table 21). Table 22 shows the D_{nssm} values obtained on cylinders as part of the resistivity round robin study from a few years back; it also includes D_{nssm} values obtained on cylinders prepared with reactive aggregate that is prone to alkali-silica reaction and D_{nssm} values obtained on Key Royale concrete slices. Finally, Tables 23 and 24 display the D_{nssm} results for tests run on concrete cylinders prepared during Spring 2016 and Summer 2016, respectively.

Table 20. D_{nssm} measured on DCL specimens.

Age (days)	DCL1	Cast	Test	$D_{nssm} \times 10^{-12}$ m²/s
1681	DCL1-2a	Dec 7, 2011	July 14, 2016	1.04
	DCL1-2b			1.18
1923	DC1-1a		Mar. 21, 2017	1.65
	DC1-27			1.3
	DC1-24			1.33
1758	DCL 2-22a	9/22/2011	7/15/2016	1.99
	DCL 2-22b	9/22/2011	7/15/2016	2.00
2037	DC2-2	9/22/2011	4/20/2017	1.80
	DC-2-23	9/22/2011	4/20/2017	2.25
	DC2-7	9/22/2011	4/20/2017	1.68
1726	DCL 3-22a	10/18/2011	7/9/2016	3.09
	DCL-3-22b	10/18/2011	7/9/2016	2.91
2011	DC3-1	10/18/2011	4/20/17	2.27
	DC3-1a	10/18/2011	4/24/17	2.62
	DC3-23	10/18/2011	4/24/17	2.24
1671	DCL 4-22a	12/21/2011	7/18/2016	1.32
	DCL 4-22b1	12/21/2011	7/18/2016	1.50
1917	DC4-7a	12/21/2011	3/21/17	1.52
	DC4-27	12/21/2011	3/21/17	1.84
	DC4-1a	12/21/2011	3/21/18	1.70
1671	DCL 5-22a	12/21/2011	7/18/2016	0.71
	DCL 5-22b	12/21/2011	7/18/2016	0.58
1947	DC5-1	12/21/2011	4/20/17	1.36
	DC5-26	12/21/2011	4/20/17	0.88
	DC5-27	12/21/2011	4/20/17	1.41
	DC5-7	12/21/2011	4/20/17	0.80
1723	DCL 6-22a	10/26/2011	7/14/2016	1.06
	DCL 6-22b	10/26/2011	7/14/2016	1.21
2007	DC6-1	10/26/2011	4/24/17	1.36
	DC6-7	10/26/2011	4/24/17	0.82
	DC6-24	10/26/2011	4/20/17	0.83

Table 20. Continues

Age (days)	DCL8	Cast	Test	$D_{nssm} \times 10^{-12}$ m^2/s
1673	DC7-22A	12/14/2011	7/13/2016	2.41
	DC7-22B	12/14/2011	7/13/2016	1.89
1916	DC7-1a-A	12/14/2011	3/13/17	3.04
	DC7-27a-A	12/14/2011	3/13/17	2.14
	DC7-7	12/14/2011	4/24/17	2.25
	DC7-7a-A	12/14/2011	3/13/17	1.92
1691	DC8-25A	11/22/2011	7/9/2016	2.73
	DC8-25B	11/22/2011	7/9/2016	2.34
1980	DC8-1	11/22/2011	4/24/17	1.12
	DC8-26	11/22/2011	4/24/17	1.15
	DC8-27	11/22/2011	4/24/17	1.42
	DC8-7	11/22/2011	4/24/17	2.63
1717	DC9-25A	11/2/2011	7/15/2016	2.96
	DC9-25B	11/2/2011	7/15/2016	3.01
1996	DC9-1	11/2/2011	4/20/17	1.63
	DC9-26	11/2/2011	4/20/17	1.63
	DC9-27	11/2/2011	4/20/17	2.23
	DC9-7	11/2/2011	4/24/17	1.07
1752	DC10-22A	9/28/2011	7/15/2016	2.95
	DC10-22B	9/28/2011	7/15/2016	3.32
1993	DC10-1a	9/28/2011	3/13/17	4.84
	DC-10-23a	9/28/2011	3/13/17	4.33
1736	DC10a-23A	10/12/2011	7/13/2016	3.67
	DC10a-23B	10/12/2011	7/13/2016	2.31
2021	DC10a-24	10/12/2011	4/24/17	1.74
	DC10a-24a	10/12/2011	4/27/17	1.57
	DC10a-27a	10/12/2011	3/13/17	4.52
	DC10a-27b	10/12/2011	3/13/17	4.34
	DC10a-1a	10/12/2011	3/13/17	2.87
1703	DC10b-23A	11/16/2011	7/15/16	2.94
	DC10b-23B	11/16/2011	7/15/16	3.07
1944	DC10b-1a	11/16/2011	3/13/17	3.07
	DC10b-24a	11/16/2011	4/24/17	1.24
	DC10b-7a	11/16/2011	4/24/17	1.36
1710	DC11-23A	11/9/2011	7/15/2016	3.05
	DC11-23B	11/9/2011	7/15/2016	2.67
1948	DC11-1A	11/9/2011	3/10/17	2.8
	DC11a-24a	11/9/2011	3/13/17	3.8
	DC11a-7a	11/9/2011	3/13/17	4.12

NOTE: The date format is mm/dd/yyyy

Table 21. D_{nssm} for specimens prepared with mixes A to L.

Test Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s	Test Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s
7/1/16	A1	0.76	6/13/16	D1	1.67
7/1/16	A2	0.62	7/6/16	D2	0.3
5/23/16	A3	2.42	7/6/16	D3	0.28
3/28/16	A12a	1.91	6/9/2017	FD22	0.33
3/28/16	A12b	1.14	6/9/2016	FD23	0.34
6/4/16	FAA23	1.33	3/15/17	FD-27a	0.74
6/1/16	FAA28	1.61	3/15/17	FD-27b	0.81
9/16/16	Ai-1	1.88	9/16/16	E1	1.48
9/16/16	Ai-2	2.82	9/16/16	E2	1.16
9/16/16	Ai-3	1.77	9/16/16	E3	1.71
3/28/16	FAi12	2.02	3/28/16	E12	1.54
3/28/16	FAi12b	1.67	3/28/16	E12	1.47
6/4/16	FA23	2.28	6/1/16	FE22	1.25
6/4/16	FA28	1.63	6/1/16	FE23	1.81
			10/27/16	FE-28	0.56
6/7/16	B1	0.39			
7/3/16	B2	0.41	7/1/16	F1	0.99
6/1/16	B3	1.61	5/23/16	F2	1.72
3/30/16	B12a	1.01	7/1/16	F3	0.7
3/30/16	B12b	1.04	9/16/16	FF-23A	0.67
10/27/16	FBB-28	0.68	9/16/16	FF-23B	0.55
6/7/16	FBB23	0.76	3/21/17	FF-27b	1.17
6/1/16	FBB27	0.85	3/10/17	FF-27A	1.15
7/3/2016	Bi1	0.84	7/2/16	G1	2.14
7/3/16	BI2	0.95	7/2/16	G2	1.99
7/3/16	BI3	1.16	5/23/16	G3	2.61
3/30/2016	Bi12a	1.07	3/29/16	G12	1.35
3/30/2016	Bi12b	1.06	3/30/16	G12b	1.61
6/7/2016	FB23	0.61	9/16/16	FG-23	1.34
6/7/16	FB29	1.13	9/16/16	FG-28	1.05
			10/27/16	FG-22	0.89
7/1/16	C1	0.81			
5/23/16	C2	1.51	7/3/16	H1	4.19
7/2/16	C3	1.69	7/3/16	H2	2.51
4/4/2016	C12a	1.20	6/1/16	H3	1.41
4/4/2016	C12b	1.18	3/28/16	H12	0.51
9/16/16	FC-23A	0.7	3/30/16	H12	1.09
9/16/16	FC-23B	0.61	6/9/2016	FH23	0.52
10/27/16	FC-22	0.75	6/7/16	FH28	0.79

Table 21 continues

Test Date	**Sample**	**D_{nssm} × 10^{-12} m^2/s**	**Test Date**	**Sample**	**D_{nssm} × 10^{-12} m^2/s**
9/16/16	I-1	1.1	3/15/17	L1	1.66
9/16/16	I-2	1.07	4/27/17	L2a	0.66
9/16/16	I-3	1.02	3/15/17	L3a	0.95
3/21/17	FI-22b	0.74	3/15/17	FL-22-A	2.17
3/21/17	FI-22a	0.89	3/15/17	FL-22-B	1.9
6/7/16	FI23	0.85	3/15/17	FL-23	1.41
6/4/16	FI28	1.19	3/15/17	FL-28a	1.31
7/2/16	J1	1.09	10/27/16	CRA-10	3.23
6/2/16	J2	1.74	10/27/16	CRA-11	3.6
7/2/16	J3	1.52	10/27/16	CRA-12	3.61
4/4/2016	J12a	0.67	7/21/16	CRA13-A	9.43
4/4/2016	J12b	0.95	7/21/16	CRA13-B	8.5
6/4/16	FJ28	0.8	7/21/16	CRA15-A	4.86
6/2/16	FJ23	1.76	7/21/16	CRA15-B	4.96
7/3/16	K1	3.84			
7/3/16	K2	1.34			
6/1/16	K3	1.09			
9/16/16	FK-23A	0.65			
9/16/16	FK-23B	0.76			
9/16/16	FK-28A	0.47			
9/16/16	FK-28B	0.46			

NOTE: The date format is mm/dd/yyyy
NOTE: The dates on the tables are the date in which the NT Build 492 was run on the named concrete cylinder slice(s) sample.

CRA specimens contain 10% FA, these specimens appear to have somewhat larger D_{nssm} values than the specimens with 20% FA (Group A and Ai). The spread of the observed D_{nssm} values on a given mix composition might be due to the different curing schedule and concrete composition.

Table 22. D_{nssm} for other concrete cylinders at FAU, and round robin samples.

Test Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s	Test Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s
9/20/16	CDOT	0.80	10/4/16	HASR1-54A-bottom	4.57
9/20/16	CEMEX-13	0.48	10/4/16	HASR1-54A-A	4.49
9/20/16	FHWA-37	1.28	10/4/16	HASR1-54AB	4.87
9/29/16	FLDOT-40	0.37	10/4/16	HASR1-54A-Top	5.62
9/20/16	NEDOT-1	0.95	10/4/16	HASR1-54B A	6.10
9/20/16	NEDOT-3	3.02	10/4/16	HASR1-54B B	5.79
9/20/16	NY-HK-174	0.43	10/4/16	HASR1-54B-bottom	5.77
9/20/16	NY-HK-174b	0.43	10/4/16	HASR1-54B-Top	5.01
9/20/16	VA-10	1.09	9/20/16	HASR2-55-bottom	5.59
9/20/16	VA-7-21	0.94	9/20/16	HASR2-55A	6.59
			9/20/16	HASR2-55B	5.80
7/3/16	FP1-B - OPC	4.21	9/20/16	HASR2-55T	5.68
7/6/16	FP2-1-UFA	0.62	10/4/16	HASR1-54A-bottom	4.57
7/1/16	FP3-2-FA	1.06	10/4/16	HASR1-54A-A	4.49
7/6/16	FP4-1-SF	0.87	10/4/16	HASR1-54AB	4.87
7/6/16	FP5-2-BFS	0.58	10/4/16	HASR1-54A-Top	5.62
7/2/16	FP6-2-MET	1.32	10/4/16	HASR1-54B A	6.10
			10/4/16	HASR1-54B B	5.79
			10/4/16	HASR1-54B-bottom	5.77

NOTE: The date format is mm/dd/yyyy

Table 23. D_{nssm} for FA and SL specimens (prepared 04/2016).

Test Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s	Test Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s
6/20/16	SL1-4	2.51	6/21/16	FA1-4	9.61
6/20/16	SL1-5	3.54	6/21/16	FA1-5	7.2
6/20/16	SL1-6	2.95	6/21/16	FA1-6	6.16
6/20/16	SL1-7	2.82	6/21/16	FA1-7	6.42
10/26/16	SL1-8	2.96	10/26/16	FA1-8	3.04
10/26/16	SL1-9	2.72	10/26/16	FA1-9	3.61
5/31/16	SL1-36-A	3.07	3/20/17	FA1-36a	4.76
5/31/16	SL1-36-B	3.03	3/10/17	FA1-36b	5.54
3/10/17	SL1-35-A	3.84	6/15/16	FA1-37a	6.14
3/10/17	SL1-35-B	2.83	6/15/16	FA1-37b	5.97
10/13/16	SL1-38	3.36	5/19/17	FA1-35a	3.91
7/21/16	SL1-39A-a	1.95	5/19/17	FA1-35b	3.88
7/21/16	SL1-39A-B	2.57	10/21/16	FA1-38	4.48
5/19/17	SL1-40A	2.38	7/21/16	FA1-40a	4.73
5/19/17	SL1-40B	2.36	7/21/16	FA1-40b	5.12
5/19/17	SL1-41A	2.58	5/19/17	FA1-41a	3.95
5/19/17	SL1-41B	2.54	5/19/17	FA1-41b	3.93
11/30/2017	SL1-45A	1.02	11/30/2017	FA1-45	0.98
11/30/2017	SL1-45B	0.82	6/15/16	FA1-53a	6.02
6/20/16	SL2-4	3.4	6/15/16	FM1-53b	5.03
6/20/16	SL2-5	2.77	6/21/16	FA2-4	11.28
6/20/16	SL2-6	1.94	6/21/16	FA2-5	11.43
6/20/16	SL2-7	1.8	6/21/16	FA2-6	8.25
10/26/16	SL2-8	1.8	6/21/16	FA2-7	9.31
10/26/16	SL2-9	2.09	10/26/16	FA2-8	3.34
3/20/17	SL2-35a	2.38	10/26/16	FA2-9	4.18
3/20/17	SL2-35b	3.04	10/21/16	FA2-54	3.88
3/20/17	SL2-56a	3.34	3/10/17	FA2-51a	3.21
3/10/17	SL2-56B	2.69	3/10/17	FA2-51b	3.33
5/31/16	SL2-54	3.23	3/20/17	FA2-52a	3.5
5/31/16	SL2-54T	3.22	3/20/17	FA2-52b	6.48
10/13/16	SL2-53	2.53	7/21/16	FA2-55a	3.15
5/19/17	SL2-58A	2.3	7/21/16	FA2-55b	3.39
5/19/17	SL2-58B	2.3	5/19/17	FA2-56A	3.51
5/19/17	SL2-51A	2.4	5/19/17	FA2-56B	3.52
5/19/17	SL2-51B	2.3	5/19/17	FA2-58A	3.78
12/11/17	SL2_60	2.9	5/19/17	FA2-58B	3.76
			11/30/2017	FA2_60	1.75

NOTE: The date format is mm/dd/yyyy

The D_{nssm} was larger on the specimens tested at the earlier age (see Table 23). In the case of SL specimens, it was close to 3×10^{-12} m^2/s and in the case of FA, 11.2×10^{-12} m^2/s. The resistivity values via the two-point method were measured before performing the vacuum step as well as after but prior to applying the potential gradient. Table 24 shows the D_{nssm} values measured on T1 and T2 specimens.

Table 24. T1 and T2 D_{nssm} Results

Date	**Sample**	**$D_{nssm} \times 10^{-12}$ m^2/s**
4/24/17	T1-4	1.4
4/24/17	T1-5	1.73
3/10/17	T1-6A	2.46
3/10/17	T1-6B	3.32
10/21/16	T1-7	3.88
3/10/17	T1-8A	3.6
3/10/17	T1-8B	3.57
3/10/17	T1-9A	2.85
3/10/17	T1-9B	2.1
5/19/17	T1-10A	1.55
5/19/17	T1-10B	1.59
Date	Sample	$D_{nssm} \times 10^{-12}$ m^2/s
4/27/17	T2-4	1.89
4/27/17	T2-5	1.71
3/6/17	T2-6-A	2.79
3/6/17	T2-6-B	4.07
10/21/16	T2-7	3.07
3/6/17	T2-8-A	3.01
3/6/17	T2-8-B	3
3/6/17	T2-11-A	3.15
3/6/17	T2-11-B	4.39
5/19/17	T2-9A	1.01
5/19/17	T2-9B	1.02
12/11/17	T2-12-A	1.52
12/11/17	T-12-B	1.40

NOTE: The date format is mm/dd/yyyy

3.6 Chloride profiles

Figure 41 displays the chloride profiles obtained after the bulk diffusion test was performed on DC1. Figure 42 displays three profiles obtained on DC2 specimens after performing the bulk diffusion test. The profiles for the other DC, DC low chloride, SL, FA, T1, T2, and A to L specimens are included in Appendices I, J, K and L.

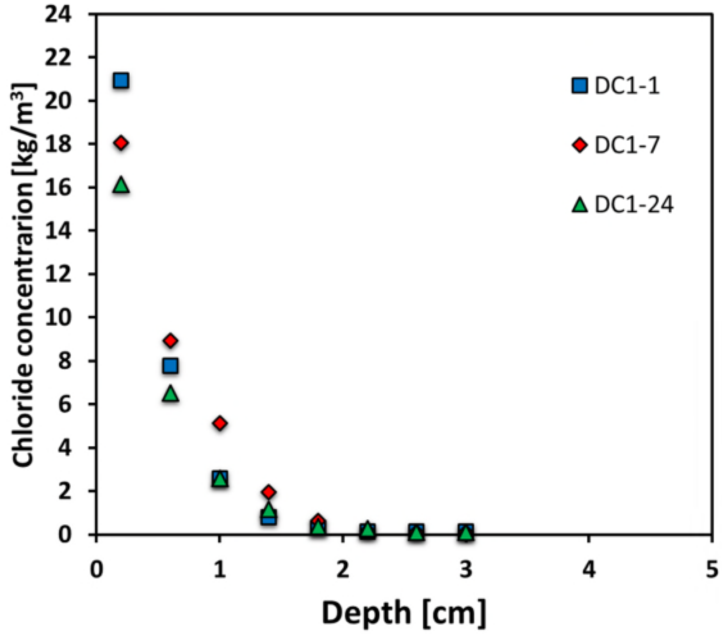


Figure 41. Chloride profiles for DC1 specimens.

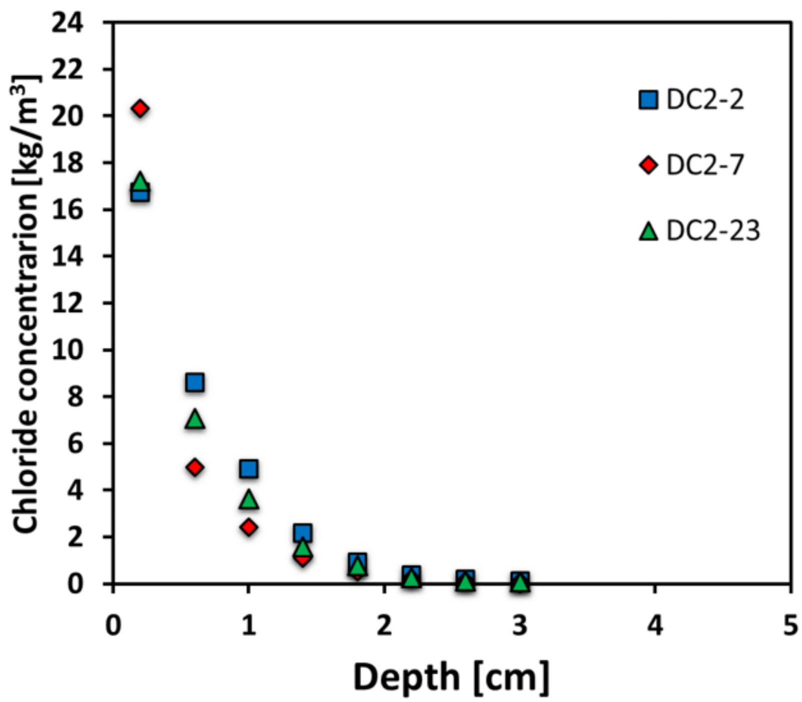


Figure 42. Chloride profiles for DC2 specimens.

Figure 43 shows the chloride profiles obtained after exposing the concrete slices (one per fender piles) obtained from the 10 cm diameter cores at the Key Royale bridge.

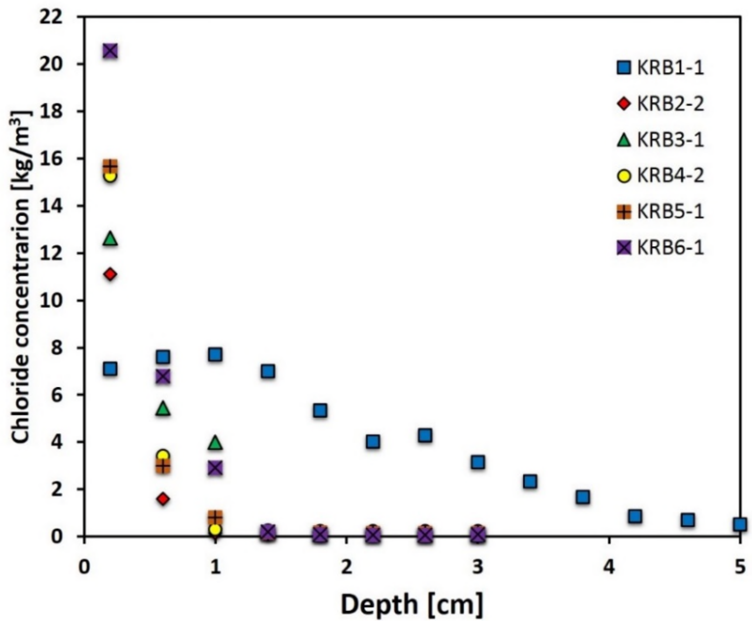


Figure 43. Chloride profiles for KRB samples.

The profiles that follow are for samples immersed in 6 g/L of NaCl. Figure 44 shows that for DC1 and DC2 the concentration on the first layer was close to 10 Kg/m^3, a significantly smaller concentration than observed in Figure 41 and Figure 42 for DC1 and DC2, respectively.

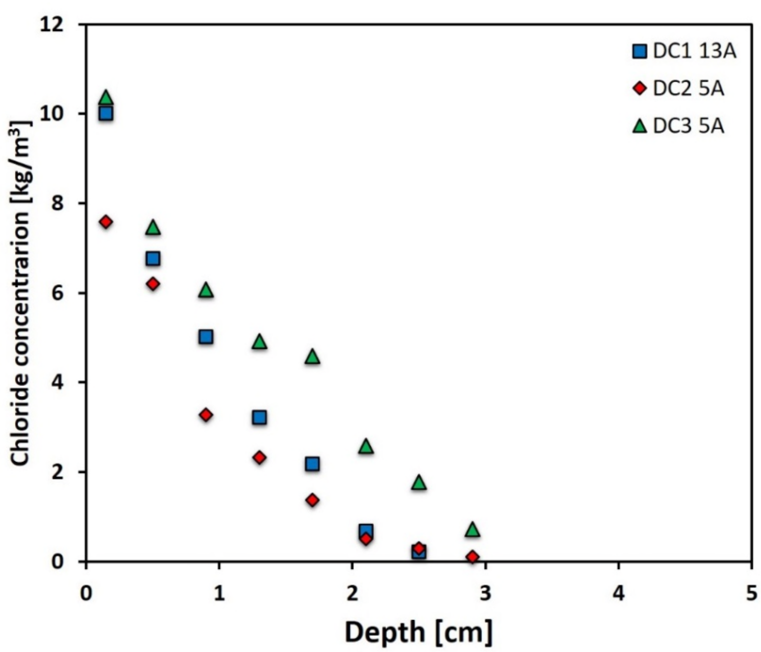


Figure 44. Chloride profiles from bulk diffusion for samples exposed to low chloride concentration.

Appendix M contains plots of the chloride profiles for the field simulated samples. The profiles were obtained at 4 elevations up to 30 months, and at 54 months of exposure. On some samples, cores were obtained at three or two elevations only (see experimental section). These plots are grouped per exposure type and elevation. The profiles on these plots are vs. percent cementitious content.

Chapter 4 – Discussion

4.1 Sorptivity vs. time

The rate of water absorption (primary and secondary) was measured over time on selected samples prepared in 2016. Figure 45 shows the primary rate of absorption measured on SL, FA, T1 and T2 samples. The primary rate of absorption for all groups appears to have some scatter. There appears to be a trend toward lower a primary rate of absorption on FA and SL samples. However, it appears that the primary rate plateaus after 200 days of age. The primary rate of absorption was first measured at 100 days on T1 and T2 samples. The primary rate of absorption remained the same on T2 samples, and on T1 samples, the smallest primary rate was observed at 100 days, and tended to show somewhat larger values at later times. However, the later values were not significantly larger than those measured at 100 days of age. The primary rate for SL and T2 samples reached a value of 0.0005 mm/s$^{1/2}$. For FA and T1 the terminal primary rate was close to 0.001 mm/s$^{1/2}$.

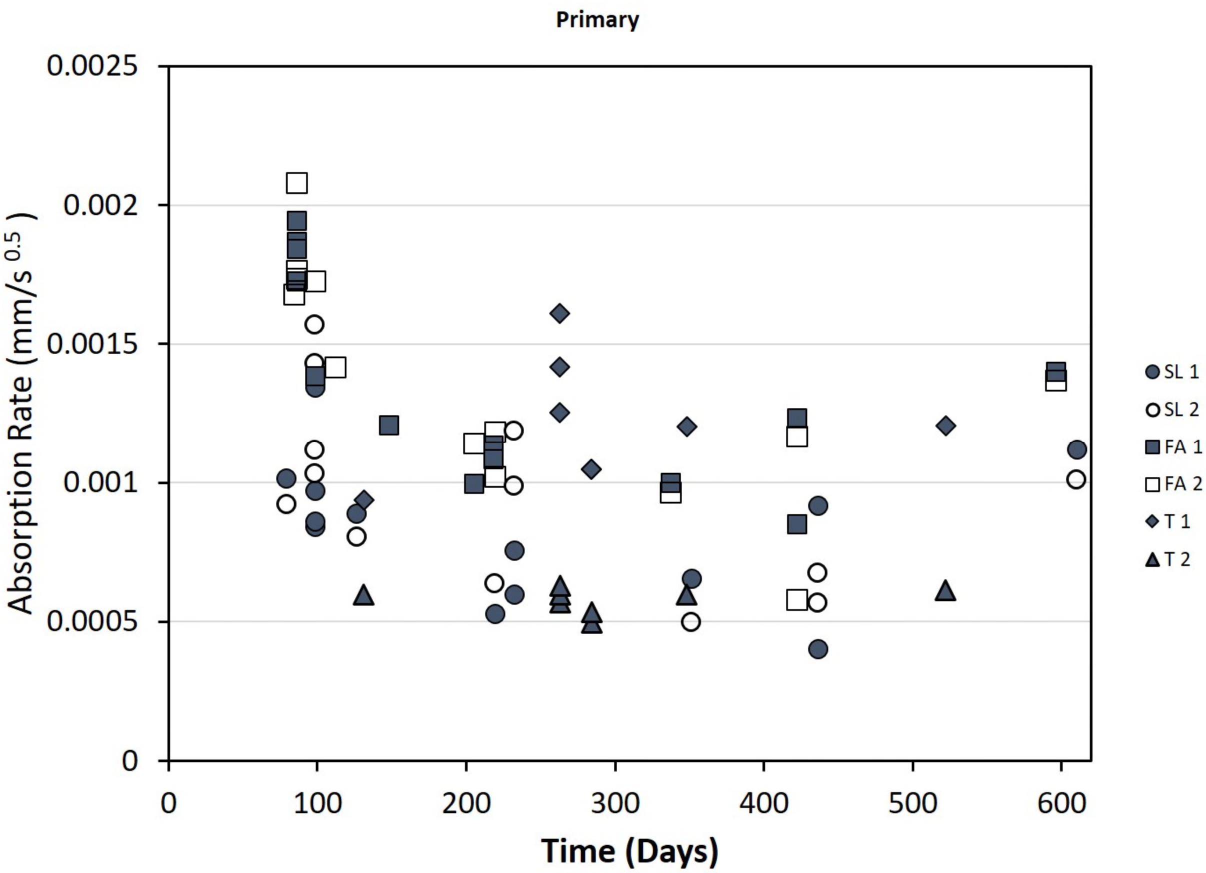


Figure 45. Primary rate of absorption vs. time

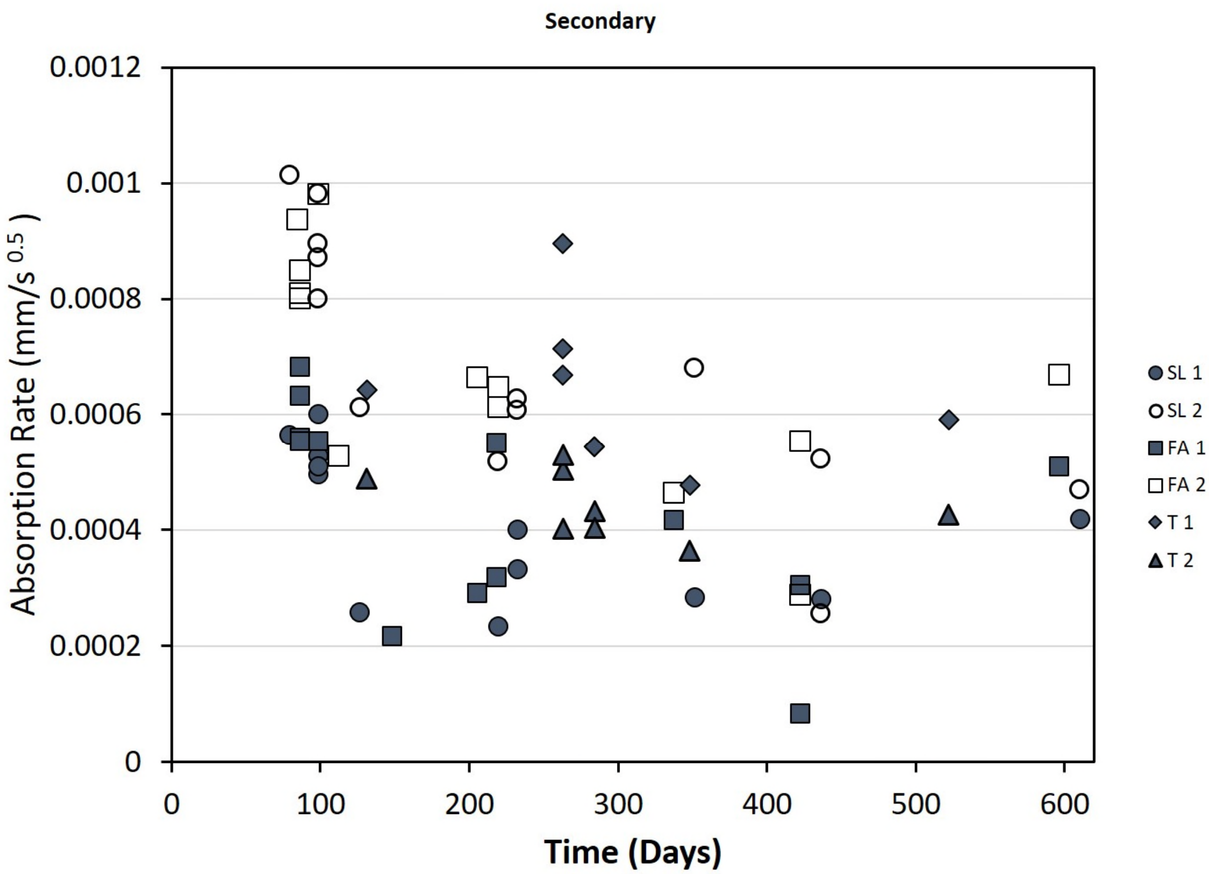


Figure 46. Secondary rate of absorption vs. time

The evolution of the secondary rate of water absorption with time is shown in Figure 46. Similar trends to those observed for the primary were also observed for the secondary rate of absorption. However, the magnitude as would be expected is significantly smaller. The primary and secondary rate of absorption were measured on concrete prepared with general use cement from Lafarge [15] and granite as coarse aggregate for samples at 12 and 24 months. Prior to the test, the specimens were immersed in calcium hydroxide all the time. The primary rate of absorption was 0.00075 $mm/s^{0.5}$ at 12 months and 0.00091 $mm/s^{0.5}$ after 24 months of exposure. The secondary rate of absorption at 12 months was 0.00057 $mm/s^{0.5}$ and at 24 months of exposure it was 0.00061 $mm/s^{0.5}$. The above presented primary and secondary rates of absorption values for SL, FA, are comparable. A number specimens had primary rate of absorption close to 0.0005 (SL and T2 groups).

4.2 Analysis and processing of D_{app}, SR, D_{nssd}, and D_{nssm}

This section presents the calculated chloride diffusivities (apparent diffusion (D_{app}) values from cored samples and non-steady state diffusion (D_{nssd}) values from bulk diffusion tests), and the calculated migration coefficients (D_{nssm}) after running NT492 tests. The surface resistivity values for bulk diffusion samples were measured prior to sample preparation for the bulk diffusion test. The surface resistivity values were converted to resistivity values (i.e., the geometric correction was applied). For samples used for D_{nssm}, the electrical resistance of the concrete slice was measured prior to running the test, the resistance values were then converted to resistivity values. The D_{nssm} vs. resistivity and D_{nssd} vs. resistivity were tabulated and plotted.

No resistivity values were measured on the cores obtained at 30 and 54 months of exposure from concrete blocks exposed to simulated field conditions; hence, no correlation is possible between resistivity and D_{app}.

4.2.1 The approach used to obtain D_{app} and D_{nssd}

The chloride concentration profiles were obtained after a chloride analysis was performed on sliced and pulverizing concrete from cored samples and bulk diffusion samples (chloride analyses were made using the FDOT method). The diffusivity values were obtained using Fick's second law fitted to the profiles. The exposure duration was converted to years (or a fraction of a year) prior to performing the diffusivity calculation. Besides the chloride concentration per layer, the thickness of the slice (or milled layer) and the center of mass of each layer were also entered prior to performing the calculation. The chloride diffusivity values are named D_{nssd} (non-steady state diffusivity) if obtained from a bulk diffusion test. The chloride diffusivity is named D_{app} (apparent diffusivity) for values calculated from profiles that resulted from slicing cores of specimens exposed to simulated field conditions (i.e., specimens exposed at the barge (samples outdoors at the intercoastal waterway), tidal tank or simulated splash tank (the latter two using seawater)).

4.2.2 D_{app} values

Cores were obtained at approximately 54 months (Spring 2016) of exposure on DCL concrete blocks exposed to simulated field marine environments (tidal, splash, and barge)[1]. The cores were obtained at three elevations on the tidal specimens for concrete blocks that have been cored twice. Tidal exposed samples prepared with mixes DCL1, DCL4, and DCL7 cores were obtained at four elevations, as these samples were not cored at 30 months of exposure. For samples exposed at the barge and splash exposures, cores were obtained at two elevations. Moreover, cores were obtained on most DCL blocks at 30 months of exposure (prior to completing a previous project [Reference], but profiles were not reported). The chloride analyses were completed and processed later. The chloride profiles were processed as part of this project and are included in Appendix M. The chloride concentration values are shown as percent of cementitious material. Appendix N presents tables that show the D_{app} values calculated. The D_{app} values obtained at 30 and 54 months are shown on the two columns on the right.

4.2.3 D_{nssd} values

D_{nssd} values were calculated from the profiles obtained after completing the bulk diffusion tests. Table 25 shows the D_{nssd} values calculated on SL specimens. Table 26 shows the D_{nssd} values calculated on FA specimens, and Table 27 shows the D_{nssd} values calculated on T1 and T2 specimens. D_{nssd} values were calculated for each sample with all layers and with one layer removed. The latter provides sometimes a smaller residual, and typically a smaller D_{nssd} value. The D_{nssd} values that will be used in the correlations are on the column on the right. The tables also show the resistivity measured prior to starting the bulk diffusion test. Appendix O presents the Dnssd values measured on DCL specimens.

Table 25. Resistivity and D_{nssd} values calculated on SL specimens.

Sample Name	Exposure Time(month)	D_{nssd} all Layers × 10^{-12} (m^2/s)	RESID	D_{nssd} 1 Layer Removed × 10^{-12} (m^2/s)	RESID*	Rho kΩ·cm	D_{nssd} for correlation × 10^{-12} m^2/s
SL1-4	8.5	2.45	18.623	1.84	5.270	15.08	1.84
SL1-5	12.0	1.41	9.064	1.14	1.307	15.50	1.14
SL1-6	12.0	1.51	7.286	1.22	0.750	17.25	1.22
SL1-7	8.5	2.41	1.310	2.45	1.158	17.94	2.41
SL1-8	11.2	1.77	7.669	1.46	1.290	18.62	1.46
SL1-9	11.2	1.30	8.445	1.00	0.162	18.52	1.00
SL2-4	6.1	1.74	3.394	1.65	3.370	19.68	1.65
SL2-5	8.5	2.11	4.586	1.83	1.980	15.08	1.83
SL2-6	8.5	1.61	29.780	0.81	7.910	17.67	0.81
SL2-7	6.1	2.39	3.693	2.67	2.290	19.21	2.39
SL2-8	11.2	0.89	1.269	0.79	0.393	18.52	0.79
SL2-9	11.2	1.11	1.318	1.03	1.156	18.20	1.03

Table 26. Resistivity and D_{nssd} values calculated on FA specimens.

Sample Name	Exposure Time(month)	D_{nssd} all Layers × 10^{-12} (m^2/s)	RESID	D_{nssd} 1 Layer Removed × 10^{-12} (m^2/s)	RESID*	Rho kΩ·cm	D_{nssd} for correlation × 10^{-12} m^2/s
FA1-4	8.0	3.63	11.314	3.27	9.805	8.10	3.27
FA1-5	11.8	2.45	2.050	2.29	1.675	8.10	2.29
FA1-6	8.0	3.60	1.615	3.60	1.614	15.40	3.60
FA1-7	6.1	4.64	0.457	4.37	0.133	15.98	4.37
FA1-8	12.0	1.46	1.427	1.41	1.376	16.83	1.41
FA1-9	12.0	2.00	7.953	1.71	4.497	15.87	1.71
FA2-4	6.1	3.61	3.211	3.17	0.869	8.41	3.17
FA2-5	8.0	4.51	16.987	3.71	9.335	7.99	3.71
FA2-6	8.0	3.78	12.218	4.94	4.697	15.82	3.78
FA2-7	11.8	2.27	3.003	2.08	2.426	15.82	2.08
FA2-8	12.0	1.69	8.666	1.36	1.151	16.88	1.36
FA2-9	12.0	1.74	1.870	1.59	1.025	17.25	1.59

Table 27. D_{nssd} and resistivity measured on T1 and T2 specimens.

Sample Name	Exposure Time (month)	D_{nssd} all Layers × 10^{-12} (m^2/s)	RESID	D_{nssd} 1 Layer Removed × 10^{-12} (m^2/s)	RESI D*	ρ kΩ·cm	D_{nssd} for correlation × 10^{-12} m^2/s
T1A	12.0	0.90	1.921	0.79	0.952	26.98	0.79
T1B	12.0	0.89	5.085	0.65	0.061	26.56	0.65
T1C	12.0	1.05	5.157	0.89	3.555	27.20	0.89
T1-4	9.0	0.49	0.536	0.31	0.002	54.29	0.31
T1-5	9.0	0.56	1.603	0.35	0.002	55.29	0.35
T2A	12.0	0.79	1.241	0.70	0.566	27.78	0.70
T2B	12.0	0.99	10.548	0.71	1.526	28.1	0.71
T2C	12.0	0.93	2.455	0.80	1.227	27.99	0.80
T2-4	9.0	0.52	0.827	0.30	0.001	78.89	0.30
T2-5	9.0	0.30	0.002	0.29	0.002	77.57	0.29

Table 28 shows the D_{nssd} values obtained from A to L mix cylinders. The table indicates the exposure time, D_{nssd} calculated values with all layers and with one layer removed.

Table 28. D_{nssd} values calculated from profiles of specimens (mixes A to L).

Sample Name	Exposure Time (month)	D_{nssd} all layers × 10^{-12} (m^2/s)	RESID	D_{nssd} one Layer Removed × 10^{-12} (m^2/s)	RESID
A1	9.8	0.60	0.376	0.47	0.002
A2	9.8	0.91	8.670	0.50	0.010
A3	9.8	0.51	0.005	0.53	0.003
FA23	9.8	3.79	47.955	8.50	15.747
FA28	9.8	0.87	3.873	0.61	0.030
Ai-1	11.0	0.62	1.365	0.45	0.053
Ai-2	11.0	0.74	0.028	0.73	0.027
Ai-3	11.0	0.35	0.014	0.41	0.000
FAA23	9.8	1.16	1.295	0.92	0.799
FAA28	13.3	0.72	1.840	0.59	0.272
B1	11.0	0.30	0.312	0.46	0.008
B2	11.0	0.38	0.401	0.26	0.004
B3	11.0	0.19	0.004	0.21	0.004
FB23	10.8	1.09	6.558	0.74	4.667
FB29	10.8	0.43	0.110	0.37	0.044
Bi1	7.5	0.78	1.015	1.30	0.203
Bi2	7.5	1.13	0.768	1.30	0.553
Bi3	7.5	1.06	5.511	2.86	0.140
FBB22	10.4	0.48	0.053	0.44	0.016
FBB23	10.8	0.52	0.935	0.45	0.870
FBB28	10.4	0.30	0.127	0.45	0.014
C1	10.1	0.23	0.018	0.15	0.003
C2	10.1	0.32	0.119	0.57	0.009
C3	10.1	0.41	1.331	0.18	0.006
FC22	12.0	0.48	6.408	1.12	3.553
FC23	11.8	0.02	0.119	0.04	0.009
FC28	12.0	0.21	0.034	0.10	0.002
D1	10.1	0.13	0.007	0.00	error
D2	10.1	0.18	0.088	0.44	0.004
D3	10.1	0.19	0.031	0.33	0.008
FD22	10.8	0.28	0.602	0.67	0.123
FD-23	9.0	0.18	0.504	0.84	0.348
E1	11.0	0.59	0.094	0.54	0.014
E2	11.0	0.41	0.026	0.45	0.001
E3	11.0	0.35	0.021	0.32	0.004
FE22	11.8	0.40	0.144	0.49	0.010
FE23	11.8	0.64	0.239	0.60	0.186
FE28	11.8	0.40	0.082	0.33	0.001

Table 28 continues

Sample Name	**Exposure Time(month)**	**D_{nssd} all Layers × 10^{-12} (m^2/s)**	**RESID**	**D_{nssd} 1 Layer Removed × 10^{-12} (m^2/s)**	**RESID***
F1	10.5	0.55	0.521	0.42	0.005
F2	10.5	0.68	4.981	0.28	0.005
F3	10.5	0.54	2.067	0.31	0.091
FF23	10.4	0.24	0.595	0.74	0.020
G1	11.0	0.80	1.196	0.21	0.000
G2	11.0	0.55	0.583	0.19	0.001
G3	11.0	0.26	0.002	0.22	0.001
FG22	10.4	0.27	0.072	0.47	0.022
FG23	10.4	0.27	0.110	0.44	0.077
FG28	10.4	0.32	0.401	0.70	0.045
H1	11.4	0.22	0.019	0.27	0.004
H2	11.4	0.30	0.128	0.21	0.002
H3	11.4	0.20	0.011	0.16	0.005
FH23	12.0	0.17	0.022	0.26	0.001
FH28	12.0	0.11	0.074	0.38	0.006
I1	11.4	0.24	0.003	0.23	0.002
I2	11.4	0.15	0.002	0.12	0.001
I3	11.4	0.31	0.020	0.25	0.002
FI23	12.0	0.26	0.025	0.22	0.001
FI28	12.0	0.23	0.015	0.20	0.002
J1	7.6	2.48	3.251	2.01	0.460
J2	7.6	1.83	0.785	1.50	0.505
J3	7.6	2.63	11.433	2.09	4.893
FJ23	12.0	0.31	1.270	0.67	0.082
FJ28	12.0	0.46	1.874	0.27	0.007
K1	10.4	0.14	0.007	0.00	N/A
K2	10.4	0.18	0.002	0.20	0.001
K3	10.4	0.13	0.082	0.62	0.002
FK23	10.4	0.20	0.056	0.48	0.003
FK28	10.4	0.15	0.021	0.42	0.001
L-1	9.0	0.12	0.004	0.21	0.004
L-2	9.0	0.06	0.006	1.67	0.003
L-3	9.0	0.07	0.002	0.46	0.001
FL-23	9.0	0.12	0.022	0.61	0.011
FL-28	9.0	0.10	0.010	0.58	0.003

Table 29. D_{nssd} vs. Rho (A to L specimens)

Sample Name	ρ kΩ·cm	$D_{nssd} \times 10^{-12}$ m^2/s	Sample Name	ρ kΩ·cm	$D_{nssd} \times 10^{-12}$ m^2/s
A1	41.27	0.46	F1	40.21	0.424
A2	38.62	0.49	F2	40.74	0.284
A3	41.27	0.51	F3	42.33	0.308
FA23	24.34	3.79	FF23	106.88	0.241
FA28	39.42	0.61	G1	19.57	0.205
Ai-1	42.33	0.45	G2	19.57	0.191
Ai-2	42.33	0.73	G3	19.04	0.259
Ai-3	43.92	0.35	FG22	20.11	0.266
FAA23	31.53	0.92	FG23	57.67	0.269
FAA28	100.90	0.59	FG28	29.63	0.317
B1	105.29	0.296	H1	82.01	0.223
B2	102.65	0.26	H2	84.13	0.209
B3	103.17	0.19	H3	83.07	0.204
FB23	117.51	0.74	FH23	174.29	0.17
FB29	85.50	0.37	FH28	85.61	0.107
Bi1	113.76	0.77			
Bi2	116.40	1.13	I1	61.38	0.253
Bi3	110.58	1.06	I2	69.31	0.148
FBB22	106.35	0.44	I3	61.38	0.253
FBB23	86.77	0.45	FI23	114.28	0.219
FBB28	115.87	0.30	FI28	106.35	0.199
C1	60.32	0.15	J1	64.55	2.007
C2	61.90	0.32	J2	65.08	1.495
C3	62.43	0.18	J3	67.195	2.088
FC22	62.59	0.48	FJ23	90.69	0.306
FC23	68.31	0.4	FJ28	106.77	0.265
FC28	79.31	0.21			
D1	223.28	0.12	K1	106.35	0.136
D2	220.63	0.18	K2	105.82	0.176
D3	211.64	0.19	K3	101.59	0.134
FD22	110.26	0.28	FK23	93.65	0.202
FD-23	110.26	0.18	FK28	125.396	0.149
E1	29.10	0.59			
E2	28.57	0.41	L-1	262.43	0.118
E3	29.10	0.345	L-2	275.13	0.064
FE22	53.17	0.396	L-3	268.25	0.074
FE23	55.39	0.60	FL-23	124.23	0.119
FE28	33.59	0.40	FL-28	92.38	0.096

Table 29 shows the D_{nssd} values calculated and the measured resistivity value measured before starting the bulk diffusion test for samples prepared with mixes A to L.

Samples from mixes A to L (samples prepared during 2010 and 2011) cured at SMO and at FAU were tested for bulk diffusion. Immersion took place once the samples reached ages ranging from 5 to 6 years. The samples cured at SMO were immersed in $Ca(OH)_2$ solution all the time with periodic solution refreshing. Samples cured at FAU were stored in an elevated temperature room, during the first 3 years the solution was calcium hydroxide, but it was changed to tap water after that. The samples were transported to SMO during Spring 2016 and were immersed in calcium hydroxide solution until the bulk diffusion test start date was reached. Surface resistivity was measured before preparing the samples for the bulk diffusion test. The exposure duration ranged from six months to one year. All samples were sliced and crushed upon reaching removal age.

D_{nssd} was obtained from the profiles measured on concrete slices obtained from the Key Royale bridge cored samples (4-inch diameter). A 5-cm slice corresponding to each of the compositions type present at the Key Royale Bridge was tested. These slices were immersed in tap water for 3 to 4 years before taking them to SMO for bulk diffusion testing during Spring 2016. Table 30 presents the results of these tests.

Table 30. Resistivity and D_{nssd} values calculated from profiles of Key Royale Bridge specimens.

Sample Name	Mix	Exposure Time (month)	D_{nssd} all Layers × 10^{-12} (m^2/s)	RESID	D_{nssd} 1 Layer Removed × 10^{-12} (m^2/s)	RESID*	ρ kΩ·cm	D_{nssd} for correlation × 10^{-12} m^2/s
KRB1-1	CEM	11.4	15.00	6.004	12.70	2.475	26.90	12.70
KRB2-2	UFA	11.4	0.17	0.002	0.15	0.001	98.90	0.15
KRB3-1	FA	11.4	0.83	3.350	1.02	2.620	39.90	0.83
KRB4-2	SF	11.4	0.24	0.096	0.20	0.086	124.00	0.20
KRB5-1	BFS	11.4	0.22	0.276	0.47	0.014	116.00	0.22
KRB6-1	MET	11.4	0.44	1.787	0.71	0.444	67.86	0.44

4.3 Correlation D_{nssd} vs. resistivity

A plot was prepared in which the resistivity values were placed on the x-axis and the corresponding D_{nssd} values on the y-axis. The plot is in log-log scale. Figure 47 shows the correlation for resistivity vs. D_{nssd} values for the various groups of samples described above.

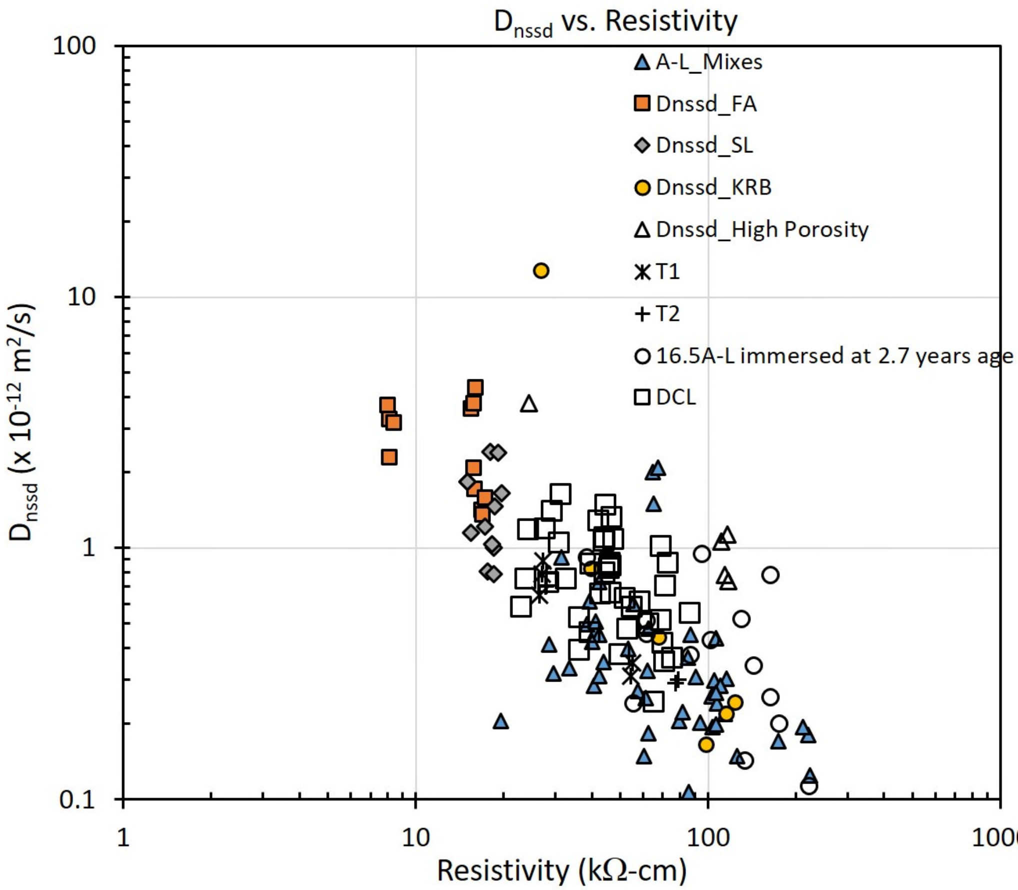


Figure 47. D_{nssd} vs. resistivity for samples tested as part of this project and a prior set for A-L.

4.4 K values obtained from D_{nssd} vs. resistivity

In this section the K values from the correlation $D_{nssd} = K/\rho$ are presented for various groupings. A K value of 28.4 was obtained when using all the D_{nssd} values measured and the corresponding resistivity measured prior to beginning the bulk diffusion testing on T1, T2, SL1, SL2, FA1, and FA2 specimens. Figure 48 shows a plot with all the data points and the fitted correlation. The R2 was 0.51. A similar correlation was obtained using all D_{nssd} vs. resistivity values from DCL specimens, a value of 32 was found for K, but the R2 was -0.02 (see Figure 49). The D_{nssd} and resistivity measured on specimens from mixes A to L were also correlated and a value of 21 was found for K (see Figure 50). Recall that some of the mixes contain high cementitious replacements, hence their resistivity was quite high. Finally, the D_{nssd} vs. resistivity of the three groups were combined and correlated. Figure 51 shows that a K of 29.8 and R2 of 0.25 were associated when all D_{nssd} values were used in the correlation. The calculated K values ranged between 21.4 and 32. These K values are lower than the K values obtained by using D_{nssm} vs. resistivity that are presented in the next section. The lower K values could be in part due to the chloride binding that takes place during the bulk diffusion test. The lower K value for A to L specimens could in part be explained by higher cementitious replacement amounts on some of the mixes, the aggregate size and the age at which the bulk diffusion test started.

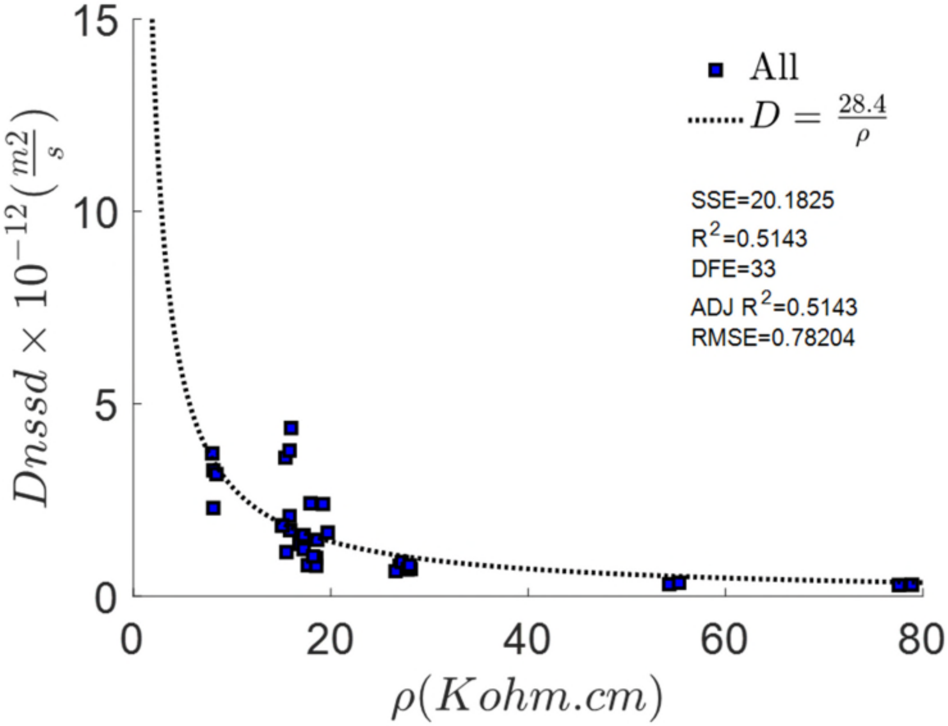


Figure 48. Correlation D_{nssd} vs. resistivity for SL, FA, T1, and T2 specimens

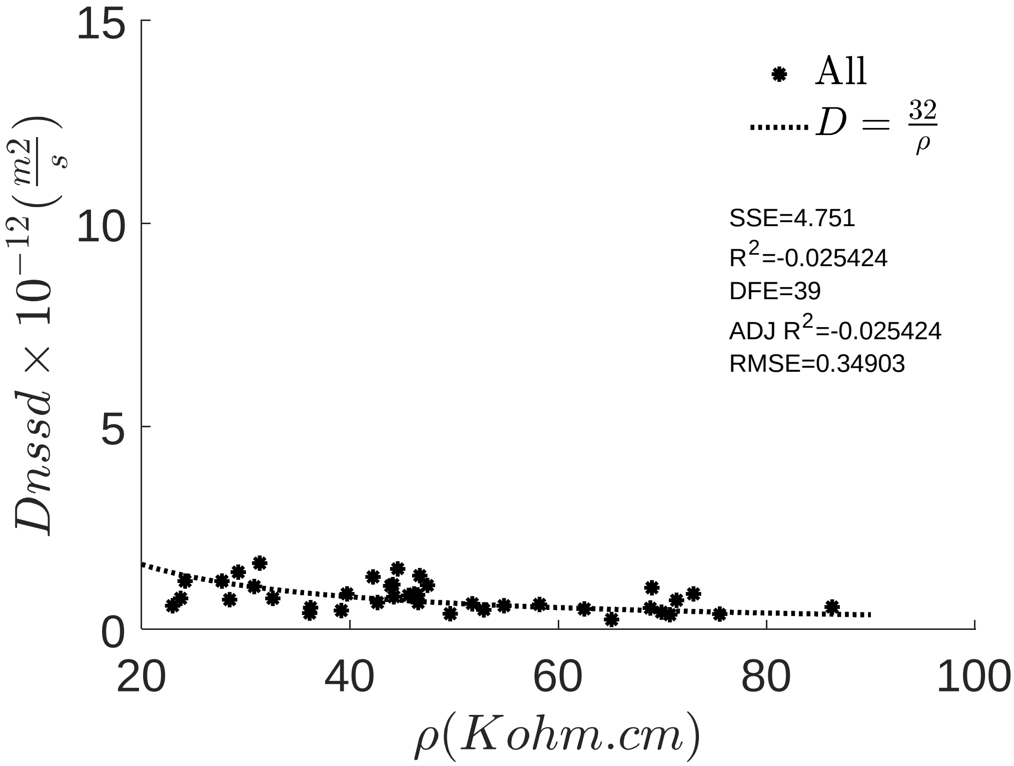


Figure 49. Correlation D_{nssd} vs. resistivity for DCL specimens

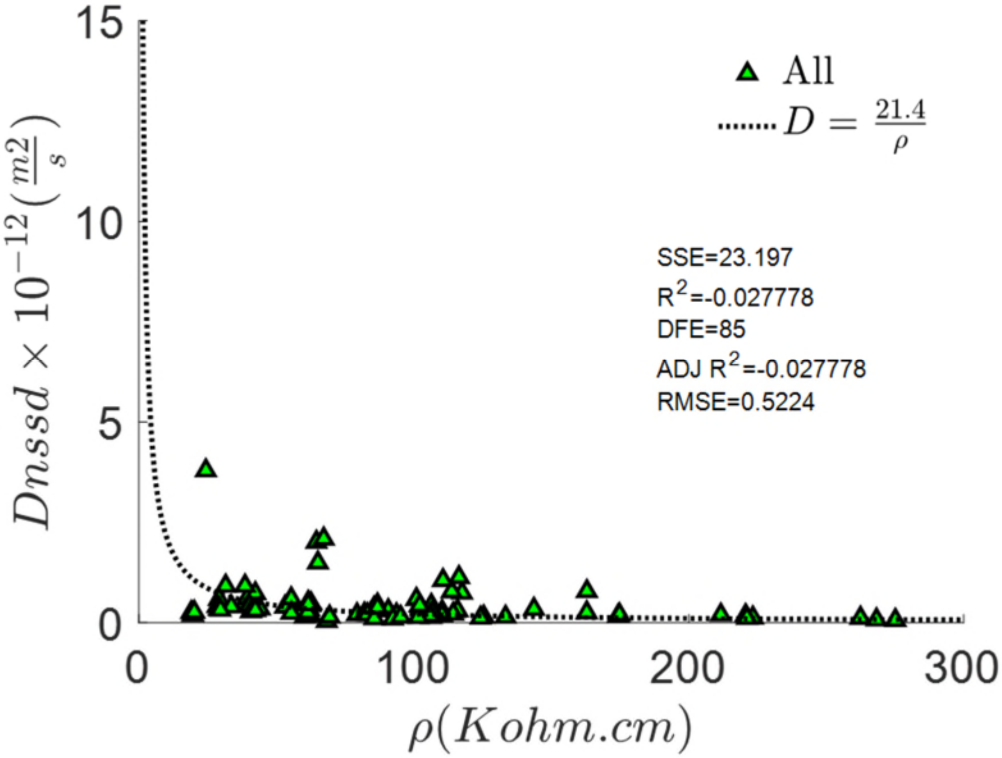


Figure 50. Correlation D_{nssd} vs. resistivity for A to L specimens

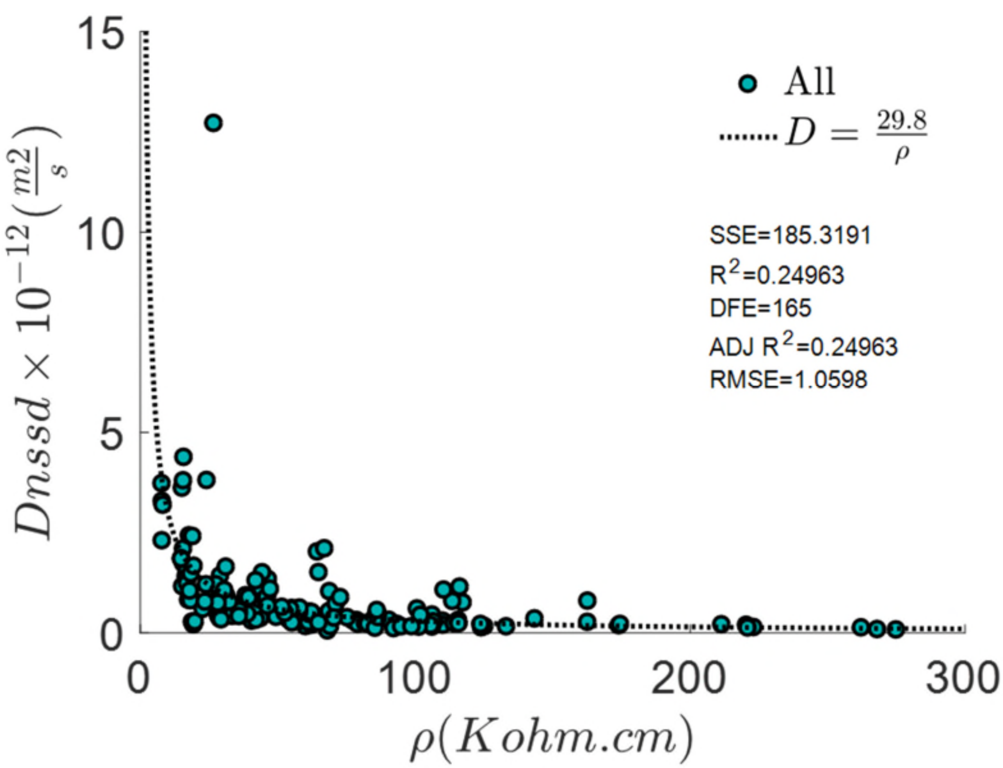


Figure 51. Correlation D_{nssd} vs. resistivity for all tested specimens

4.5 D_{nssd} vs. age at immersion

Two sets of samples (A to L group and DCL group) have been tested for bulk diffusion over time. In this case, different samples from the same mix composition were immersed at various ages. This section presents the results from the recent measurements, combined with values published previously. For A to L mixes, it also includes a set of values that were not available at the time the previous report was completed. This section presents how the D_{nssd} evolved as a function of the age of the sample when the bulk diffusion test started. This analysis was done for samples prepared with DCL mixes and prepared with A to L mixes.

4.5.1 D_{nssd} vs. age at immersion for A to L mixes

This section describes how D_{nssd} evolved based on when the sample was immersed for bulk diffusion test for samples from mixes A to L. Table 31 consists of several columns. It includes the mix identification, the supplementary cementitious material used on each mix. The letter next to the cementitious type indicates the coarse aggregate used. Limestone is indicated with 'L' and granite indicated with the letter 'G'. The D_{nssd} was obtained for samples immersed over time (five instances). NC indicates normal cure or 28 days curing in the fog room. NC=AC indicates the time it took for samples in the normal cure to reach the resistivity measured on cylinders subjected to accelerated curing. Table 51 in Appendix C indicates the age at which NC=AC samples were immersed for bulk diffusion testing. The Dnssd values on the third column in Table 31 corresponds to D_{nssd} values for cylinders immersed at one year of age (sometimes specimens NC=AC exceeded one year). The D_{nssd} values shown on column four are for samples immersed at ages ranging from 2.7 to 3 years. The D_{nssd} values on the column farthest to the right correspond to bulk diffusion tests performed on cylinders that were immersed at an age of 5.3 years (or slightly older, see Table 51 in appendix C). The samples immersed at 2.7 to 3 years were immersed for about half a year (179 to 188 days), and those immersed as part of this project (>5.3 years of age) were immersed for durations that ranged from 7.5 months to one year (see Table 50 for immersion duration). The average of three values were used for D_{nssd}(NC), and for D_{nssd}(NC=AC). The D_{nssd}(1yr) and $D_{nssd(2.7yr)}$ values represent the D_{nssd} measured on one cylinder. The D_{nssd}(>5.3yr) is the average of 3 values corresponding to values measured on the cylinders cured at SMO immersed in calcium hydroxide. The exception is for mix J; in this case, the D_{nssd}(>5.3yr) value shown is the average of 2 values calculated after exposing cylinders FJ23 and FJ28.

It can be observed that for Mixes Ai, A, J, Bi, B, and D (samples with FA ranging from 20 to 50 percent and with limestone), the D_{nssd}(NC) was greater than 3×10^{-12} m^2/s, compared to the D_{nssd}(1yr) the values ranged from 0.64 (50 percent fly ash) to 1 (20 percent fly ash) $\times 10^{-12}$ m^2/s. The more recent D_{nssd}(5.3yr) values ranged from 0.17 to 0.5×10^{-12} m^2/s, for these same mixes. The D_{nssd}(2.7yr) values were comparable ranging from 0.14 to 0.5×10^{-12} m^2/s.

The $D_{nssd(NC)}$ obtained on samples with fly ash and granite aggregate ranged between 2.11 and 2.8 $\times 10^{-12}$ m^2/s, whereas the $D_{nssd\text{-}(NC)}$ for samples with slag or slag and fly ash ranged between 1.3 and 1.8×10^{-12} m^2/s. The $D_{nssd(1yr)}$ for samples with fly ash and granite decreased to values that ranged between 0.73 and 0.86×10^{-12} m^2/s, and $D_{nssd(5.3yr)}$ ranged from 0.09 to 0.22×10^{-12} m^2/s. These D_{nssd} values are smaller (although the same order of magnitude) than those measured on samples with fly ash and limestone. A similar reduction in D_{nssd} was observed for the samples prepared with slag or slag and fly ash. In a few instances the $D_{nssd(2.7yr)}$ were larger (about three times) than $D_{nssd(5.3yr)}$, this was observed on C, G and H mixes. For the other groups $D_{nssd(2.7yr)}$ and $D_{nssd(5.3yr)}$ were comparable. The $D_{nssd-(5.3yr)}$ and most of the $D_{nssd(2.7yr)}$ are of comparable magnitude to the D_{app} reported from field cores.

Table 31. D_{nssd} vs. age at immersion time for A to L mixes

		D_{nssd} (×10^{-12} m^2/sec)				
immersed at		NC at 28 days	NC=AC	1 yr RT	2.7 to 3 years	>5.3 years
20% FA-L	Ai	3.16	1.48	1.16	0.51	0.51
20% FA-L	A	3.19	1.52	0.99	0.45	0.49
40% FA-L	Bi	3.05	0.74	0.86	0.52	0.63
40% FA-L	B	3.59	1.27	0.98	0.14	0.25
20% FA-G	C	2.18	0.81	0.74	0.94	0.22
50% FA-L	D	3.14	0.89	0.64	0.20	0.17
50% SL-L	E	1.83	1.08	1.09	0.24	0.45
70% SL-L	F	1.47	0.80	0.80	0.37	0.34
50% SL-G	G	1.32	0.84	1.02	0.92	0.22
20% FA50%SL-L	H	1.47	0.41	0.51	0.78	0.21
10% FA60%SL-L	I	1.65	0.78	0.63	0.34	0.22
30% FA-L	J	3.13	1.19	0.73	0.43	0.29
30% FA-G	K	2.81	0.71	0.47	0.25	0.15
50% FA-G	L	2.11	0.53	0.86	0.11	0.09

Figure 52 shows the D_{nssd} vs. age at immersion for mixes Ai and Bi, which had a higher air voids content than the target. Figure 53 shows how D_{nssd} evolved with time for the different samples prepared with Fly ash and that had limestone as the coarse aggregate. It is apparent that there is a plateau in D_{nssd} for samples of all types of mixes for samples immersed after 1000 days. Figure 54 shows similar plots for samples prepared with slag or slag and fly ash. A similar trend is observed than was observed for samples prepared with fly ash and limestone as the coarse aggregate. Figure 55 shows graphically how D_{nssd} vs. age at immersion compared for the samples prepared with granite as a coarse aggregate. There were two exceptions as to when the plateau was reached for samples prepared with mix C and G.

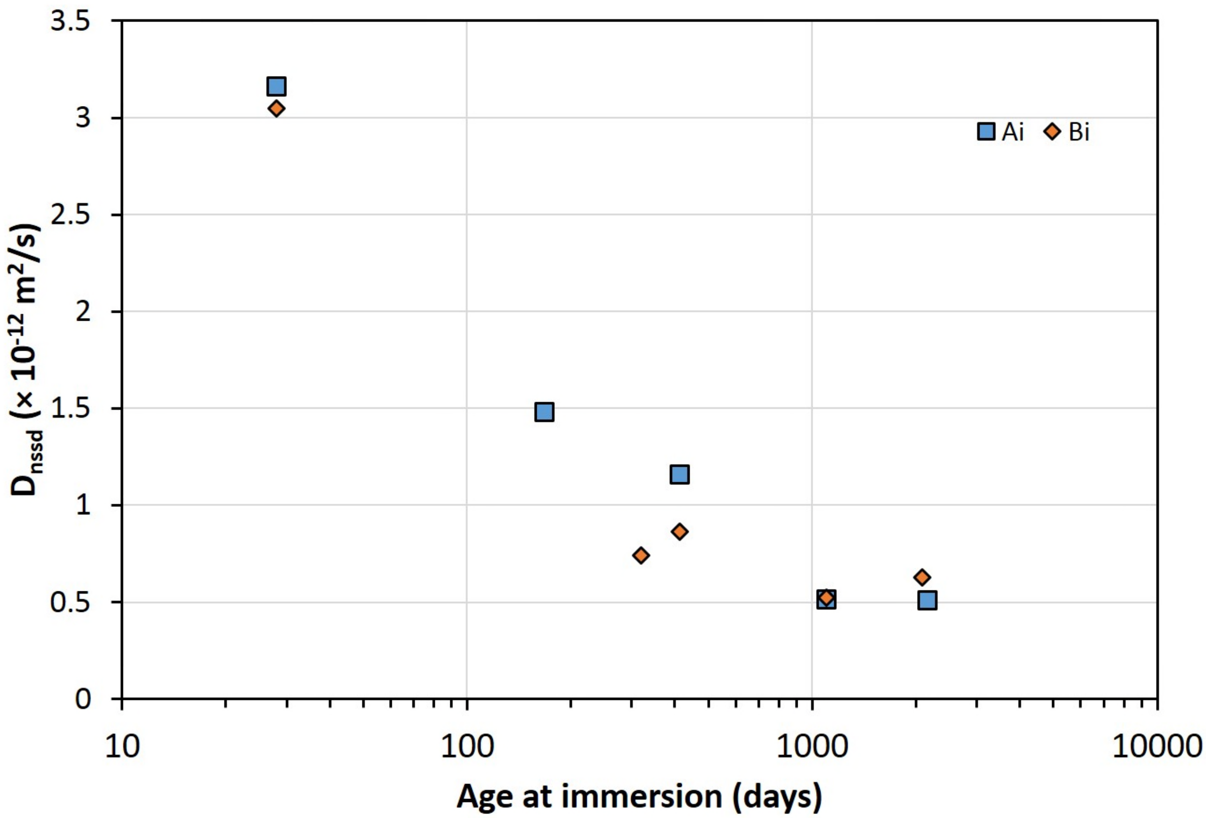


Figure 52. D_{nssd} vs. age at immersion measured on Ai and Bi specimens

Figure 53. D_{nssd} vs. age at immersion measured on A, B, J, and D specimens

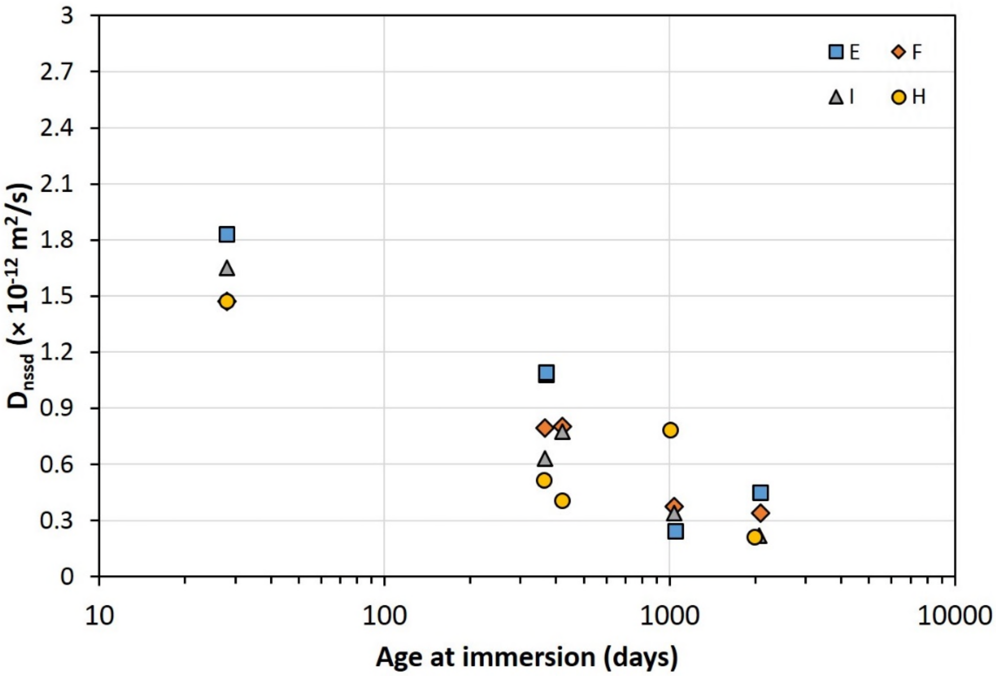


Figure 54. D_{nssd} vs age at immersion measured on E, F, I, and H specimens

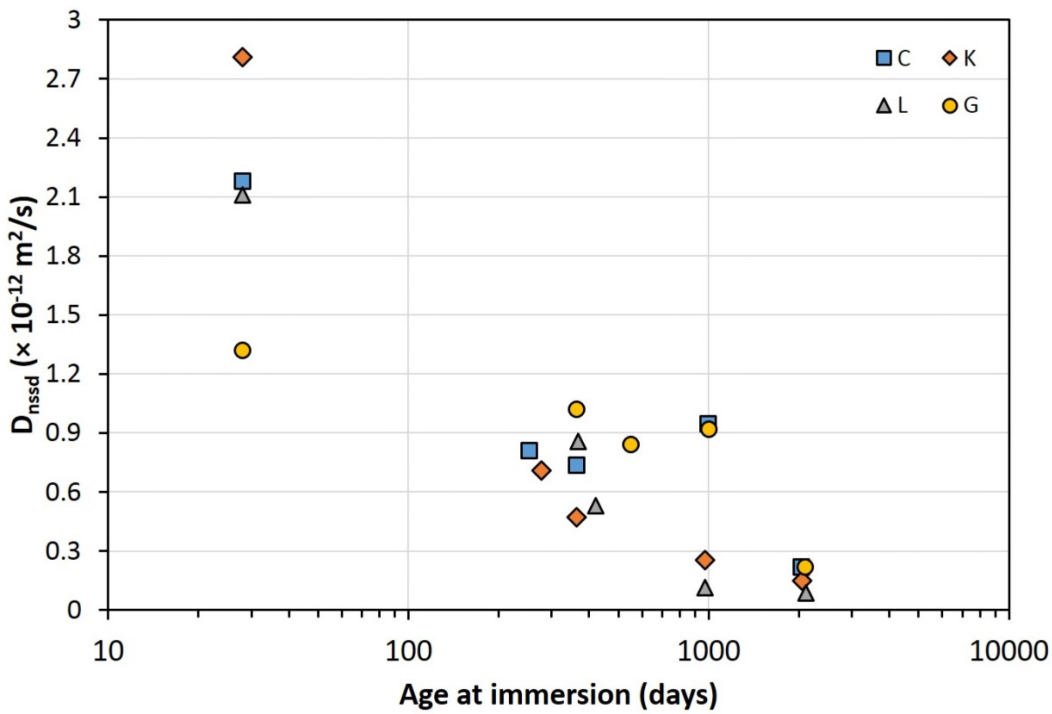


Figure 55. D_{nssd} vs. age at immersion measured on C, K, L, and G specimens

4.5.2 D_{nssd} vs. age at immersion for DCL samples

Table 32 presents the D_{nssd} measured on DCL specimens for specimens that were immersed at 28 days, NC<AC (just selected mixes), NC=AC, 700 days and at an age of more than 1950 days. The column NC=AC, corresponds to samples immersed once samples under normal cure reached the resistivity measured on cylinders subjected to accelerated curing (See Reference [1]). Figure 56 to Figure 59 show graphically on the x-axis the age at which DCL samples reached NC=AC (or NC<AC), i.e., at what age these specimens were immersed for bulk diffusion testing. The samples were immersed in 16.5 % NaCl. The samples immersed at 28 days, samples immersed at NC<AC, and samples NC=AC were exposed in this solution for one year, the D_{nssd} value shown is the average D_{nssd} from 3 samples per mix. The samples immersed at 700 days of age were immersed for 102 to 138 days (see table 54 in Appendix C for exposure period for each sample). Only one specimen per mix was immersed. Finally, the immersion lasted from 9 to 11 months for samples immersed at an age of more 1950 days (see Table 10); the D_{nssd} value shown is the average D_{nssd} from 3 or 4 samples per mix.

Table 32. D_{nssd} vs. age at immersion time for DCL mixes

	Dnssd (×10^{-12} m^2/sec)					
	28 days	NC<AC	NC=AC	700 days	1,950 days	Exposed to low Cl- for 1,640 days
DCL 1	2.94		1.24	0.38	0.71	0.55
DCL 2	3.41	3.19	2.04	0.79	0.85	0.48
DCL 3	4.45	3.80	3.10	1.87	1.06	1.23
DCL 4	1.58		0.93	0.36	0.46	0.40
DCL 5	2.35		0.92	0.74	0.55	0.44
DCL 6	2.99		1.24	1.05	0.55	0.61
DCL 7	2.83		2.01	1.21	0.70	0.30
DCL 8	2.27		1.44	0.87	0.69	0.44
DCL 9	3.42		1.45	1.24	1.08	0.56
DCL 10	4.75	3.87	2.99	0.95	1.07	1.21
DCL 10a	4.54	3.47	2.06	1.75	0.97	0.43
DCL 10b	5.06		3.23	1.82	1.15	0.56
DCL 11	4.65		2.76	1.78		0.55

The column farthest to the right in Table 32 shows the D_{nssd} for samples immersed at 200 days of age in a lower chloride concentration and for an immersion that lasted for 1640 days. It is included for comparison purposes. The D_{nssd} measured on DCL1 over time went from 2.94 × 10^{-12} m^2/s (immersed at 28 days) to 1.24 × 10^{-12} m^2/s (on the sample immersed when SR NC=AC), D_{nssd}700 was 0.38 × 10^{-12} m^2/s, and finally D_{nssd} reached a value of 0.71 × 10^{-12} m^2/s for samples immersed at 1950 days. This compares with a D_{nssd} value of 0.55 × 10^{-12} m^2/s calculated for the DCL1 sample immersed for 1640 days in low chloride concentration. DCL4 are samples with fly ash and silica fume and a w/cm of 0.37. The D_{nssd} for DCL4 samples went from 1.58 × 10^{-12} m^2/s NC to 0.93 × 10^{-12} m^2/s NC=AC, 0.36 × 10^{-12} m^2/s $D_{nssd(700days)}$ and reached an average value of 0.45 × 10^{-12} m^2/s for the samples immersed at 1950 days of age. The average D_{nssd} for samples immersed after 1950 days was 0.85 × 10^{-12} m^2/s and 1.06 × 10^{-12} m^2/s for DCL2 and DCL3, respectively. Samples prepared with mixes A (previous section) and DCL2 had similar composition, but different max aggregate size. The $D_{nssd(5.3yr)}$ was 0.49×10^{-12} m^2/s for A samples and DCL2 $D_{nssd(5.3yr)}$ was 0.85×10^{-12} m^2/s, and a value of 0.48×10^{-12} m^2/s was calculated for the DCL2 samples immersed at 200 days for 1640 days. Recall that DCL samples subjected to bulk diffusion testing at 1950 days were exposed to high humidity for several years prior to 30 days immersion in lime water that preceded the bulk diffusion test for samples immersed at 5.3 year (or older). A subsequent section will compare the D_{nssd} vs. D_{app} measured on samples exposed to field simulated conditions (below water). For each sub-group, those with the lower w/cm had the lower $D_{nssd(5.3yr)}$; it was 0.71×10^{-12} m^2/s, 0.45×10^{-12} m^2/s, and 0.7×10^{-12} m^2/s for DCL1(FA), DCL4(FA+SF), and DCL7(SL), respectively. The $D_{nssd(5.3yr)}$ for samples with the higher w/cm (0.47) with fly ash (DCL3) and slag (DCL9) had $D_{nssd(5.3yr)}$ values greater than 1×10^{-12} m^2/s, but was 0.55×10^{-12} m^2/s for DCL6. Figure 56 shows graphically how D_{nssd} evolved with time for DCL1, DCL2 and DCL3 samples. It appears that a plateau reached in D_{nssd} was reached by DCL1 and DCL2 samples immersed at 700 days. It is not clear if the plateau has been reached by day 2000 for DCL3 samples. Figure 57 shows graphically how D_{nssd} vs. age at immersion evolved on DCL4, DCL5 and DCL6. The transition to a plateau values was observed on specimens from DCL4 and DCL5 mixes (similar D_{nssd} values for samples immersed after 700 days and 1950 days of age). The D_{nssd} vs. age at immersion for DCL7, DCL8 and DCL9 are shown in Figure 58. DCL8 and DCL9 reached the D_{nssd} plateau. Figure 59 shows the cementitious content effect on D_{nssd} vs. age at immersion. DCL10a and DCL10b did not appear to reach a plateau.

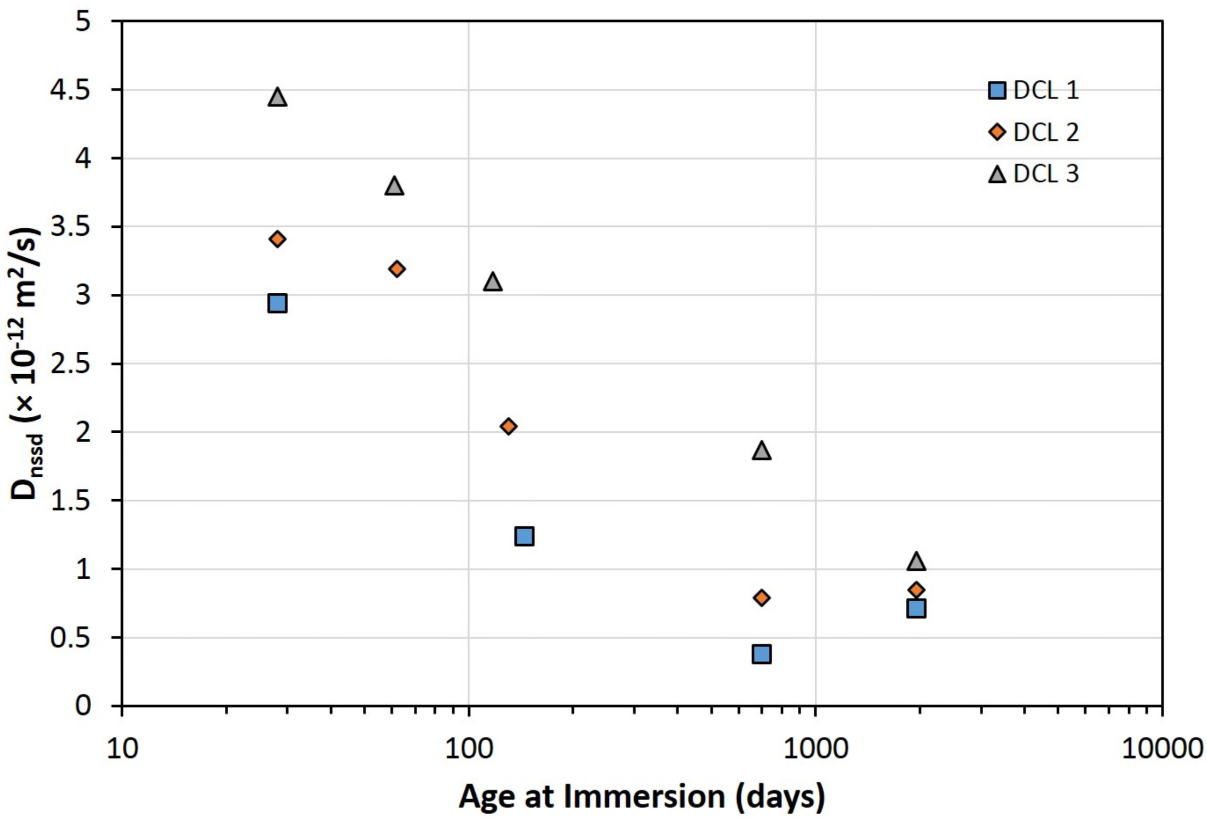


Figure 56. D_{nssd} vs. age at immersion measured on DC1, DC2, and DC3 specimens

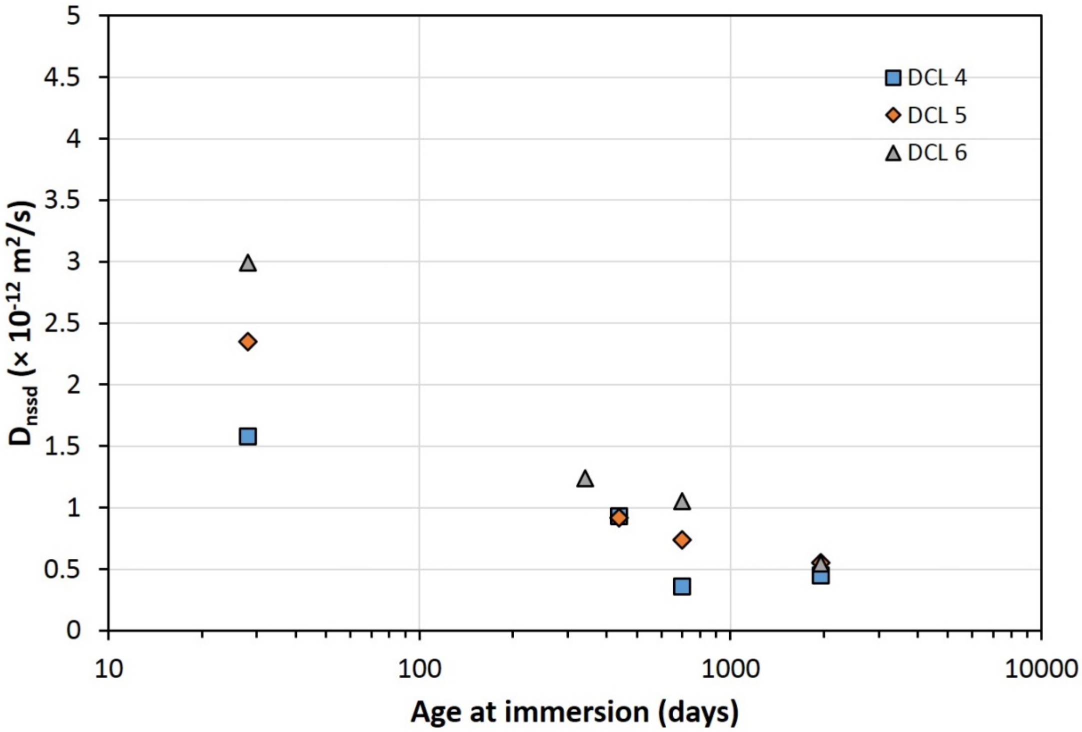


Figure 57. D_{nssd} vs. age at immersion measured on DC4, DC5, and DC6 specimens

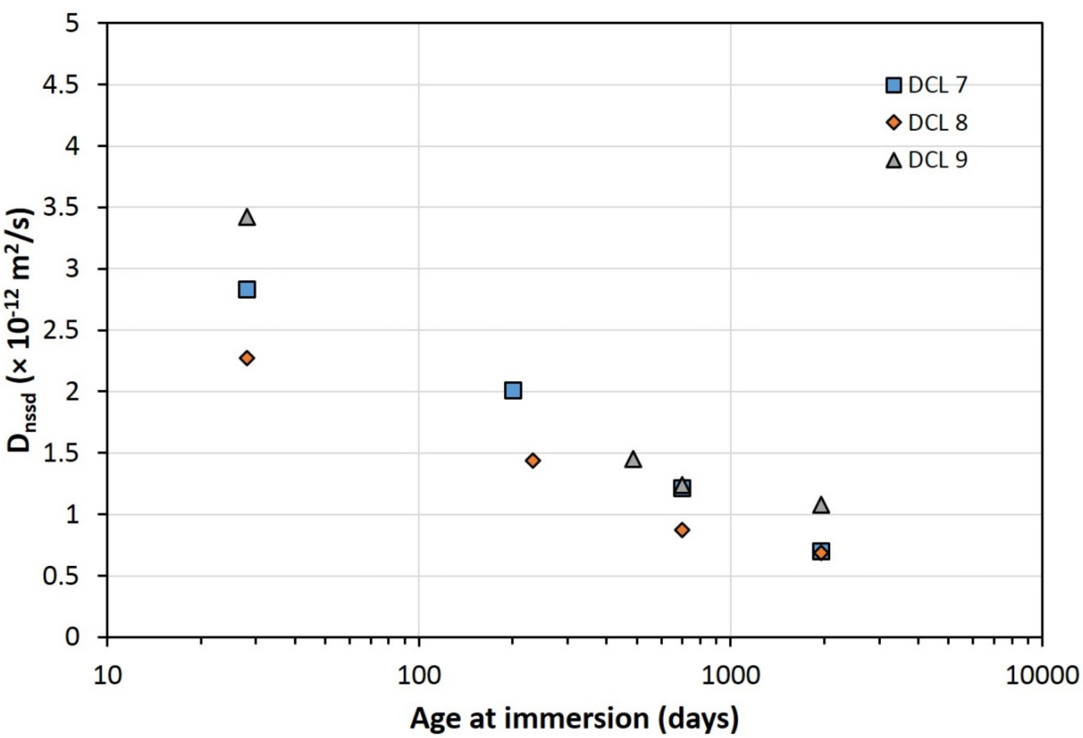


Figure 58. D_{nssd} vs. age at immersion measured on DC4, DC5, and DC6 specimens

Figure 59. D_{nssd} vs. age at immersion measured on DC2, DC10, DC10a, DCL10b, and DC11 specimens

4.6 D_{nssm} vs. resistivity

The tables in this section include the sample name, the measured resistivity prior to performing the migration tests (on the concrete slice), and the measured D_{nssm}. Table 33 presents the D_{nssm} and resistivity values for samples prepared with SL and FA mixes. Table 34 shows the D_{nssm} and resistivity values measured on samples prepared with T1 and T2 mixes cast during August 2016.

Figure 60 shows a plot with the D_{nssm} vs. resistivity presented in Table 33 and Table 34. The resistivity tended to increase and the D_{nssm} tended to decrease as the concrete aged, particularly for FA specimens. For SL specimens the resistivity did not increase significantly, but the measured D_{nssm} decreased as the concrete aged. Similar trends were observed in T1 and T2 tested samples with respect to the D_{nssm} gathered values.

Table 33. D_{nssm} for FA and SL specimens (prepared 04/2016)

Sample	$D_{nssm} \times 10^{-12}$ m^2/s	ρ, kΩ·cm	Sample	$D_{nssm} \times 10^{-12}$ m^2/s	ρ, kΩ·cm
SL1-4	2.51	21.9	FA1-4	9.61	9.61
SL1-5	3.54	21.6	FA1-5	7.2	7.2
SL1-6	2.95	21.9	FA1-6	6.16	6.16
SL1-7	2.82	23.7	FA1-7	6.42	6.42
SL1-8	2.96	19.0	FA1-8	3.04	3.04
SL1-9	2.72	20.2	FA1-9	3.61	3.61
SL1-36-A	3.07	17.1	FA1-36a	4.76	4.76
SL1-36-B	3.03	17.2	FA1-36b	5.54	5.54
SL1-35-A	3.84	20.3	FA1-37a	6.14	6.14
SL1-35-B	2.83	20.8	FA1-37b	5.97	5.97
SL1-38	3.36	19.3	FA1-35a	3.91	3.91
SL1-39A-a	1.95	18.9	FA1-35b	3.88	3.88
SL1-39A-B	2.57	19.3	FA1-38	4.48	4.48
SL1-40A	2.38	20.5	FA1-40a	4.73	4.73
SL1-40B	2.36	20.0	FA1-40b	5.12	18.7
SL1-41A	2.58	20.6	FA1-41a	3.95	27.5
SL1-41B	2.54	20.6	FA1-41b	3.93	27.0
SL1-45A	1.02	23.0	FA1-45	0.98	39.1
SL1-45B	0.82	23.0	FA1-53a	6.02	8.6
SL2-4	3.4	20.5	FA1-53b	5.03	8.6
SL2-5	2.77	22.4	FA2-4	11.28	11.1
SL2-6	1.94	23.7	FA2-5	11.43	10.6
SL2-7	1.8	24.7	FA2-6	8.25	23.7
SL2-8	1.8	21.4	FA2-7	9.31	18.2
SL2-9	2.09	20.0	FA2-8	3.34	20.6
SL2-55a	2.38	20.3	FA2-9	4.18	21.0
SL2-55b	3.04	20.1	FA2-54	3.88	15.5
SL2-56a	3.34	21.2	FA2-51a	3.21	15.0
SL2-56B	2.69	21.1	FA2-51b	3.33	22.3
SL2-54	3.23	15.5	FA2-52a	3.5	24.7
SL2-54T	3.22	18.2	FA2-52b	6.48	22.5
SL2-53	2.53	18.9	FA2-55a	3.15	19.2
SL2-58A	2.3	21.1	FA2-55b	3.39	18.5
SL2-58B	2.3	20.8	FA2-56A	3.51	23.6
SL2-51A	2.4	20.3	FA2-56B	3.52	23.1
SL2-51B	2.3	20.6	FA2-58A	3.78	27.5
SL2_60a	2.94	21	FA2-58B	3.76	28.7
SL2_60b	2.9	21	FA2_60	1.75	36.2

Table 34. D_{nssm} and resistivity measured on T1 and T2 specimens.

Sample	D_{nssm} × 10^{-12} m^2/s	ρ, kΩ·cm	Sample	D_{nssm} × 10^{-12} m^2/s	ρ, kΩ·cm
T2-4	1.89	93.5	T1-4	1.4	67.1
T2-5	1.71	95.6	T1-5	1.73	70.2
T2-6-A	2.79	87.9	T1-6A	2.46	61.9
T2-6-B	4.07	89.4	T1-6B	3.32	56.5
T2-7	3.07	45.6	T1-7	3.88	35.1
T2-8-A	3.01	77.4	T1-8A	3.6	54.8
T2-8-B	3	78.3	T1-8B	3.57	61.7
T2-11-A	3.15	81.6	T1-9A	2.85	52.1
T2-11-B	4.39	80.5	T1-9B	2.1	54.9
T2-9A	1.01	82.5	T1-10A	1.55	58.4
T2-9B	1.02	81.7	T1-10B	1.59	59.0
T2-12A	1.51	95.00	T1-11-A	0.98	77.0
T2-12B	1.398	95.00	T1-11-A	0.98	77.0

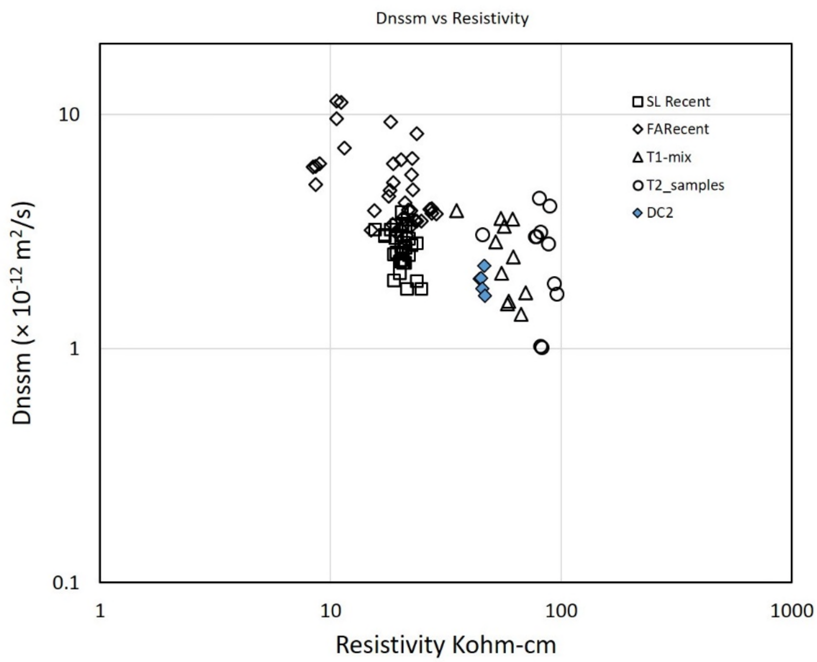


Figure 60. D_{nssm} vs. resistivity for samples prepared with mixes SL, FA, T1, and T2.

For a given composition and samples with the same resistivity (or similar resistivity values), the corresponding D_{nssm} can range over half a decade. This, in part, is due to the heterogeneity of the concrete, the difference between samples, and another factor is the age of the concrete at the time of the test. An additional contribution in the range of values measured could be due to error(s) from the technician when measuring the penetration depth. For concrete with supplementary cementitious materials that react relatively fast, the concrete does not change much in resistivity magnitude but can change significantly in D_{nssm} as the concrete ages.

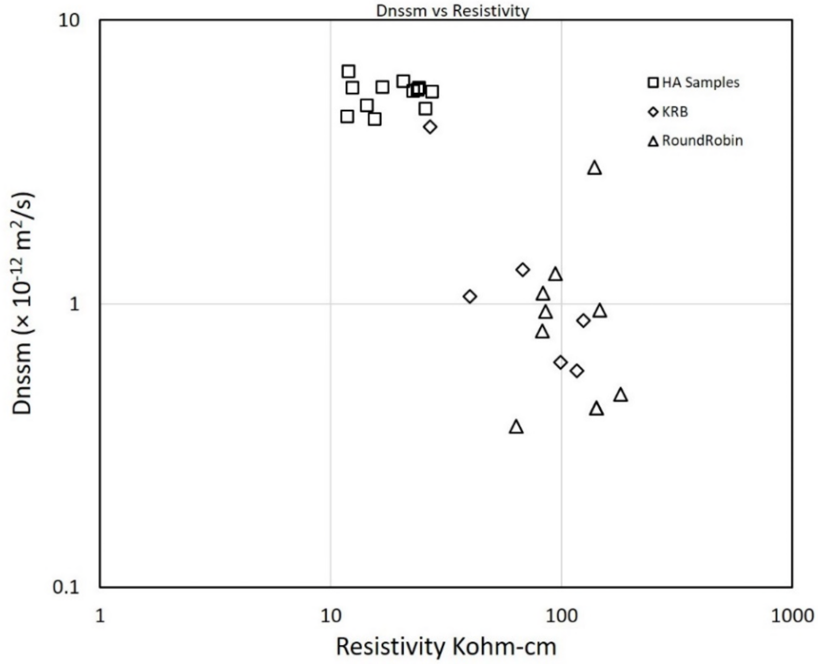


Figure 61. D_{nssm} vs. resistivity for older samples prepared (round robin, KRB, and HA mixes).

Figure 61 shows D_{nssm} vs. resistivity values corresponding to older samples. Samples from the surface resistivity round robin project, Key Royale Bridge slices and the D_{nssm} and resistivity values were measured on samples of the HA mixes. Figure 62 shows D_{nssm} vs. resistivity for selected samples from mixes A to L. Figure 63 shows the D_{nssm} vs. resistivity for selected DCL samples.

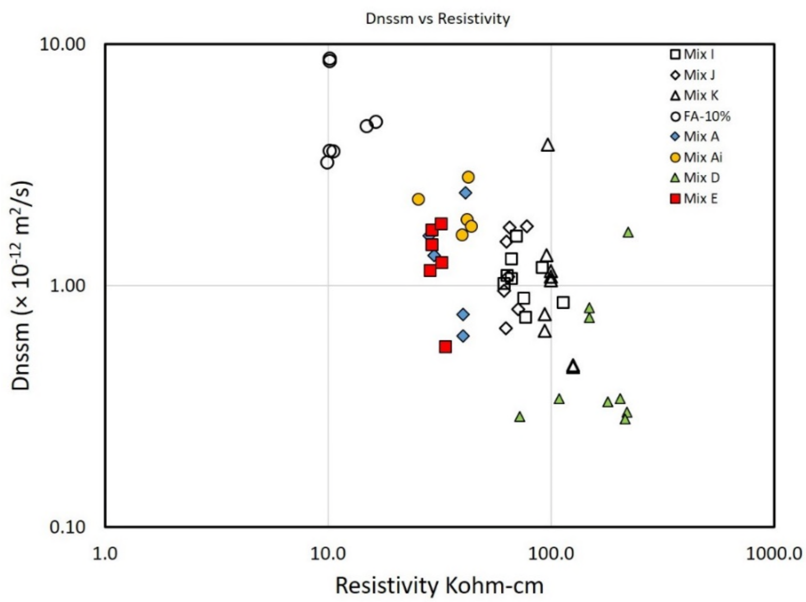


Figure 62. D_{nssm} vs. resistivity for samples prepared with mixes A to L

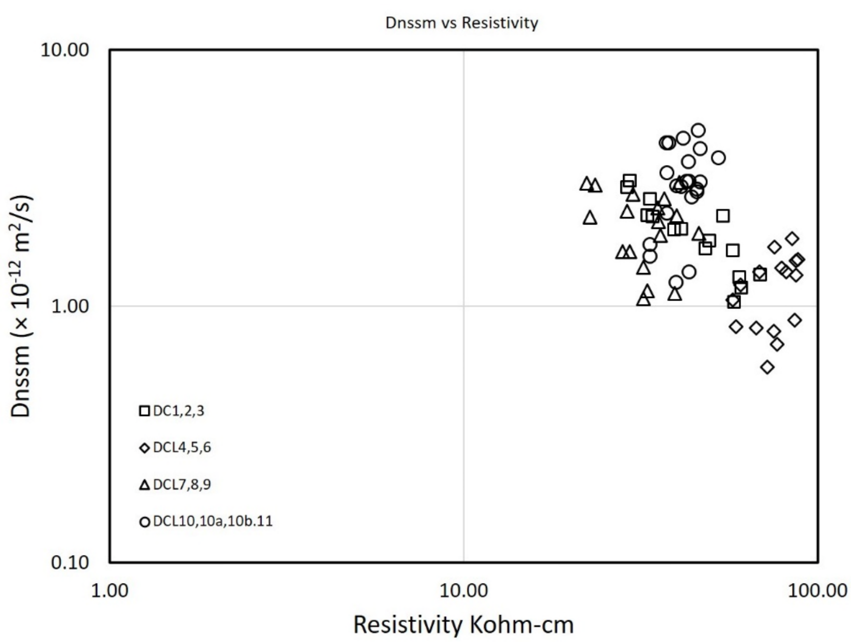


Figure 63. D_{nssm} vs. resistivity from tests performed on DC mix specimens.

Table 35. D_{nssm} vs. resistivity for samples of mixes A to L

Sample	$D_{nssm} \times 10^{-12}$ m^2/s	Resistivity	Sample	$D_{nssm} \times 10^{-12}$ m^2/s	Resistivity
A1	0.76	40.5	C1	0.81	58.0
A2	0.62	40.2	C2	1.51	61.9
A3	2.42	41.3	C3	1.69	62.4
A12a	1.91	40.6	C12a	1.20	62.2
A12b	1.14	40.6	C12b	1.18	58.8
FAA23	1.33	29.9	FC-23A	0.7	60.6
FAA28	1.61	28.5	FC-23B	0.61	64.9
			FC-22	0.75	60.0
Ai-1	1.88	41.9	FC28	0.13	76.7
Ai-2	2.82	42.3	D1	1.67	222.2
Ai-3	1.77	43.9	D2	0.3	219.6
FAi12	2.02	42.7	D3	0.28	215.3
FAi12b	1.67	42.7	D12a	0.287	72.3
FA23	2.28	25.3	D12b	0.34	204.8
FA28	1.63	39.9	FD22	0.33	180.2
			FD23	0.34	108.5
B1	0.39	101.6	FD-27a	0.74	148.8
B2	0.41	103.7	FD-27b	0.81	148.8
B3	1.61	97.9			
B12a	1.01	110.1	E1	1.48	29.1
B12b	1.04	101.6	E2	1.16	28.6
FBB-28	0.68	105.3	E3	1.71	29.1
FBB23	0.76	122.8	E12	1.32	28.9
FBB27	0.85	98.6	E12	1.47	28.9
			FE22	1.25	32.3
Bi1	0.84	113.8	FE23	1.81	32.1
BI2	0.95	113.0	FE-28	0.56	33.6
BI3	1.16	110.6			
Bi12a	1.07	98.9	J1	1.09	64.6
Bi12b	1.06	96.8	J2	1.74	65.1

Table 35 continues

Sample	D_{nssm} x 10^{-12} m^2/s	Resistivity		Sample	D_{nssm} x 10^{-12} m^2/s	Resistivity
FB23	0.61	119.4		J3	1.52	63.0
FB29	1.13	91.2		J12a	0.67	62.8
				J12b	0.95	61.5
F1	0.99	40.2		FJ28	0.8	71.3
F2	1.72	40.7		FJ23	1.76	77.8
F3	0.7	42.3				
F12	1.7	41.0		K1	3.84	96.9
F12b	1.91	39.2		K2	1.34	95.3
FF-23A	0.67	98.2		K3	1.09	99.8
FF-23B	0.55	107.0		K12a	1.15	100.0
FF-27b	1.17	50.3		K17	1.05	100.0
FF-27A	1.15	50.3		FK-23A	0.65	93.7
				FK-23B	0.76	93.7
G1	2.14	19.6		FK-28A	0.47	125.4
G2	1.99	19.6		FK-28B	0.46	125.4
G3	2.61	21.7				
G12	1.35	20.3		L1	1.66	258.7
G12b	1.61	20.3		L2a	0.66	242.7
FG-23	1.34	43.5		L3a	0.95	211.2
FG-28	1.05	29.3		L10	1.36	218.0
FG-22	0.89	39.7		L12b	1.37	199.8
				FL-22-A	2.17	219.9
H1	4.19	82.0		FL-22-B	1.9	219.6
H2	2.51	84.1		FL-23	1.41	124.2
H3	1.41	83.1		FL-28a	1.31	96.7
H12	0.51	83.1				
H12b	1.09	83.1		CRA-10	3.23	9.9
FH23	0.52	154.6		CRA-11	3.6	10.6
FH28	0.79	85.9		CRA-12	3.61	10.2
				CRA13-A	8.7	10.1
I-1	1.1	63.5		CRA13-B	8.5	10.1
I-2	1.07	66.6		CRA15-A	4.58	14.9
I-3	1.02	61.4		CRA15-B	4.76	16.4
I12a	1.6	69.8				
I-12b	1.29	66.5				
FI-22b	0.74	76.9				
FI-22a	0.89	75.4				
FI23	0.85	113.3				
FI28	1.19	91.1				

Table 35 shows the D_{nssm} values and resistivity values measured on mixes A to L and CRA mix (which contained 10% FA). Table 36 shows the D_{nssm} and resistivity values measured on DCL samples.

Table 36. D_{nssm} and resistivity measured on DC1, DC2, and DC3 specimens.

Age (days)	Specimen	Cast	Test	D_{nssm} x 10^{-12} m^2/s	Resistivity
1681	DCL1-2a	12/7/2011	7/14/2016	1.04	58.19
	DCL1-2b	12/7/2011	7/14/2016	1.18	60.72
1923	DC1-1a	12/7/2011	3/13/17	1.65	57.50
	DC1-27	12/7/2011	4/24/17	1.3	60.15
	DC1-24	12/7/2011	3/21/17	1.33	68.73
1758	DCL 2-22a	9/22/2011	7/15/2016	1.99	39.33
	DCL 2-22b	9/22/2011	7/15/2016	2.00	41.27
2037	DC2-2	9/22/2011	4/20/2017	1.80	49.50
	DC-2-23	9/22/2011	4/20/2017	2.25	54.09
	DC2-7	9/22/2011	4/20/2017	1.68	48.14
1726	DCL 3-22a	10/18/2011	7/9/2016	3.09	29.50
	DCL-3-22b	10/18/2011	7/9/2016	2.91	29.02
2011	DC3-1	10/18/2011	4/20/17	2.27	33.01
	DC3-1a	10/18/2011	4/24/17	2.62	33.65
	DC3-23	10/18/2011	4/24/17	2.24	34.16
1671	DCL 4-22a	12/21/2011	7/18/2016	1.32	87.05
	DCL 4-22b1	12/21/2011	7/18/2016	1.50	87.05
1917	DC4-7a	12/21/2011	3/21/17	1.52	88.00
	DC4-27	12/21/2011	3/21/17	1.84	84.60
	DC4-1a	12/21/2011	3/21/18	1.70	75.50
1671	DCL 5-22a	12/21/2011	7/18/2016	0.71	76.70
	DCL 5-22b	12/21/2011	7/18/2016	0.58	72.20
1947	DC5-1	12/21/2011	4/20/17	1.36	81.55
	DC5-26	12/21/2011	4/20/17	0.88	86.20
	DC5-27	12/21/2011	4/20/17	1.41	79.01
	DC5-7	12/21/2011	4/20/17	0.80	75.07

NOTE: The date format is mm/dd/yyyy

Table 36 Continues

Age (days)	Specimen	Cast	Test	D_{nssm} x 10^{-12} m^2/s	Resistivity
1723	DCL 6-22a	10/26/2011	7/14/2016	1.06	57.5
	DCL 6-22b	10/26/2011	7/14/2016	1.21	60.61
2007	DC6-1	10/26/2011	4/24/17	1.36	68.40
	DC6-7	10/26/2011	4/24/17	0.82	67.03
	DC6-26	10/26/2011	4/20/17	0.83	58.85
1673	DC7-22A	12/14/2011	7/13/2016	2.41	35.3
	DC7-22B	12/14/2011	7/13/2016	1.89	35.95
1916	DC7-1a-A	12/14/2011	3/13/17	3.04	40.72
	DC7-27a-A	12/14/2011	3/13/17	2.14	35.49
	DC7-7	12/14/2011	4/24/17	2.25	40.03
	DC7-7a-A	12/14/2011	3/13/17	1.92	46.12
1691	DC8-25A	11/22/2011	7/9/2016	2.73	30.14
	DC8-25B	11/22/2011	7/9/2016	2.34	29.02
1980	DC8-1	11/22/2011	4/24/17	1.12	39.52
	DC8-26	11/22/2011	4/24/17	1.15	33.07
	DC8-27	11/22/2011	4/24/17	1.42	32.23
	DC8-7	11/22/2011	4/24/17	2.63	36.89
1717	DC9-25A	11/2/2011	7/15/2016	2.96	23.54
	DC9-25B	11/2/2011	7/15/2016	3.01	22.25
1996	DC9-1	11/2/2011	4/20/17	1.63	29.41
	DC9-26	11/2/2011	4/20/17	1.63	28.06
	DC9-27	11/2/2011	4/20/17	2.23	22.71
	DC9-7	11/2/2011	4/24/17	1.07	32.19

NOTE: The date format is mm/dd/yyyy

Table 36 Continues

Age (days)		**Cast**	**Test**	**D_{nssm} x 10^{-12} m^2/s**	**Resistivity**
1752	DC10-22A	9/28/2011	7/15/2016	2.95	39.98
	DC10-22B	9/28/2011	7/15/2016	3.32	37.56
1993	DC10-1a	9/28/2011	3/13/17	4.84	46.08
	DC-10-23a	9/28/2011	3/13/17	4.33	38.02
1736	DC10a-23A	10/12/2011	7/13/2016	3.67	43.2
	DC10a-23B	10/12/2011	7/13/2016	2.31	37.56
2021	DC10a-24	10/12/2011	4/24/17	1.74	33.6
	DC10a-24a	10/12/2011	4/27/17	1.57	33.59
	DC10a-27a	10/12/2011	3/13/17	4.52	41.69
	DC10a-27b	10/12/2011	3/13/17	4.34	37.41
	DC10a-1a	10/12/2011	3/13/17	2.87	45.51
1703	DC10b-23A	11/16/2011	7/15/16	2.94	41.11
	DC10b-23B	11/16/2011	7/15/16	3.07	42.56
1944	DC10b-1a	11/16/2011	3/13/17	3.07	43.37
	DC10b-24a	11/16/2011	4/24/17	1.24	39.84
	DC10b-7a	11/16/2011	4/24/17	1.36	43.37
1710	DC11-23A	11/9/2011	7/15/2016	3.05	46.59
	DC11-23B	11/9/2011	7/15/2016	2.67	44.01
1948	DC11-1A	11/9/2011	3/10/17	2.8	45.68
	DC11a-24a	11/9/2011	3/13/17	3.8	52.34
	DC11a-7a	11/9/2011	3/13/17	4.12	46.62

NOTE: The date format is mm/dd/yyyy

4.7 D_{nssm} vs. time SL, FA, T1 and T2 specimens

The rapid migration test was measured five times over 600 days on SL1, SL2, FA1, and FA2 specimens. Figure 64 shows D_{nssm} values vs. time measured on SL1 and SL2 specimens. Most D_{nssm} values were between 1.7 and 3.6 × 10^{-12} m^2/s, only the last 2 readings on SL1 specimens were smaller than 1 × 10^{-12} m^2/s. The D_{nssm} does not appear to change much with time for SL specimens. Figure 65 shows D_{nssm} values vs. time measured on FA specimens. The D_{nssm} initially ranged between 3.5 and 11.3 × 10^{-12} m^2/s, and the most recent D_{nssm} values were smaller than 2 × 10^{-12} m^2/s; for the FA samples, the D_{nssm} appears to decrease as the concrete ages. Figure 66 shows D_{nssm} vs. time for tests performed on T1 and T2 specimens. These two mixes contained both FA and SL or FA and silica fume, respectively. The D_{nssm} range was smaller on these specimens and tended to modestly decrease with time. By day 500, the D_{nssm} was close to 1 × 10^{-12} m^2/s on samples from both mixes.

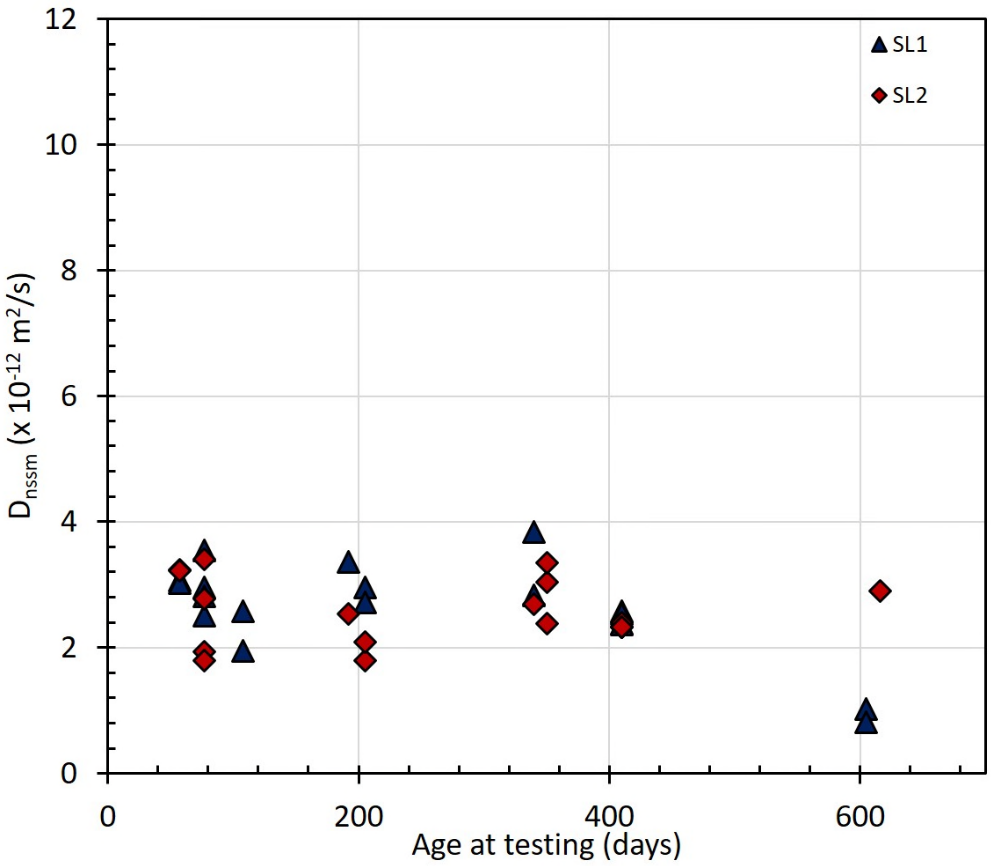


Figure 64. D_{nssm} vs. time measured on SL1 and SL2 specimens.

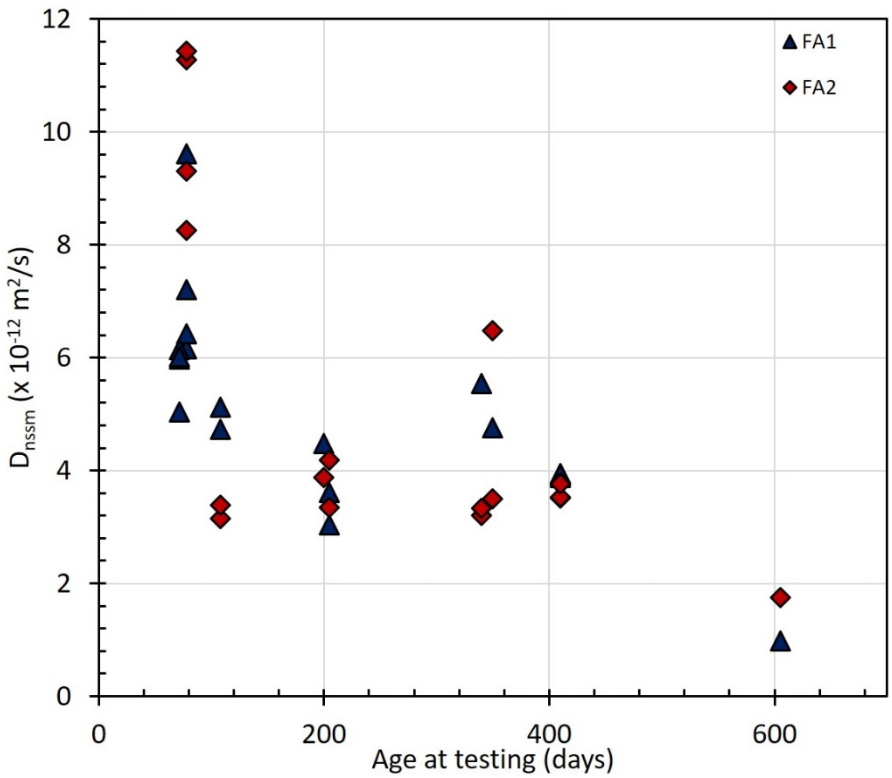


Figure 65. D_{nssm} vs. time measured on FA1 and FA2 specimens.

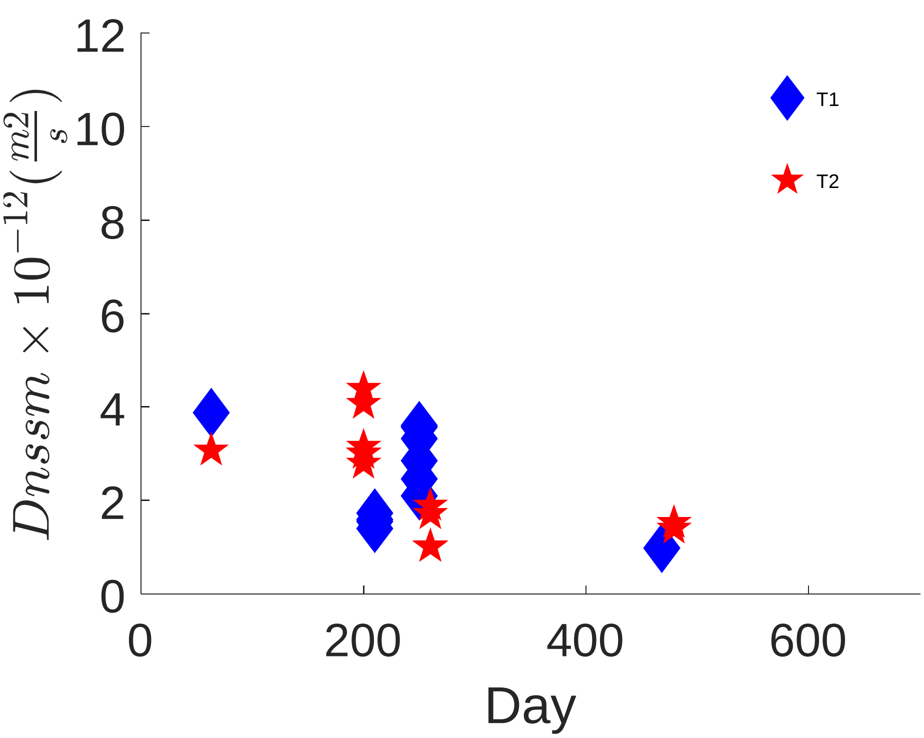


Figure 66. D_{nssm} vs. time measured on T1 and T2 specimens.

4.8 D_{nssm} vs. time for DCL specimens

Figure 67 shows D_{nssm} vs. time for DCL1 to DCL6 samples. The plot includes tests performed as part of a previous project and tests performed recently (> 1,500 days of age). The data displayed is slightly offset when the actual tests were performed so as to better identify the range of D_{nssm} for each mix. The wider range observed for measurements performed at 90 days are influenced by the concrete age, but also the different curing regimes that these samples were subjected to. The curing regime appears to have a lesser effect as the concrete ages. The DC3 mix appears to have the larger D_{nssm} at any given time and it is likely due to the higher w/cm ratio on specimens with this mix. The D_{nssm} values for DC1 and DC2 do not appear to change after 1 year of age, whereas for the DC3 there appears to be a modest decrease in the magnitude of D_{nssm}. Similar trends are observed for the D_{nssm} vs. time shown on the bottom plot for DC4, DC5 and DC6. Initially, the D_{nssm} was larger for DCL6 samples, but the last set of measurements show that the D_{nssm} is comparable for all three groups.

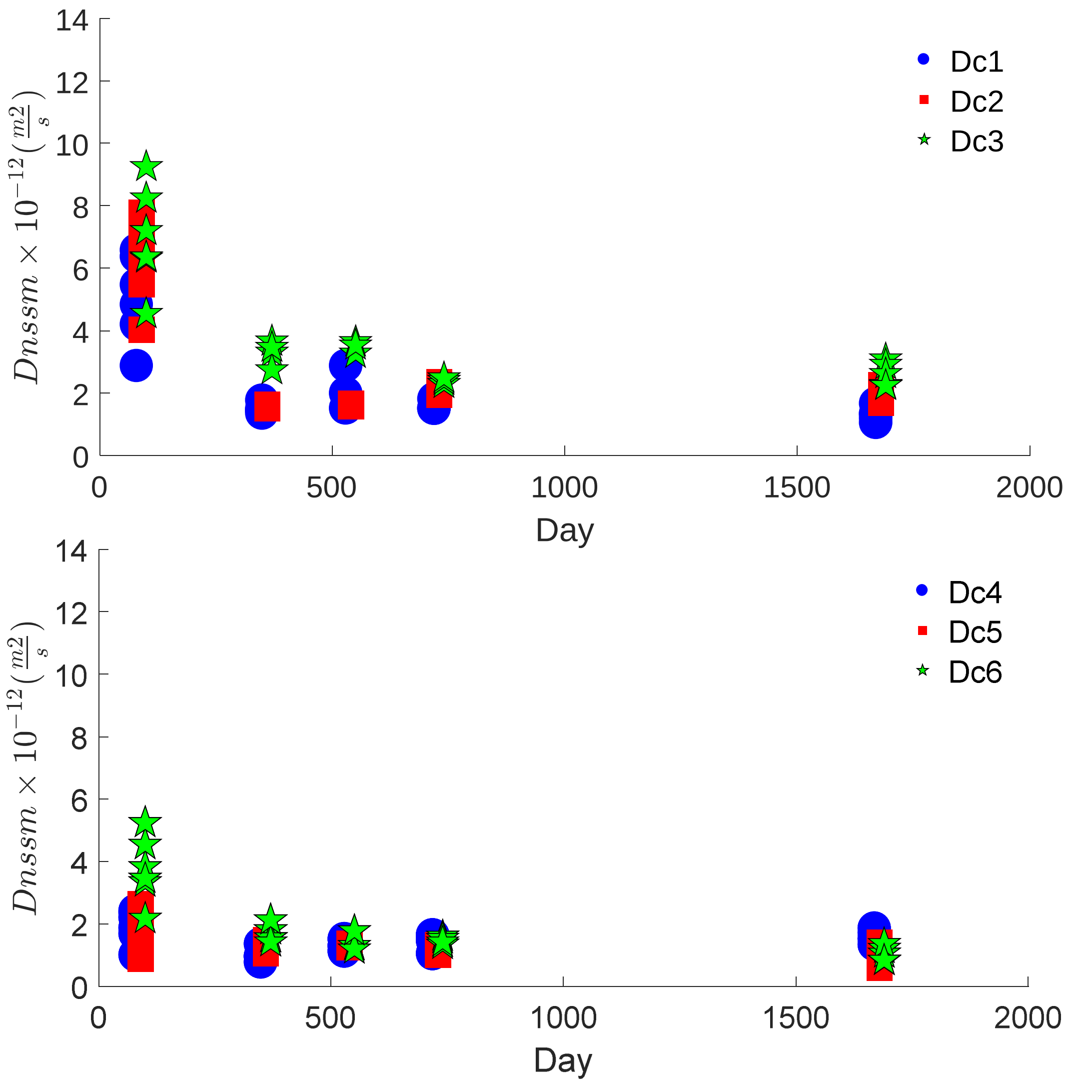


Figure 67. D_{nssm} vs. time measured on DC1, DC2, and DC3 specimens.

Figure 68 shows how the D_{nssm} changed vs. time for the other DC mixes (i.e., DC7 to DCL11). The top plot shows that there were similar trends that those described for DCL1 to DCL3. For the samples with slag, (DC7 to DCL9) there appears to be a plateau after 500 days on the average D_{nssm}. The range within a given time was slightly different. Note that the first set of measurements the range is larger, this is due to some of the samples were subjected to curing at elevated temperature which likely accelerated the curing on these samples. The reduction in cementitious content did not appear to significantly affect the measured D_{nssm} (DCL10, DCL10a, DCL10b, and DCL11 compare to DCL2 samples). The spread of D_{nssm} values for DCL10b and DCL11 at 100 days was smaller than that observed on DCL10 and DCL10a samples. The former had smaller amounts of entrained air.

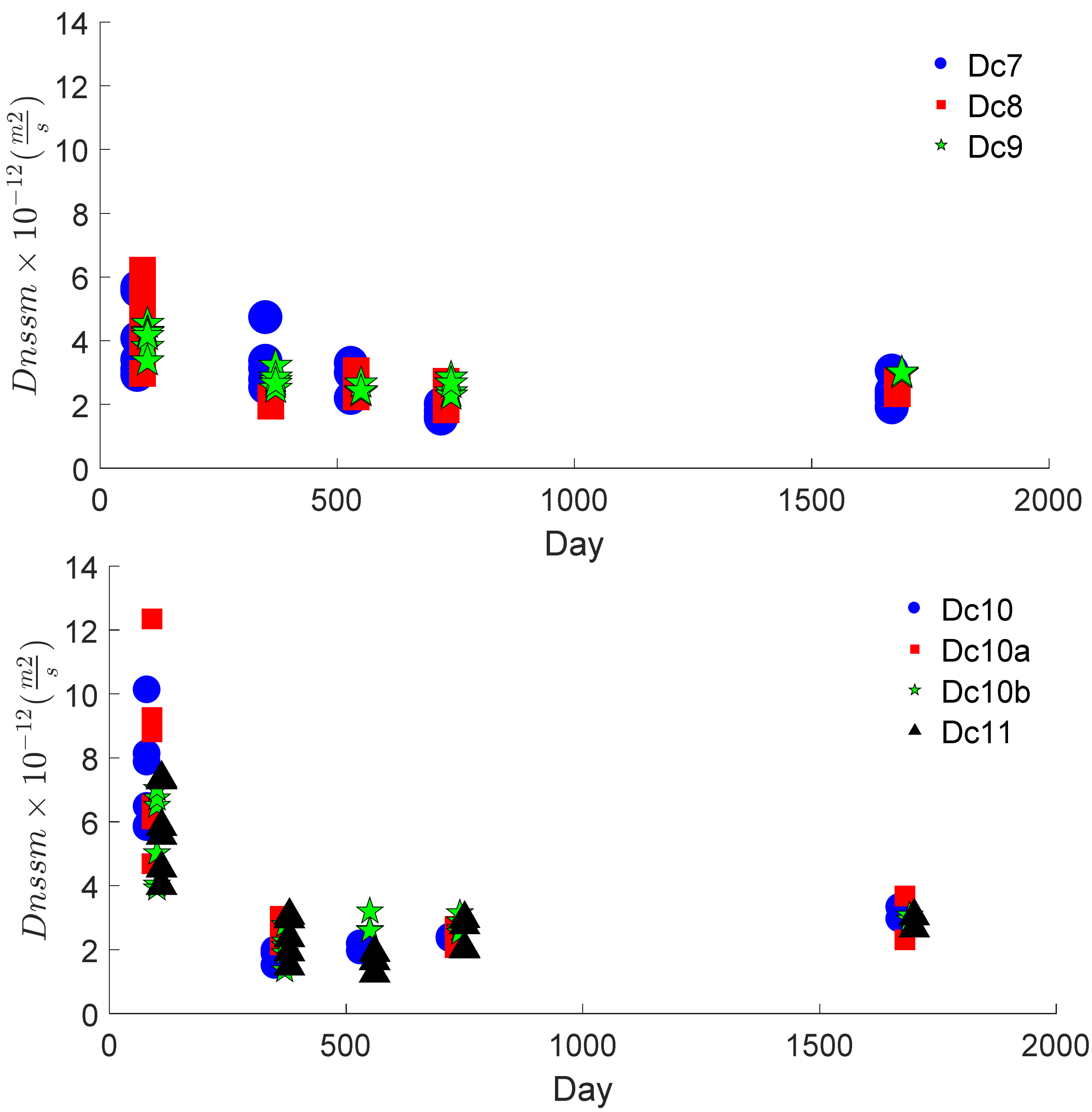


Figure 68. D_{nssm} vs. time measured on DC7, DC8, DC9, DC10, DC10a, DC10b, and DC11 specimens.

4.9 K values from D_{nssm} vs. resistivity

Non-steady state diffusion coefficients (D_{nssm}) were calculated based on the NT-492 tests performed during this project. The results section presented the measured D_{nssm} values. The concrete resistivity was measured in most cases on the concrete slice prior to the test. In some cases, the resistivity reported here is the concrete resistivity of the whole cylinder prior to slicing after applying the geometric correction (the surface resistivity cell constant for 10 x 20 cm is approx. 1.89). The D_{nssm} vs. resistivity section presented plots and tables listing the obtained values. In this section the K values from the correlation $D_{nssm} = K/\rho$ are presented for various groupings.

4.9.1 K values for recently prepared specimens

Recall that SL1, SL2, FA1, FA2, T1, and T2 are the ID given to the concrete compositions prepared during April 2016 and August 2016. Figure 69, Figure 70, and Figure 71 show the D_{nssm} vs. resistivity correlation for these tested samples and include the calculated K values. Figure 69 shows fitted data on the SL specimens, the top plot shows only values measured on SL1 (batch 1) specimens, the center plots shows the values and the fit for SL2 specimens, and the plot at the bottom shows both: the K values were 52.6, 53.3 and 53.4 $\times 10^{-2}$ kΩ-m^3/s, respectively. Figure 70 shows D_{nssm} vs. resistivity measured on FA1 and FA2 specimens, the top plot shows that FA1 specimens had a K value of 70.7, whereas the concrete cylinders for batch 2 (FA2) had a K value of 100, and the combined K value for FA1 and FA2 specimens was 81. Figure 71 shows that the T1 specimens the K value was 142, whereas for T2 specimens (those with FA + SF), they had a K value of 189. These values are somewhat larger than previously reported for concrete with a similar composition.

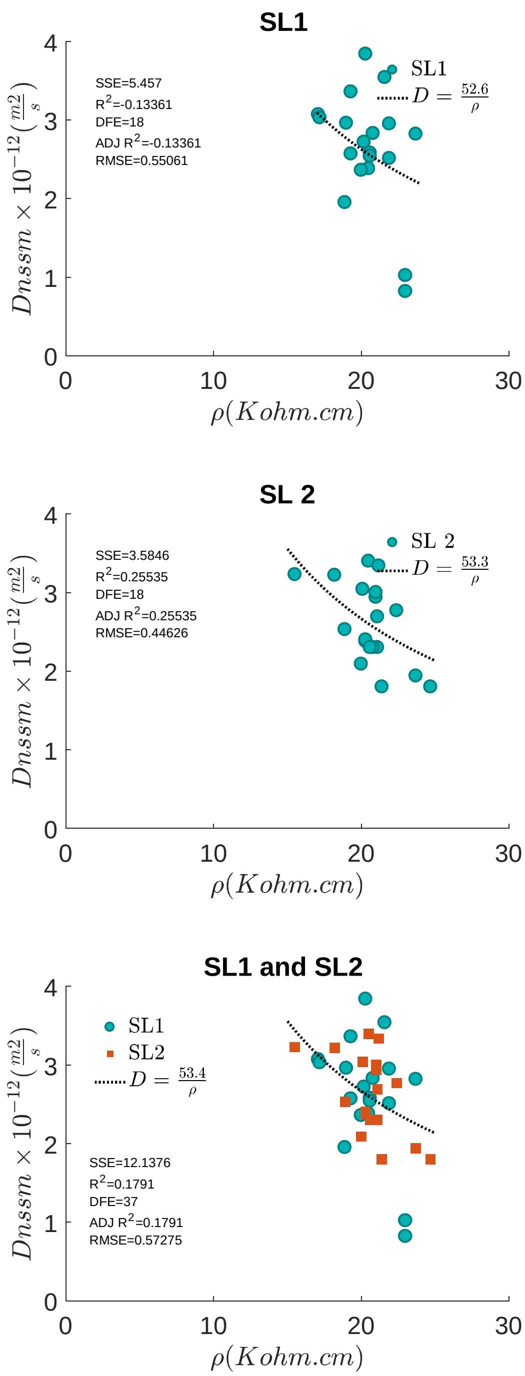


Figure 69. D_{nssm} vs. resistivity for SL1, SL2, with K values.

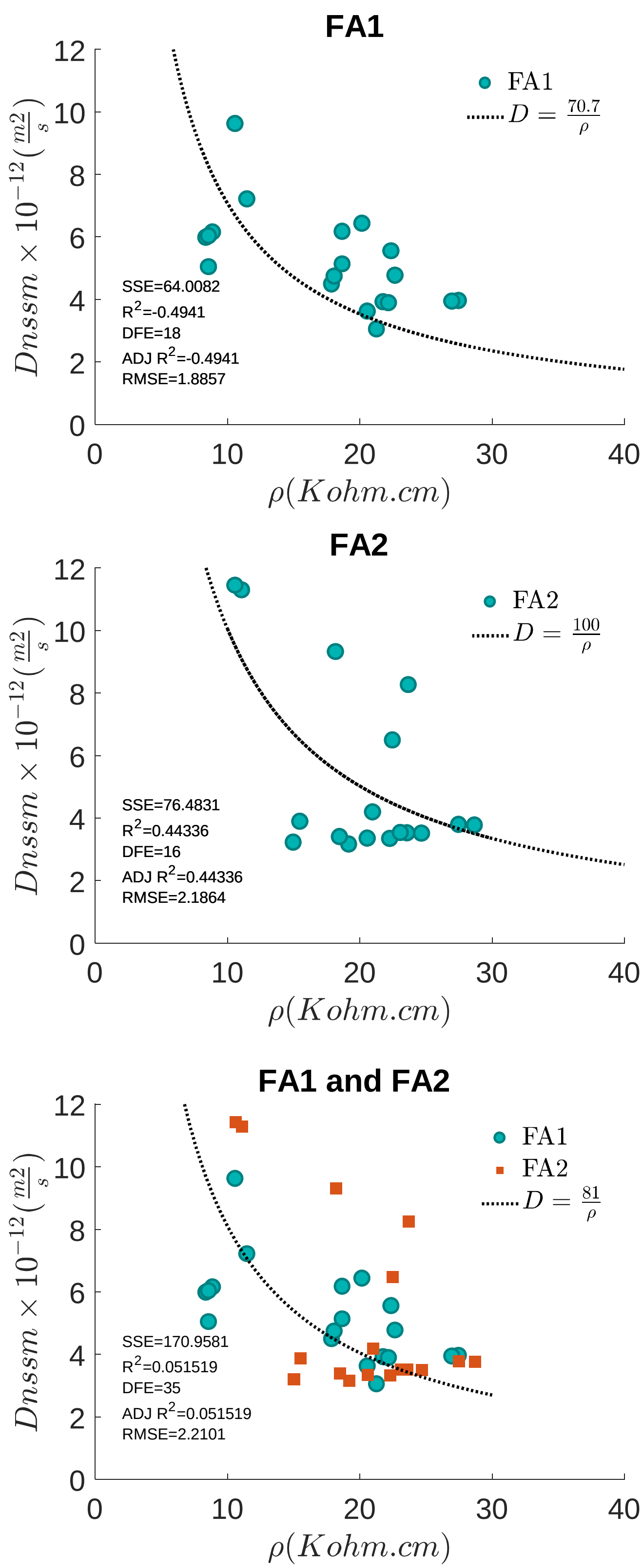


Figure 70. D_{nssm} vs. resistivity for FA1, FA2, with K values.

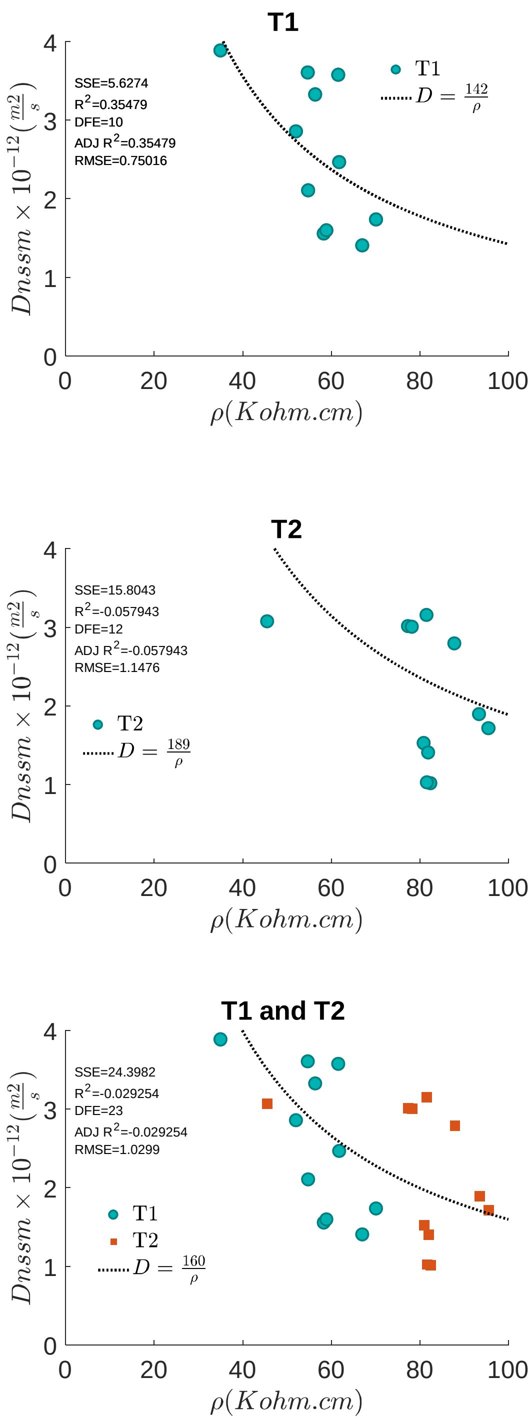


Figure 71. D_{nssm} vs. resistivity for T1 and T2 with K values.

4.9.2 K values for A to L mixes

Figure 72 shows the correlation obtained on samples tested at 1 year of age and also the recent set of measurements (performed at more than 2000 days of age) on samples from A to L mixes. Mixes A to L (not including Ai and Bi specimens) had a K value of 81.6 at 1 year; the K value at more than 2000 days was 49.8 × 10^{-2} kΩ-m^3/s, which is lower. A similar reduction in K value was observed for the K values obtained after correlating the D_{nssm} vs. resistivity of specimens Ai and

Bi (which had a higher porosity); the K value was 120 at one year and changed to 79 after more than 200 days of age. There appears to be more scatter on the set of measurements performed recently.

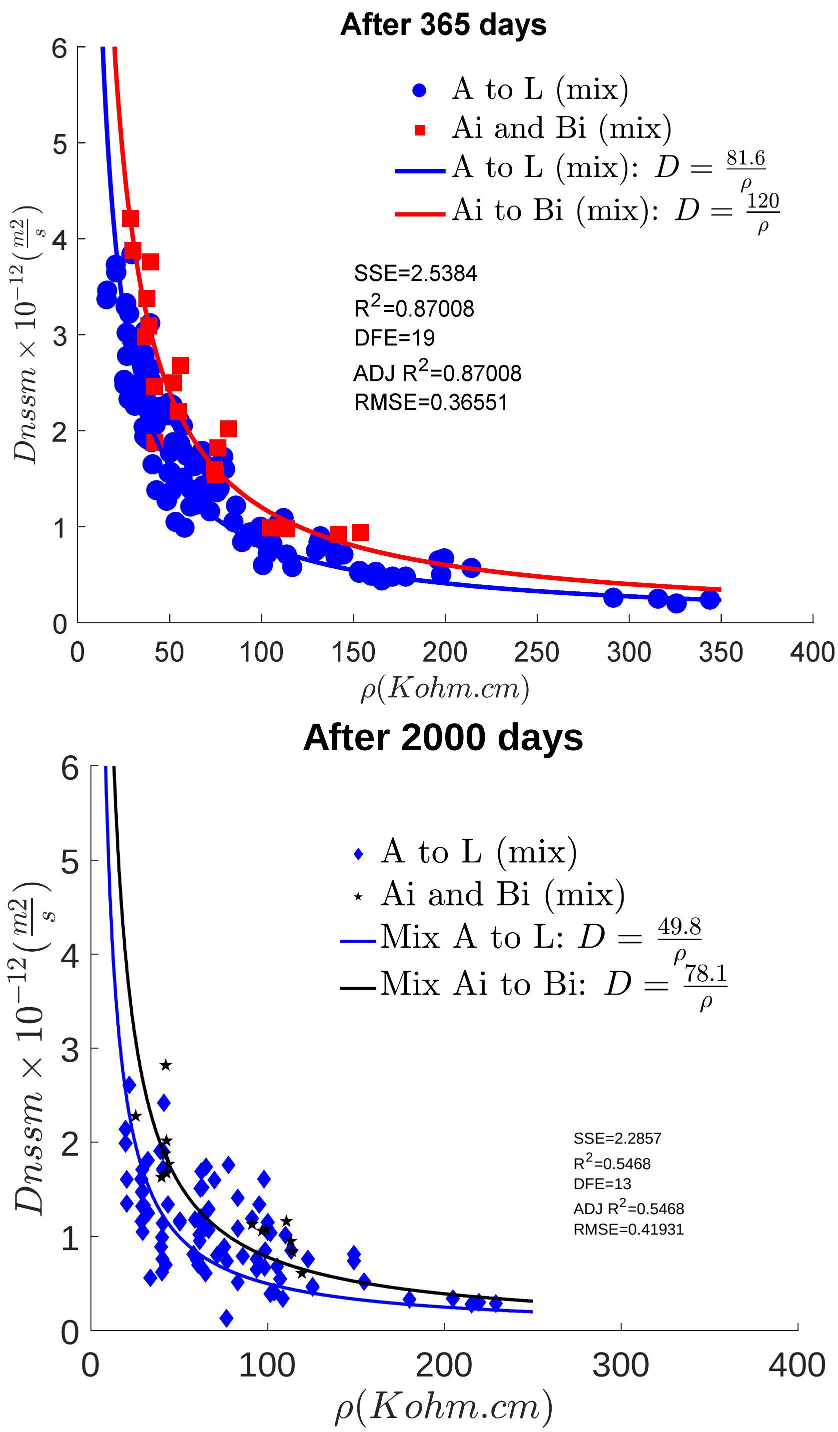


Figure 72. D_{nssm} vs. resistivity for A to L, Ai, and Bi samples tested a) at 365 days and b) more than 2000 days.

4.9.3 K values for DCL specimens

The correlation between the D_{nssm} and the resistivity of the sample was also investigated on DCL specimens. Prior rapid migration tests were performed at 90-100 days of age, 365 days, 540 days and 730 days of age. In addition, similar tests were done as part of the current project, the tests were performed after 1600 days (see table 36 for the actual age at testing). In here, the K values using various groupings are presented in the table and in plot formats. Table 37 presents the K values obtained from measurements performed on a given date on each concrete mix. The last two columns show the K and R^2 values when all D_{nssm} measured on samples of a given mix type were included in the correlation. The K_{all} ranged from 61.7 to 133.

Table 37. K and R^2 values.

Mixture	K_{90}	R^2_{90}	K_{365}	R^2_{365}	K_{540}	R^2_{540}	K_{730}	R^2_{730}	K_{1681}	R^2_{1681}	K_{all}	R^2_{all}
DC1	111.5	0.63	58.8	0.80	97.4	0.64	84.8	0.87	78.8	0.93	98.7	0.79
DC2	102.0	0.63	48.5	0.8	57.2	0.64	85.4	0.75	87.7	0.69	90.3	0.70
DC3	94.7	0.87	70.4	0.83	88.6	0.66	56.0	0.72	83.5	0.85	85.9	0.87
DC4	152.9	0.16	79.2	0.38	120.5	0.64	133.5	0.88	132.6	0.97	127	0.16
DC5	117.6	0.19	82.5	0.92	95.8	0.79	86.5	0.93	73.8	0.86	93.3	0.19
DC6	152.8	0.57	87.6	0.78	90.4	0.82	84.3	0.89	65.1	0.74	112	0.57
DC7	93.8	0.53	78.6	0.83	79.5	0.53	54.0	0.85	86.9	0.79	82.2	0.53
DC8	101.3	0.29	45.2	0.82	66.3	0.65	58.4	0.76	96.0	0.70	74.1	0.29
DC9	69.1	0.00	55.8	0.00	50.7	0.00	55.2	0.00	83.6	0.00	61.7	0.29
DC10	141.5	0.73	58.5	0.00	73.4	0.99	95.6	0.00	131.6	0.18	124	0.76
DC10a	153.2	0.66	80.5	0.73	NA	NA	87.9	0.35	134.5	0.00	133	0.74
DC10b	98.9	0.69	63.2	0.00	96.2	0.00	100.7	0.1	156.3	0.00	94.1	0.73
DC11	105.8	0.43	75.5	0.00	57.7	0.18	93.9	0.00	155.2	0.00	96.9	0.72

Table 38 shows the K values for cases grouped by cementitious type (e.g., DCL1, DCL2, and DCL3 for specimens with 20% FA). The K values were larger for specimens with fly ash and silica fume, followed by those with fly ash and finally, the smaller K values were those observed for specimens only with slag (DC7, DC8, and DC9). The difference between K values obtained on younger (90-100 days) concrete specimens and the K values on specimens older than 1 year were significant. The K values obtained using the D_{nssm} measured at all ages for these subgroups were in between the maximum and minimum D_{nssm} measured. This is as would be expected. The K values appear to depend to some extent on the type of supplementary cementitious material used.

Table 38. K values obtained for the indicated groupings.

			K	*R*	**R^2**
20% FA	DC1 DC2 DC3	90	100.11	0.74	0.55
		365	62.42	0.89	0.79
		540	83.55	0.69	0.48
		730	67.06	0.00	0.00
		1,680	83.96	0.90	0.81
		365, 540, 730	90.5	0.69	0.47
		90, 365, 540, 730	89.89	0.88	0.78
		365, 540, 730, 1680	71.8	0.70	0.49
		90, 365, 540, 730, 1,680	89.4	0.89	0.80
20% FA+8% SF	DC4 DC5 DC6	90	144.52	0.88	0.78
		365	84.57	0.77	0.60
		540	98.43	0.53	0.28
		730	94.10	0.00	0.00
		1,680	83.95	0.75	0.57
		365, 540, 730	68.6	0.22	0.05
		90, 365, 540, 730	114.6	0.75	0.57
		365, 540, 730, 1,680	88.7	0.48	0.23
		90, 365, 540, 730, 1,680	109.2	0.71	0.50
50% Slag	DC7 DC8 DC9	90	85.37	0.00	0.00
		365	58.61	0.00	0.00
		540	62.21	1.52	2.3
		730	55.88	0.00	0.00
		1,680	87.44	0.46	0.21
		365, 540, 730	58.7	0.33	0.11
		90, 365, 540, 730	69.8	0.52	0.27
		365, 540, 730, 1,680	61.8	0.69	0.47
		90, 365, 540, 730, 1,680	71.05	0.52	0.27
	DC10 DC10a DC10b DC11	90	123.69	0.58	0.34
		365	70.07	0.00	0.00
		540	76.74	0.39	0.15
		730	94.46	0.22	0.05
		1,680	142.19	0.84	0.70
		365, 540, 730	416.7	0.17	0.03
		90, 365, 540, 730	216.4	0.00	0.00
		365, 540, 730, 1,680	442.	0.24	0.06
		90, 365, 540, 730, 1,680	110.5	0.82	0.67

In the figures to be described next, the D_{nssm} vs. resistivity are identified with a different symbol series per each testing time. The K value shown in the plots corresponds to that including all data/symbols on a given plot, i.e., includes all D_{nssm} and resistivity pairs shown in the plot. Figure 73 shows plots for DC1 (top plot), DC2 (middle plot) and DC3 (bottom plot). For each test period, there are up to 6 samples that were used. As a general trend, the migration coefficient is inversely proportional to resistivity as has been reported by others. There appears to be some effect due to the different w/cm (DC1=0.37, DC2=0.41, and DC3=0.47). Figure 74 presents the corresponding plots for DC4, DC5, and DC6. Figure 75 presents the plots for DC7, DC8, and DC9, whereas Figure 76 presents the plots for DC10, DC10a, DC10b and DC11. Figure 77 show the correlations used grouped per cementitious (as on Table 38) for the case when all tests were used to obtain K (i.e., includes 90, 365, 540, 730, and 1,680 days tests).

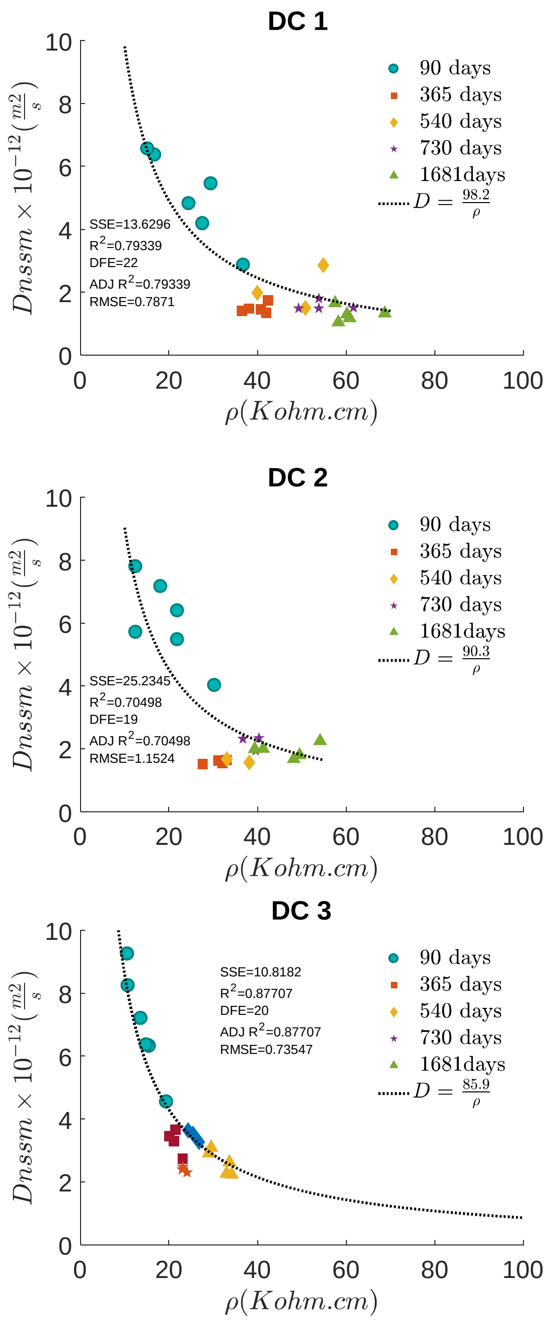


Figure 73. D_{nssm} vs. resistivity for DC1 through DC3 with K values.

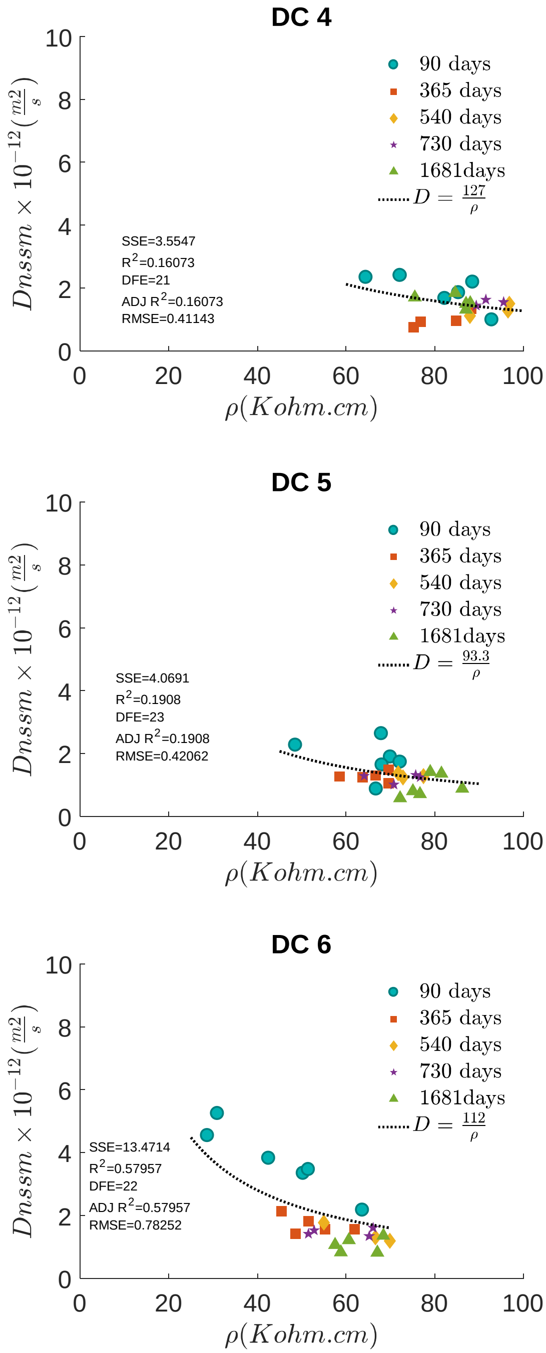


Figure 74. D_{nssm} vs. resistivity for DC4 through DC6 with K values.

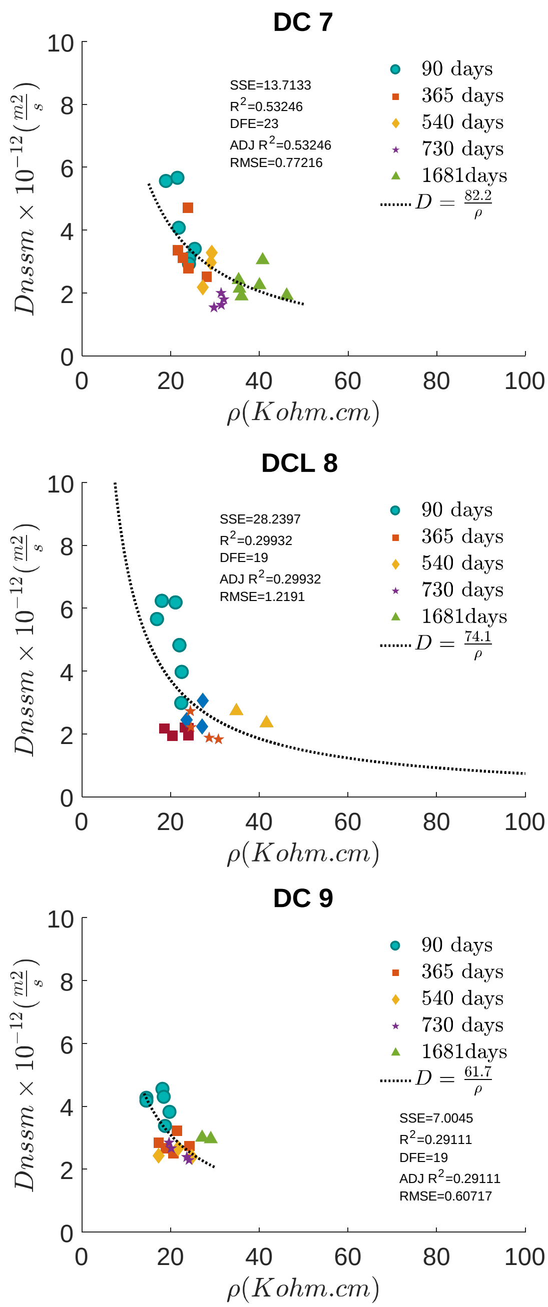


Figure 75. D_{nssm} vs. resistivity for DC7 through DC9 with K values.

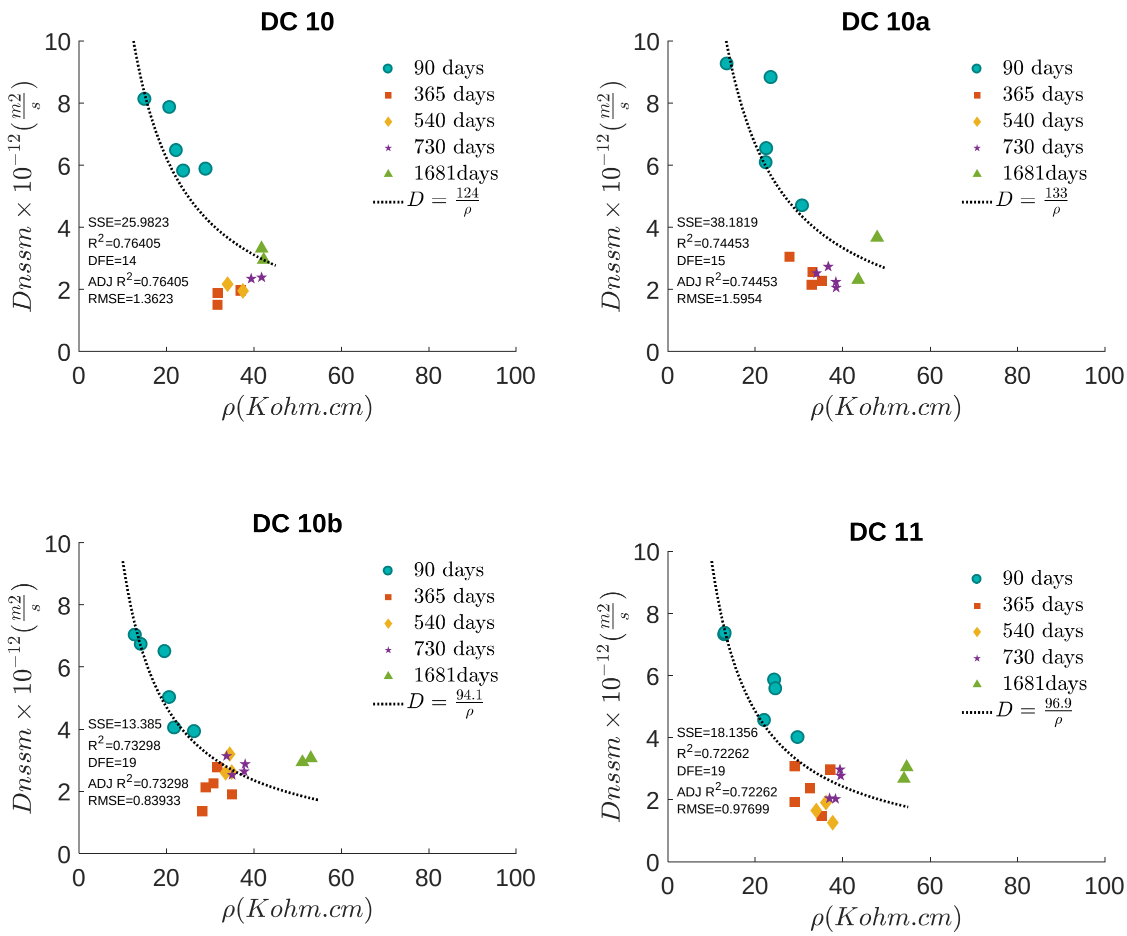


Figure 76. D_{nssm} vs. resistivity group for DC10, DC10a, DC10b and DC11 with K values.

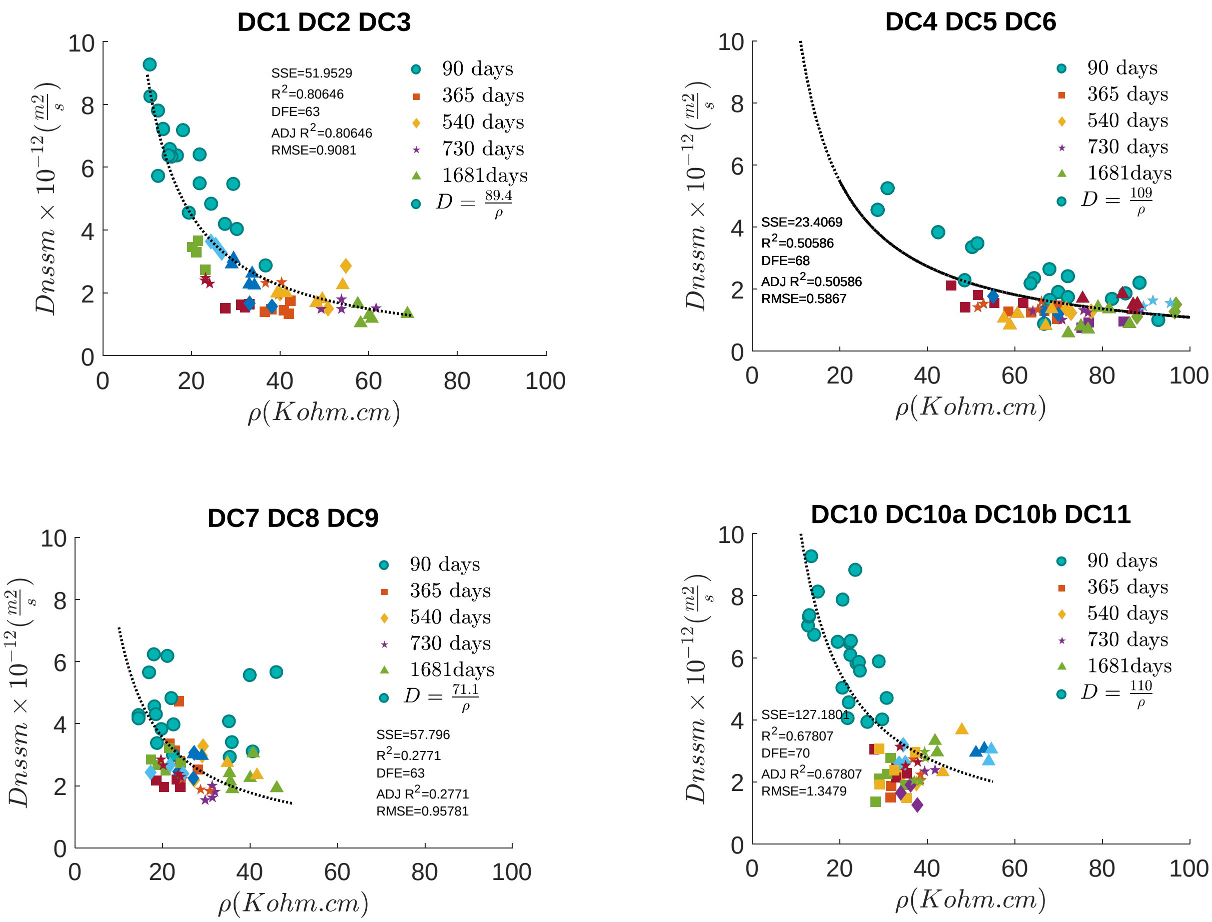


Figure 77. D_{nssm} vs. resistivity grouped per main cementitious material (as indicated in the plot).

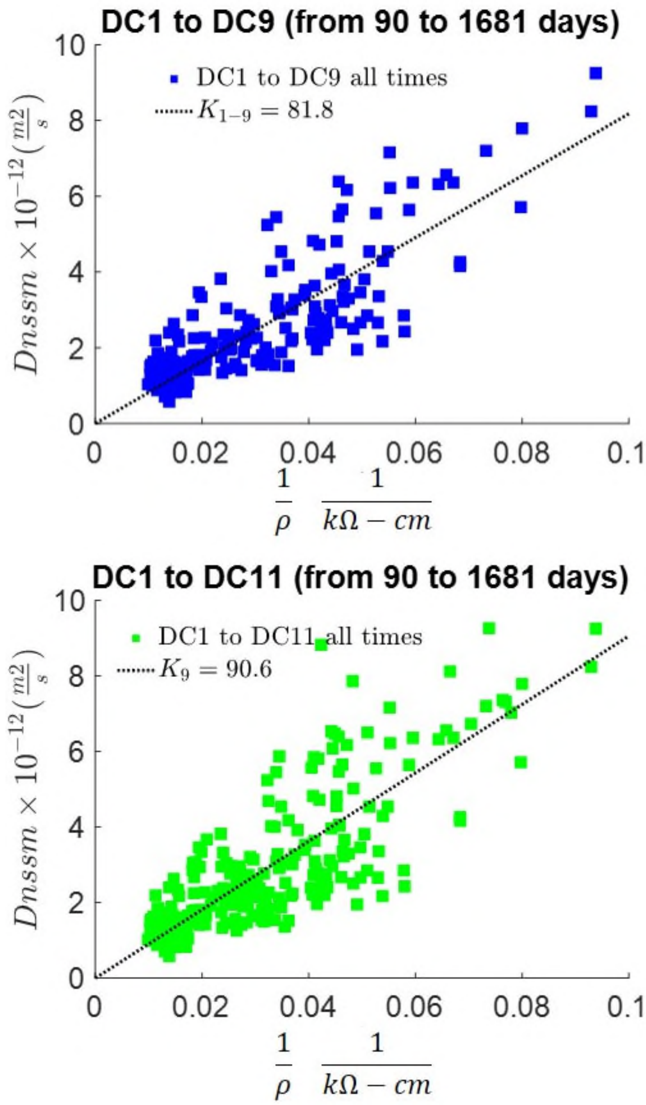


Figure 78. K values for DC mix samples.

Figure 78 presents the data not identifying the different groups. It groups the D_{nssm} and resistivity pairs obtained over time on the DCL mixes as indicated on each plot. The top plot includes the data for mixes DC1 to DC9 and the bottom plot includes the data for DC1 to DC11. The K obtained from D_{nssm} and resistivity values for mixes DC1 to DC9 was 81.8 kΩ-m^3/s and when including DC1 to DC11 (including DC10 and DC10a samples) the value increased to 90.6 kΩ-m^3/s. The K value obtained at 90-100 days was K=106 × 10^{-2} kΩ-m^3/s: DCL1 to DC11 and K= 97 × 10^{-2} kΩ-m^3/s: DCL1 to 9). The K value calculated that included all the tests performed at different times was between 16 and 15 points smaller. The K value obtained for these groupings at 1 year or later ranged between 61 × 10^{-2} kΩ-m^3/s and 72× 10^{-2} kΩ-m^3/s.

4.9.4 K values obtained from D_{nssm} vs. resistivity additional groupings

A K value of 79.5 was obtained when using all the D_{nssm} values measured and the corresponding resistivity measured on T1, T2, SL1, SL2, FA1, and FA2 specimens. Figure 79 shows a plot with all the data points and the fitted correlation. The R2 was 0.27.

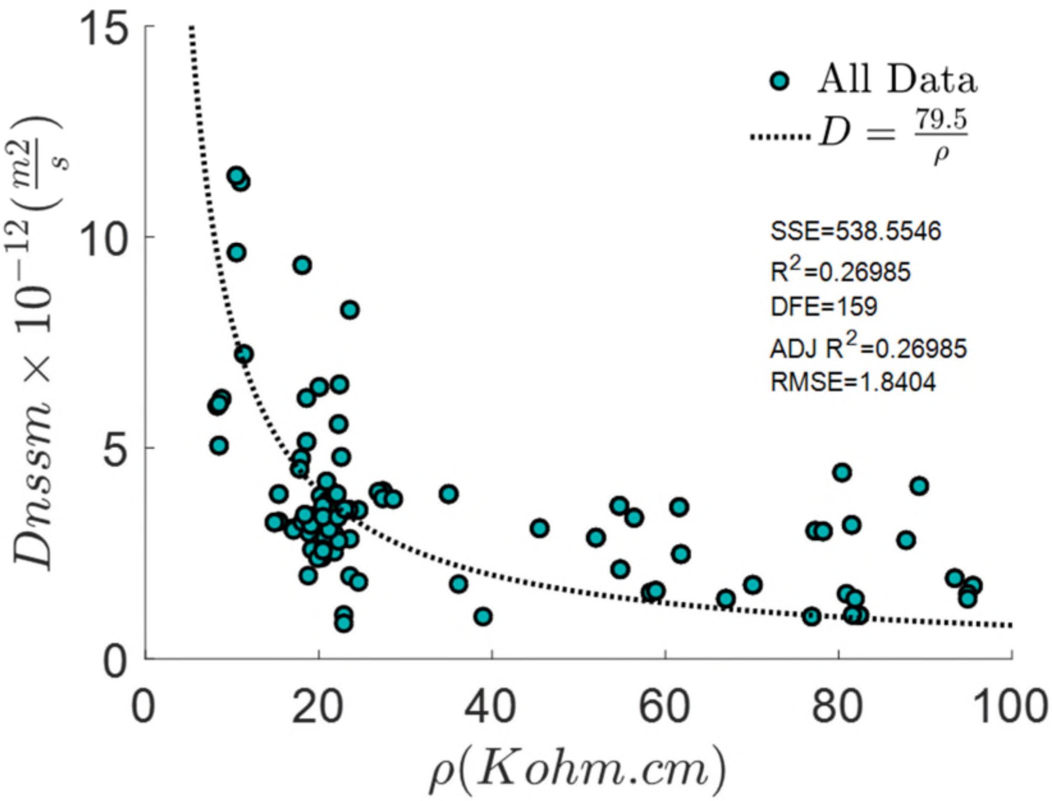


Figure 79. Correlation D_{nssm} vs. resistivity for all SL, FA, T1, and T2.

A correlation was found using D_{nssm} and resistivity measured on samples with high alkalinity and with coarse aggregate-prone to alkali-silica reaction samples. The grouping also include concrete slices from the resistivity round robin study and the values measured on slices from the cores obtained at fender piles of the Key Royale Bridge. The result was a K=86.8 (R2=0.69). Figure 80 shows a plot with the data and the correlation. This K value is 7 points larger than that obtained using the samples prepared in 2016.

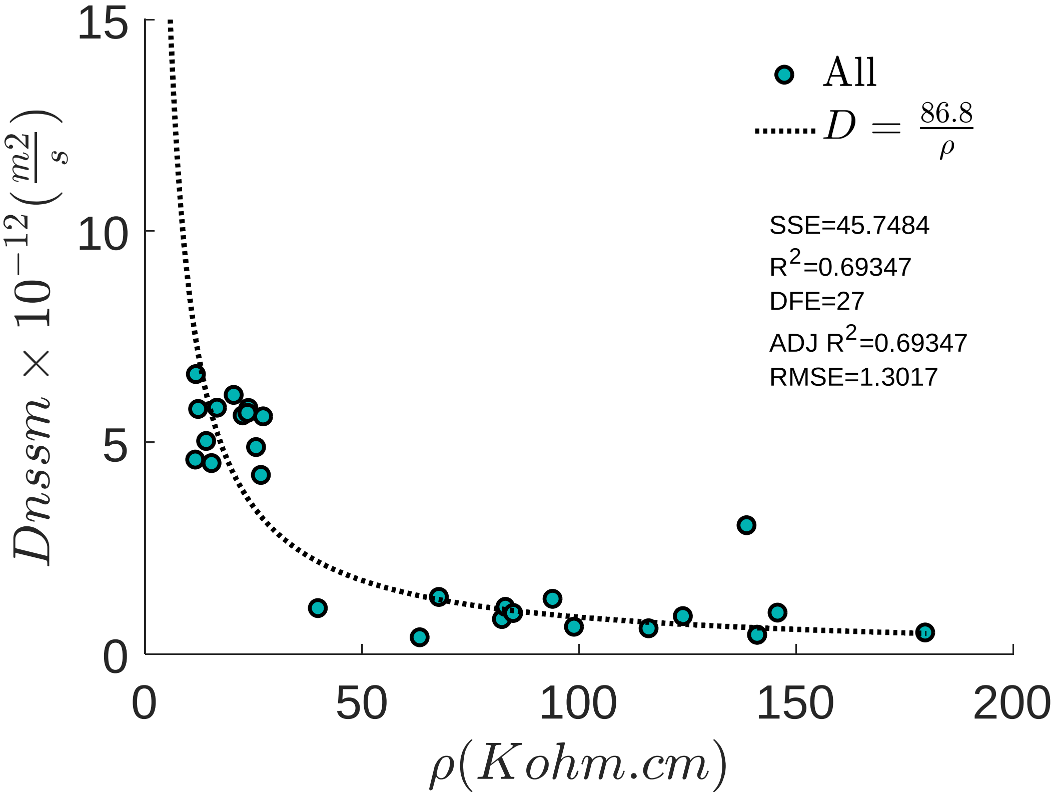


Figure 80. Correlation D_{nssm} vs. resistivity for data shown in Figure 47.

Additional groupings were done with the pairs of D_{nssm} and resistivity values. All samples with 20 percent fly ash (i.e., samples from mixes DC1, DC2, DC3, FA1, FA2, A, and C) were used to obtain the D_{nssm} vs. resistivity correlation; a K value of 82.5 was obtained with an R2 of 0.56. This correlation is shown in Figure 81. A K=62.3 (R2=0.35) was found for samples with slag as the main cementitious replacement material. A K=125 (R2=0.5) was found from samples prepared with fly ash and slag (samples prepared with T1, I, and H mixes). K=110 (R2=0.52) was found on the D_{nssm} and resistivity measured on samples with fly ash and silica fume. The D_{nssm} and resistivity obtained on samples with various amounts of fly ash (20, 30, 40 and 50 percent: mixes A, B, D, and J) and limestone. As the coarse aggregate were grouped and correlated, the result was K=60 (R2=0.21). A similar grouping was done for samples with various amounts of fly ash with granite as a coarse aggregate; the result was K=82.2 (R2=-1.3). For some reason, the D_{nssm} measured recently was large on a few samples with high resistivity. Finally, the effect of cementitious content on K was studied by grouping the D_{nssm} and resistivity pairings from DCL2, DCL10b and DC11 tested samples. K=93.7 (R2=0.71) and included the values measured as part of a previous project.

Appendix P contains the plots for the correlations calculated for tested as part of this project grouped per mix composition: specimens with slag, specimens prepared with fly ash and slag, samples with fly ash and silica fume, and the other groupings just described.

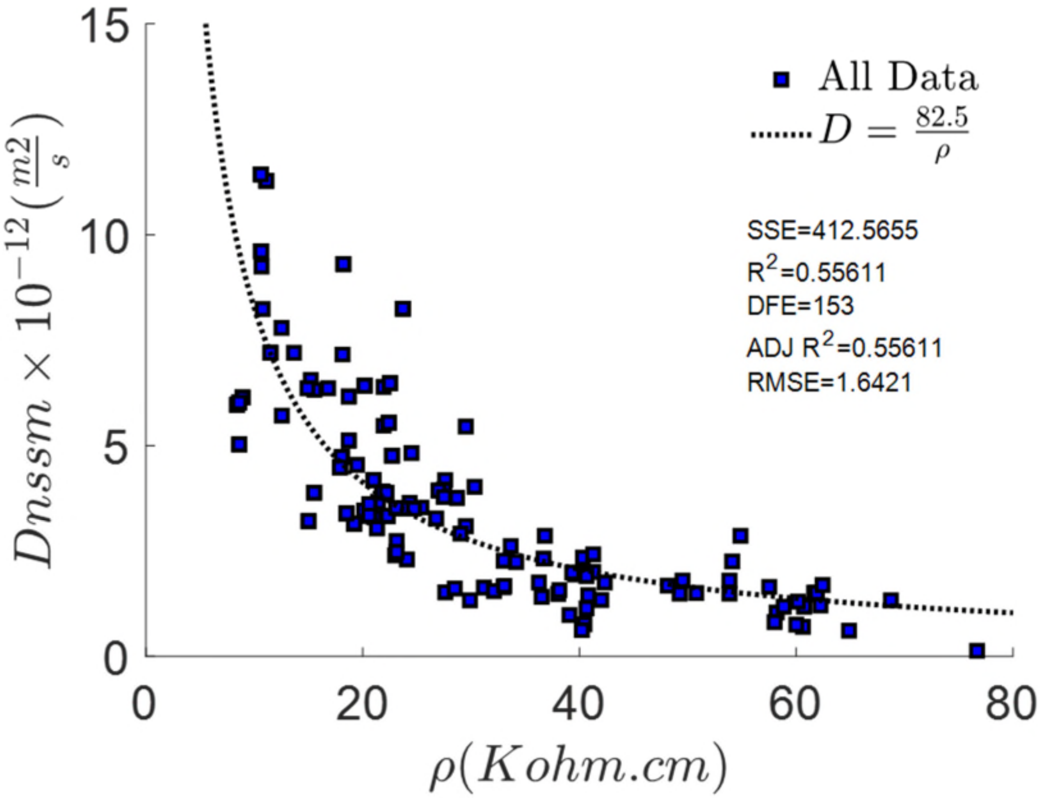


Figure 81. Correlation D_{nssm} vs. resistivity for samples with 20% fly ash.

4.10 D_{app} vs. time – field simulated conditions

Appendix Q shows D_{app} vs. exposure time plots for the three different exposures and the different elevations. In here only selected D_{app} vs. time plots from those obtained at elevation A are described.

The simulated field samples were deployed at ages ranging from 100 to 120 days. Profiles were obtained from both sides of the cores for samples exposed in the tidal and barge. The D_{app} was calculated after obtaining each profile. Figure 82 shows the D_{app} vs. exposure time for elevation A (below water) tidal samples DC1, DC2, and DC3. Side B and side T identify the core sides. The plot on the top shows the D_{app} vs. exposure time for side B and the bottom plot shows similar values for side T. Note that both axes are plotted in log10 scale. The shortest exposure was approx. 180 days (6 months). In general, a larger D_{app} was observed for the short exposure duration. The D_{app} for DC2 decay during the first 4 periods, but the last recorded value was somewhat larger than the fourth D_{app} value. The D_{app} value for DC3 appears to have reached a plateau (or at least a significantly slower reduction rate after the second D_{app} value) at 300 days. The D_{app} for DC1 appears to continue to decrease up to the longer exposure period. (An arrest in D_{app} was observed between the 2nd and 3rd D_{app} values).

Figure 83 shows how D_{app} vs. exposure time evolved for elevation A tidal samples DC4, DCL5 and DCL6. As indicated above the top plots shows side B and the bottom plot shows side T. The rate of D_{app} decay vs. exposure time is not as pronounced. The D_{app} for DCL4 and DCL5 appears to continue to decrease, whereas the D_{app} for DCL6 and increase in D_{app} was observed on the last exposure period. The longer the exposure time and the greater the w/cm the greater the risk of having chlorides contributing from the side and bottom, i.e., no longer under one-dimensional diffusion.

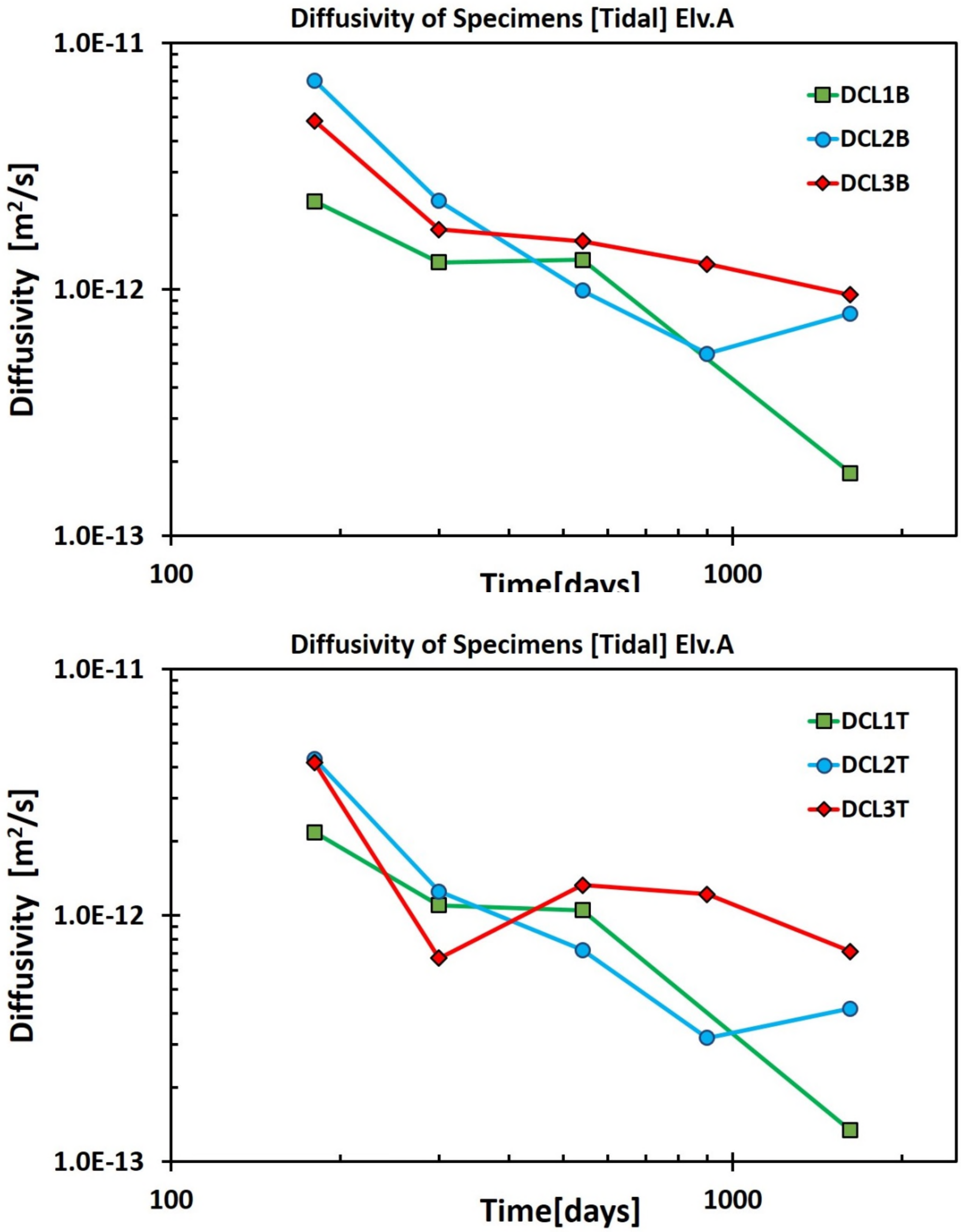
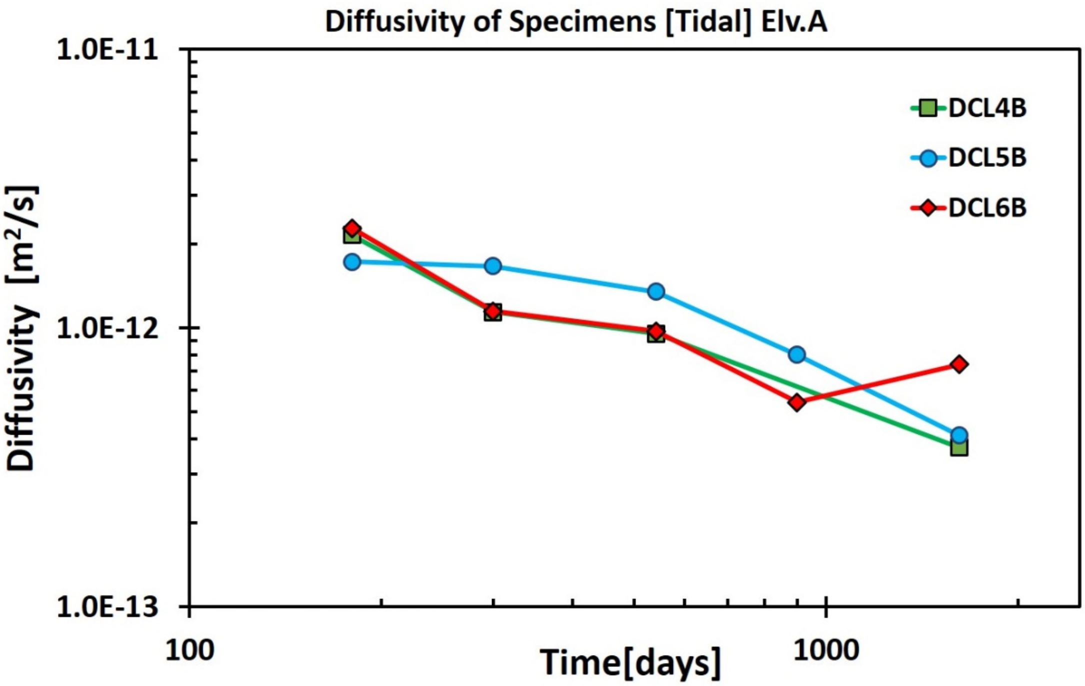


Figure 82. D_{app} vs. exposure duration: tidal exposure DCL1, DCL2 and DCL3



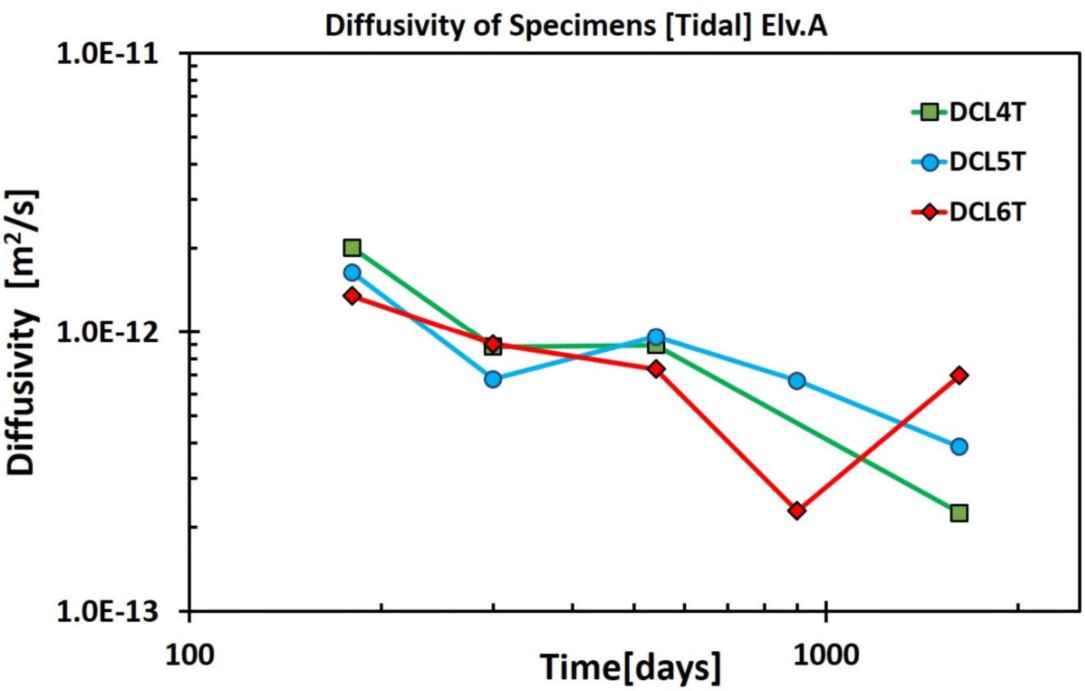


Figure 83. D_{app} vs. exposure duration: tidal exposure DCL4, DCL5 and DCL6

4.11 Aging factor (m) calculated using D_{app} values

The D_{app} values vs. exposure duration were used to calculate the m values in two ways. In one case the exposure duration was used, and in the other, the total age of the sample was used (age at exposure + exposure duration). The fittings were obtained for all cases, but not all gave a good R^2 values. Tables 39 to Table 42 show the m values obtained when using the elevation A D_{app} values. Appendix R includes the tables with the m values calculated for the other elevations.

Table 39. m values: tidal simulation at elevation A

Tidal	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1B	1.12	0.90	1.19	0.91
DCL1T	1.23	0.92	1.30	0.93
DCL2B	1.04	0.79	1.10	0.78
DCL2T	1.09	0.84	1.15	0.83
DCL3B	0.65	0.83	0.68	0.82
DCL3T	0.53	0.39	0.55	0.38
DCL4B	0.76	0.97	0.80	0.97
DCL4T	0.93	0.93	0.98	0.93
DCL5B	0.66	0.89	0.70	0.90
DCL5T	0.52	0.73	0.55	0.73
DCL6B	0.54	0.76	0.57	0.74
DCL6T	0.48	0.40	0.50	0.39
DCL7B	0.40	0.62	0.42	0.62
DCL7T	0.48	0.77	0.51	0.76
DCL8B	0.29	0.68	0.31	0.68
DCL8T	0.08	0.03	0.08	0.03
DCL9B	0.16	0.27	0.17	0.27
DCL9T	0.15	0.12	0.15	0.11
DCL10aB	0.80	0.90	0.85	0.89
DCL10aT	0.16	0.05	0.17	0.04
DCL10bB	0.63	0.60	0.68	0.60
DCL10bT	0.48	0.80	0.51	0.81
DCL11B	0.60	0.47	0.65	0.49
DCL11T	0.49	0.41	0.53	0.43

Table 40. m values: barge simulation at elevation A

Barge	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL2B	0.76	0.36	0.79	0.35
DCL2T	0.27	0.09	0.28	0.08
DCL3B	0.62	0.86	0.67	0.87
DCL3T	0.07	0.02	0.07	0.01
DCL6B	0.88	0.88	0.95	0.89
DCL6T	0.26	0.18	0.27	0.17
DCL9B	0.64	0.96	0.69	0.96
DCL9T	0.24	0.39	0.26	0.40
DCL10aB	0.05	0.01	0.06	0.01
DCL10aT	0.45	0.66	0.48	0.67
DCL10bB	1.01	0.97	1.10	0.97
DCL10bT	0.73	0.55	0.81	0.57
DCL11B	0.78	0.92	0.85	0.92
DCL11T	0.94	0.74	1.03	0.75

Table 41. m values: splash simulation at elevation A

Splash	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1	0.21	0.54	0.22	0.52
DCL2	0.54	0.61	0.57	0.59
DCL3	0.84	0.64	0.89	0.63
DCL4	0.33	0.43	0.34	0.41
DCL5	0.08	0.02	0.08	0.01
DCL6	0.35	0.09	0.35	0.08
DCL7	0.53	0.24	0.56	0.23
DCL8	0.38	0.22	0.39	0.21
DCL9	0.24	0.07	0.27	0.08
DCL10a	0.42	0.67	0.44	0.66
DCL10b	0.51	0.70	0.55	0.71
DCL11	0.51	0.75	0.54	0.74

Table 42. m values: splash simulation 10% SW at elevation A

Splash %10 SW	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL3	0.30	0.20	0.33	0.21
DCL6	0.07	0.01	0.06	0.01
DCL9	0.46	0.55	0.50	0.57

The m values obtained from the D_{app} vs. time corresponding to elevation A had the expected slope direction, and the R^2 was typically larger than 0.7 on a number of them (see Table 39, Table 40, Table 41 and Table 42 above). For example, the m values for Barge Elevation A, DCL3=0.67, DCL6 m=0.95, DCL9 m=0.69, DCL10b m=1.1, DCL11 m=0.85 to 1.03. For the splash simulated exposure at elevation A, only DCL10b and DCL11 had R2>0.6, and m=0.55 for both. In Tidal Elevation A, 13 of the m values out of 24 had an R2 greater than 0.7. DCL1 m=1.3 to 1.19, DCL2 m = 1.15 to 1.1, DCL3 0.68, DCL4 m =0.98 - 0.8, DCL5=0.7 - 0.55, DCL6 m=0.57, DCL7 m=0.51. For Tidal Elevation B, (see Appendix R) 15 m values out of 24 had an R^2 greater than 0.75. For example, for DCL1 m= 0.75, DCL4 m ranged between 0.5 to 0.64, DCL5 m=0.72-0.64, DCL6 m=0.63. DCL7 m=0.94 to 0.46. The moisture at this elevation is high as it corresponds to the low tide exposure region.

4.12 Comparison of D_{app} and D_{nssd} measured at a mature age

The D_{app} values (elevation A at54 months of exposure) were compared with the D_{nssd} values measured from recently completed bulk diffusion testing. The D_{app} section describes how D_{app} varied at other elevations. Even at the low tidal (elevation B) region, the concrete likely was not as saturated as at elevation A (which was immersed all the time). Presuel et al. [1] reported that D_{app} from field cores taken at elevations at or below the marine growth (i.e., low tidal region that is immersed during high tide) ranged between 0.1 and 0.6 (or even 0.8) × 10^{-12} m^2/s for high performance concrete (composition was determined via wet resistivity).

Table 43 presents the maximum and minimum D_{app} values measured after 54 months of exposure on field-simulated samples at elevation A (below water/immersed section). The table also includes the D_{nssd} values obtained on DCL samples that were immersed at an age of 700 days and average D_{nssd} values obtained on samples immersed at an age > 1950 days. The values shown for D_{nssd} for samples immersed at an age of >1950 days is the average of 4 or 5 values. The column on the right shows the D_{nssd} obtained on samples that were immersed at 200 days of age in low chloride solution for approximately 1900 days (close to 54 months of exposure).

Table 43. Comparison of D_{nssd} and D_{app} values

	D_{nssd} × 10^{-12} m^2/s		D_{app} × 10^{-12} m^2/s		D_{nssd} × 10^{-12} m^2/s
Mixture	Immersed at 700 days	Immersed at 1,950 days	Min	Max	Immersed at 200 days for ~1,900 days
DC1	0.38	0.71	0.13	0.498	0.55
DC2	0.79	0.85	0.4	0.81	0.48
DC3	1.87	1.06	0.71	1.37	1.23
DC4	0.36	0.45	0.23	0.59	0.4
DC5	0.74	0.55	0.39	0.91	0.44
DC6	1.05	0.54	0.36	0.86	0.61
DC7	1.21	0.697	0.34	0.78	0.3
DC8	0.87	0.685	0.54	0.646	0.44
DC9	1.24	1.077	0.57	0.94	0.56
DC10	0.95	1.07			1.21
DC10a	1.75	0.97	0.56	1.13	0.43
DC10b	1.82	1.15	0.72	1.16	0.56
DC11	1.78		0.66	1.01	0.55

The D_{app} values from field simulation exposure were not averaged. The magnitude of D_{nssd} was sometimes smaller for those measured after immersion at 700 days, e.g., DCL1, DCL2, DCL4. But, for most other mixes, the D_{nssd} for samples immersed at >1950 days was smaller. In some cases the recent D_{nssd} value measured on samples immersed at >1950 days was 52% (DCL6) of the value measured on samples immersed after 700.

If the 54-month D_{app} values are compared to the smaller of the two D_{nssd} values shown, it is apparent that for most cases the D_{nssd} values is within the range of values observed for D_{app} for any given composition.

For most compositions, the D_{app} value measured on a given sample after 30 months on the tidal exposure was greater from one side than from the opposite side. It is believed that a mortar surface layer might have been better compacted on one side than the other side of the sample. For example, for DCL2 D_{nssd} ranged between 0.79 and 0.85 × 10^{-12} m^2/s and the D_{app} ranged between 0.32 and 0.8 (Tidal), 0.63 to 0.98 barge and 0.49 to 0.63 × 10^{-12} m^2/s for splash.

Expected trends were observed as to what series of samples had the smaller D_{app} and smaller D_{nssd}; these were the samples with lower w/cm (DC1, DC4 and DC7). With DC4 having the smaller and the DCL7 and DC1 having comparable $D_{nssd(5.7\ yr)}$.

DCL3 (fly ash) and DCL9 (slag) samples were the mixes with higher w/cm which showed the larger $D_{nssd(5.7\ yr)}$ compared to DC2, and DC8.

The D_{nssd} ranged between 0.45 and 0.85 × 10^{-12} m^2/s for samples with w/cm of 0.41 (not including mixes with lower cementitious content), and the D_{app} from the simulated field ranged between 0.13 and 0.92 × 10^{-12} m^2/s. As indicated above, field D_{app} values from cores gathered below or at the MG ranged between 0.1 and 0.6 × 10^{-12} m^2/s. The range of values are comparable.

Incidentally, values at other elevations (e.g., tidal region on tidal samples, and splash region on samples exposed to simulated splash) were sometimes larger than those described for elevation A. However, regions that had lower moisture content (e.g., barge or tidal elevation D), had values that were up to one order of magnitude smaller. Such values have been also observed from field D_{app} values, when the cores are obtained from regions that have low moisture, i.e., several feet above the high tide mark.

As a side note, it important to note that the D_{app} does not necessarily tell the amount of chlorides that have penetrated the concrete.

For cores obtained at elevation D, at early exposure periods (<300 days), the D_{app} was extremely low and this was as a result of low chloride due to low moisture content in the concrete.

The D_{app} measured from field (bridges) appears have a wide range, even if only the D_{app} from profiles obtained on bridges built after 1990. The wide range observed are influenced by the elevation at which the core was obtained, environment (e.g., splash vs. no splash, or tidal zone) and moisture content as a function of depth. The moisture concrete is likely to be lower than fully immersed. Except for cores obtained below the marine growth or below the low tide mark, cores taken at these elevations might approximate moisture content of concrete section below water all the time.

Chapter 5 – Conclusions

5.1 Sorptivity

Sorptivity was measured on mature and on samples prepared in 2016. Samples from SL1, SL2, FA1, FA2, T1 and T2 were tested four to five times over the duration of the project. The sorptivity appear to decrease on FA1 and FA2 samples that contain fly ash as the only supplementary cementitious material.

5.2 K values for D_{nssd} vs. resistivity

Correlations were calculated and the K values obtained were as follow. For samples prepared in 2016 K=28.4, for DCL specimens K=32, for the A to L mixes K = 21.4, and a K=29.8 was obtained when all D_{nssd} vs. resistivity pairs were included.

5.3 D_{nssd} vs. time

A plateau in D_{nssd} appears to take place after approximately 1000 days on samples from mixes A to L. Whereas the transition to almost constant D_{nssd} value took place at approximately 700 days for DCL specimens.

5.4 K values for D_{nssm} vs. resistivity

The K values computed were larger for D_{nssm} vs. resistivity than for D_{nssd} vs resistivity. For samples prepared in 2016 K=79, for DCL1 to DCL9 for samples teste at an age > 1600 days was approximately K=85, but when all specimens are included (i.e., tested at 90 to > 1600 days) then for DCL1 to DCL9 K=81.8 and for DCL1 to DCL11 K=90.6, for specimens prepared with A to L mixes K = 49.8 (it does not include Ai or Bi specimens). The K values from D_{nssm} vs. resistivity are two to three times larger than the K values calculated when using D_{nssd} vs. resistivity values.

The D_{nssm} was observed be larger than the corresponding D_{nssd} for any given composition.

5.5 Aging factor (m) calculated using D_{app} values

The m values ranged from 0.55 to 1.1 for cases with R^2 > 0.7 at elevation A.
A plateau or a lower rate of change in D_{app} was observed on a number of cases.

5.6 Comparison of D_{app} (below water) vs. D_{nssd} measured at a mature age

For most cases the D_{nssd} values is within the range of values observed for D_{app} at elevation A (field simulated) for any given DCL composition. D_{app} values for elevation C and D were up to one order of magnitude smaller.

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Appendix A – Note on Sorptivity Test

A sorptivity test measures the rate of absorption of water when one surface of a concrete specimen is exposed to water, with all other surfaces coated. Capillary suction is the reason for water absorption into a concrete specimen. DeSouza et al. [16] presented the rate of absorption by using the sorptivity relation considering that the specimen is in contact with water from one of its surfaces:

$$I = \frac{\Delta mass}{A.\rho}$$

Where I is cumulative water absorption in millimeter, $\Delta mass$ is the change in the mass of the specimen which is in contact with water in gram and represents the amount of water absorbed by the specimen, A is the cross-section area of the specimen in mm^2 , and ρ is water density in g/mm^3.

Fluid and ion transport in concrete has been studied extensively over the years and has formed the basis for *ASTM C1585* Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes [4]. the cumulative absorbed volume per unit area of the inflow surface and the square root of the elapsed time, most often expressed as:

$$I = s\sqrt{t}$$

where S is water sorptivity $\frac{mm}{\sqrt{s}}$ and t is time oa f absorption in second. In other words, if I is plotted against the square root of time, the data typically tends to follow a straight line, water sorptivity in m$\frac{mm}{\sqrt{s}}$ is determined as the slope of the least-squares linear regression analysis.

Studies by Hooton and Bickley (2006) showed that the penetration and absorption of fluids depend on the continuity of capillary and size of the pores and for unsaturated concrete, the capillary tension draw the solution into a depth of between 5-15 mm inwards from the top surface in a few hours until the surface becomes saturated.

Water absorption is strongly affected by the moisture condition of the concrete at the time of testing, so standard amounts of concrete moisture must be assigned and reached for the test. Previous works (DeSouza et al., [17]) have indicated that certain pre-conditioning regimes must be applied to obtain a uniform moisture distribution in specimens.

Appendix B – Concrete Compositions (prepared in 2016)

Table 44. Slag mix 1 prepared on 4/4/16.

TRIAL BATCH -- DATA AND CALCULATIONS
(Saturated, Surface-dry Aggregates)

Specification					Date:	April 4, 2016
Cement Content:	658	lbs			Project:	**FAU - Slag MIX1**
W/CM (lbs/lbs):	**0.410**					
C. A. Gradation:	# 89				Weights by:	
Air Content (%):	1.5	to	5.0		Mixing By:	
Slump Range (in):	5	to	8		Design By:	
Fine Agg. SSD:	0.30	Lab =	0.00		Witness By:	
Coarse Agg. SSD:	4.60	Lab =	6.88			
Batch Size (ft^3):	6.0	C.F. =	0.2222			
Ratio of Fine Agg:	41.9 %	by volume				

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Cemex	329	3.15	1.67	73.1	73.1	
FLY ASH							
GGBF SLAG		329	2.86	1.84	73.1	73.1	
ULTRA FINE FA							
METAKAOLIN							
SILICA FUME							
WATER	Local	270	1.00	4.33	60.0	52.3	
FINE AGG.	GA-397	1318	2.63	8.03	292.9	292.0	
COARSE AGG.	87-090	1701	2.45	11.13	378.0	386.6	
AIR ENTRAINER	WR Grace Darex AEA	3.3 oz			21.7 ml	21.7 ml	3 oz.cwt
ADMIXTURE	WR Grace WRDA 60	39.5 oz			259.6 ml	259.6 ml	6 oz.cwt
ADMIXTURE	ADVACAST 600	29.6 oz			194.5 ml	194.5 ml	See Remarks
TOTAL				27.00			

Plastic Property			
Slump (in):	1	Slump By:	
Air (%)	4.20%	Air By:	
Mix Temp (°F):	66	Temp By:	
Unit Weight (lb/ft^3):	139.36	Unit Weight By:	
Workability:	good	Cylinders By:	
Initial Set (min):		Air Temp (°F):	70
Final Set (min):		Final Bleed:	

Remarks: extra 50 mL of Advacast 600

Moisture Calculations	
rock weight - wet(lb)	rock weight - dry (lb)
14.6	13.66

Table 45. Slag mix 2 prepared on 4/4/16.

TRIAL BATCH -- DATA AND CALCULATIONS

(Saturated, Surface-dry Aggregates)

Specification					Date:	April 4, 2016
Cement Content:	658	lbs			Project:	**FAU - Slag MIX2**
W/CM (lbs/lbs):	**0.410**					
C. A. Gradation:	# 89				Weights by:	
Air Content (%):	1.5	to	5.0		Mixing By:	
Slump Range (in):	5	to	8		Design By:	
Fine Agg. SSD:	0.30	Lab =	0.00		Witness By:	
Coarse Agg. SSD:	4.60	Lab =	6.88			
Batch Size (ft^3):	6.0	C.F. =	0.2222			
Ratio of Fine Agg:	41.9 %	by volume				

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Cemex	329	3.15	1.67	73.1	73.1	
FLY ASH							
GGBF SLAG		329	2.86	1.84	73.1	73.1	
ULTRA FINE FA							
METAKAOLIN							
SILICA FUME							
WATER	Local	270	1.00	4.33	60.0	52.3	
FINE AGG.	GA-397	1318	2.63	8.03	292.9	292.0	
COARSE AGG.	87-090	1701	2.45	11.13	378.0	386.6	
AIR ENTRAINER	WR Grace Darex AEA	3.3 oz			21.7 ml	21.7 ml	3 oz.cwt
ADMIXTURE	WR Grace WRDA 60	39.5 oz			259.6 ml	259.6 ml	6 oz.cwt
ADMIXTURE	ADVACAST 600	29.6 oz			194.5 ml	194.5 ml	See Remarks
TOTAL				27.00			

Plastic Property			
Slump (in):	0.75	Slump By:	
Air (%)	3.10%	Air By:	
Mix Temp (°F):	65	Temp By:	
Unit Weight (lb/ft^3):	141.28	Unit Weight By:	
Workability:	good	Cylinders By:	
Initial Set (min):		Air Temp (°F):	71
Final Set (min):		Final Bleed:	

Remarks: extra 75 mL of Advacast 600

Moisture Calculations	
rock weight - wet(lb)	rock weight - dry (lb)
14.6	13.66

Table 46. Fly ash mix 1 prepared on 4/18/16

TRIAL BATCH -- DATA AND CALCULATIONS

(Saturated, Surface-dry Aggregates)

Specification					Date:	April 18, 2016
Cement Content:	658	lbs			Project:	**FAU - Fly Ash**
W/CM (lbs/lbs):	**0.410**					
C. A. Gradation:	# 89				Weights by:	
Air Content (%):	1.5	to	5.0		Mixing By:	
Slump Range (in):	5	to	8		Design By:	
Fine Agg. SSD:	0.30	Lab =	0.00		Witness By:	
Coarse Agg. SSD:	4.60	Lab =	8.26			
Batch Size (ft^3):	6.0	C.F. =	0.2222			
Ratio of Fine Agg:	52.0 %	by volume				

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Cemex	526	3.15	2.68	116.9	116.9	
FLY ASH		132	2.43	0.87	29.3	29.3	
GGBF SLAG							
ULTRA FINE FA							
METAKAOLIN							
SILICA FUME							
WATER	Local	270	1.00	4.33	60.0	49.7	
FINE AGG.	GA-397	1631	2.63	9.94	362.4	361.4	
COARSE AGG.	87-090	1404	2.45	9.18	312.0	323.4	
AIR ENTRAINER	WR Grace Darex AEA	3.3 oz			21.7 ml	21.7 ml	3 oz.cwt
ADMIXTURE	WR Grace WRDA 60	39.5 oz			259.6 ml	259.6 ml	6 oz.cwt
ADMIXTURE	ADVACAST 600	29.6 oz			194.5 ml	194.5 ml	See Remarks
TOTAL				27.00			

Plastic Property			
Slump (in):	1.75	Slump By:	
Air (%)	8.50%	Air By:	
Mix Temp (°F):	65	Temp By:	
Unit Weight (lb/ft^3):	135.8	Unit Weight By:	
Workability:		Cylinders By:	
Initial Set (min):		Air Temp (°F):	
Final Set (min):		Final Bleed:	

Remarks:

Moisture Calculations	
rock weight - wet(lb)	rock weight - dry (lb)
18.34	16.94

Table 47. Fly ash mix 2 prepared on 4/18/16.

TRIAL BATCH -- DATA AND CALCULATIONS

(Saturated, Surface-dry Aggregates)

Specification					Date:	April 18, 2016
Cement Content:	658	lbs			Project:	**FAU - Fly Ash**
W/CM (lbs/lbs):	**0.410**					
C. A. Gradation:	# 89				Weights by:	
Air Content (%):	1.5	to	5.0		Mixing By:	
Slump Range (in):	5	to	8		Design By:	
Fine Agg. SSD:	0.30	Lab =	0.00		Witness By:	
Coarse Agg. SSD:	4.60	Lab =	8.26			
Batch Size (ft^3):	6.0	C.F. =	0.2222			
Ratio of Fine Agg:	52.0 %	by volume				

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Cemex	526	3.15	2.68	116.9	116.9	
FLY ASH		132	2.43	0.87	29.3	29.3	
GGBF SLAG							
ULTRA FINE FA							
METAKAOLIN							
SILICA FUME							
WATER	Local	270	1.00	4.33	60.0	49.7	
FINE AGG.	GA-397	1631	2.63	9.94	362.4	361.4	
COARSE AGG.	87-090	1404	2.45	9.18	312.0	323.4	
AIR ENTRAINER	WR Grace Darex AEA	3.3 oz			21.7 ml	21.7 ml	3 oz.cwt
ADMIXTURE	WR Grace WRDA 60	39.5 oz			259.6 ml	259.6 ml	6 oz.cwt
ADMIXTURE	ADVACAST 600	29.6 oz			194.5 ml	194.5 ml	See Remarks
TOTAL				27.00			

Plastic Property			
Slump (in):	5	Slump By:	
Air (%)	10.00%	Air By:	
Mix Temp (°F):	65	Temp By:	
Unit Weight (lb/ft^3):	130	Unit Weight By:	
Workability:		Cylinders By:	
Initial Set (min):		Air Temp (°F):	70.7
Final Set (min):		Final Bleed:	
Remarks:			

Moisture Calculations	
rock weight - wet(lb)	rock weight - dry (lb)
18.34	16.94

Table 48. Mix T1 prepared 8/19/17

TRIAL BATCH -- DATA AND CALCULATIONS

(Saturated, Surface-dry Aggregates)

Specification					Date:	July 1, 2016
Cement Content:	658	lbs			Project:	**Ternary**
W/CM (lbs/lbs):	**0.410**					
C. A. Gradation:	# 89				Weights by:	
Air Content (%):	1.5	to	5.0		Mixing By:	
Slump Range (in):	5	to	8		Design By:	
Fine Agg. SSD:	0.30	Lab =	0.00		Witness By:	
Coarse Agg. SSD:	4.60	Lab =	8.77			
Batch Size (ft^3):	6.5	C.F. =	0.2407			
Ratio of Fine Agg:	41.3 %	by volume				

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Cemex	198	3.15	1.01	47.6	47.6	
FLY ASH		132	2.39	0.88	31.7	31.7	20% FA
GGBF SLAG		329	2.86	1.84	79.2	79.2	50% Slag
ULTRA FINE FA							
METAKAOLIN							
SILICA FUME							
WATER	Local	270	1.00	4.33	65.0	50.5	
FINE AGG.	GA-397	1283	2.63	7.82	308.9	307.9	
COARSE AGG.	87-090	1701	2.45	11.13	409.5	426.6	
AIR ENTRAINER	WR Grace Darex AEA	13.2 oz			93.8 ml	93.8 ml	2 oz.cwt
ADMIXTURE	WR Grace WRDA 60	39.5 oz			281.3 ml	281.3 ml	6 oz.cwt
ADMIXTURE	ADVACAST 600	32.9 oz			234.4 ml	234.4 ml	5 oz cwt See
TOTAL				27.00			

Plastic Property			
Slump (in):	6.5	Slump By:	
Air (%)	12.40%	Air By:	
Mix Temp (°F):	74	Temp By:	
Unit Weight (lb/ft^3):	127.04	Unit Weight By:	
Workability:	Relatively Wet	Cylinders By:	
Initial Set (min):		Air Temp (°F):	
Final Set (min):		Final Bleed:	

Remarks: use up to double this amount if needed

Moisture Calculations	
rock weight - wet(lb)	rock weight - dry (lb)
18.6	17.1

Table 49. Mix T2 Prepare – 08/19/2017

TRIAL BATCH -- DATA AND CALCULATIONS

(Saturated, Surface-dry Aggregates)

Specification					Date:	July 1, 2016	
Cement Content:	658	lbs			Project:	Ternary	
W/CM (lbs/lbs):	**0.370**	0.37 UPDTA					
C. A. Gradation:	# 89				Weights by:		
Air Content (%):	1.5	to	5.0		Mixing By:		
Slump Range (in):	5	to	8		Design By:		
Fine Agg. SSD:	0.30	Lab =	0.00		Witness By:		
Coarse Agg. SSD:	4.60	Lab =	8.77				
Batch Size (ft^3):	5.5	C.F. =	0.2037				
Ratio of Fine Agg:	41.3 %	by volume					

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Cemex	487	3.15	2.48	99.2	99.2	
FLY ASH		118	2.39	0.79	24.0	24.0	18% FA
GGBF SLAG			2.86				
ULTRA FINE FA							
METAKAOLIN							
SILICA FUME		53	2.20	0.39	10.8	10.8	8% SF
WATER	Local	230	1.00	3.69	46.9	32.7	+ 2.8 lbs
FINE AGG.	GA-397	1332	2.63	8.12	271.3	270.5	
COARSE AGG.	87-090	1764	2.45	11.54	359.3	374.3	
AIR ENTRAINER	WR Grace Darex AEA	13.2 oz			79.3 ml	79.3 ml	2 oz.cwt
ADMIXTURE	WR Grace WRDA 60	39.5 oz			237.8 ml	237.8 ml	6 oz.cwt
ADMIXTURE	ADVACAST 600	32.9 oz			198.2 ml	198.2 ml	5 oz cwt See Remarks
TOTAL				27.00			

Plastic Property			
Slump (in):	8	Slump By:	
Air (%)	20.00%	Air By:	
Mix Temp (°F):	77	Temp By:	
Unit Weight (lb/ft^3):	114.08	Unit Weight By:	
Workability:	Stiff Until Admix Added	Cylinders By:	
Initial Set (min):		Air Temp (°F):	
Final Set (min):		Final Bleed:	

Remarks: use up to double this amount if needed

Added 80 mL extra Advacast 600

Moisture Calculations	
rock weight - wet(lb)	rock weight - dry (lb)
18.6	17.1

Appendix C – List of Samples Tested for BD at Intermediate Age

Table 50. A to L cylinders subjected to BD, age at immersion and immersion duration

Samples	Age at immersion		Immersion time (Days)	
	Years	Days	16.5%	3%
Ai	3.0	1,101	188	193
A	2.9	1,075	188	193
Bi	3.0	1,101	188	193
B	2.9	1,075	188	193
C	2.7	996	188	193
D	2.9	1,052	181	189
E	2.9	1,052	181	189
F	2.8	1,039	181	189
G	2.7	1,002	181	189
H	2.8	1,008	181	189
I	2.8	1,040	179	186
J	2.8	1,009	179	186
K	2.7	974	179	186
L	2.7	974	179	186

NOTE: Cylinder 36 was subjected from each mix was subjected to BD testing

Table 51. A to L cylinders subjected to BD, age at immersion

	Age at immersion (days)			
	NC=AC	Nominal 1yr	2.7 - 3 yr	> 5 yr
A_i	168	412	1,101	2,156
B_i	320	412	1,101	2,085
A	185	386	1,075	2,114
J	196	364	1,009	2,072
B	329	386	1,075	2,114
D	308	370	1,052	2,100
E	370	370	1,052	2,085
F	420	365	1,039	2,083
I	420	365	1,040	2,056
H	420	364	1,008	1,985
C	252	364	996	2,035
K	277	364	974	2,050
L	420	368	974	2,103
G	551	364	1,002	2,095

Table 52. DCL cylinder subjected to BD at an age of 700 days, immersion duration

	Immersion Time (Days)	
	16.5%	3%
DCL01	119	104
DCL02	127	142
DCL03	127	142
DCL04	102	110
DCL05	102	110
DCL06	127	142
DCL07	102	111
DCL08	104	120
DCL09	104	120
DCL10	138	143
DC10a	138	143
DC10b	104	120
DCL11	104	120

Note The selected concrete cylinder per mix was cured for 14 days room temperature followed by 77 days at elevated temperature, followed by RT curing till 700 days.

Appendix D – Surface Resistivity vs. Time

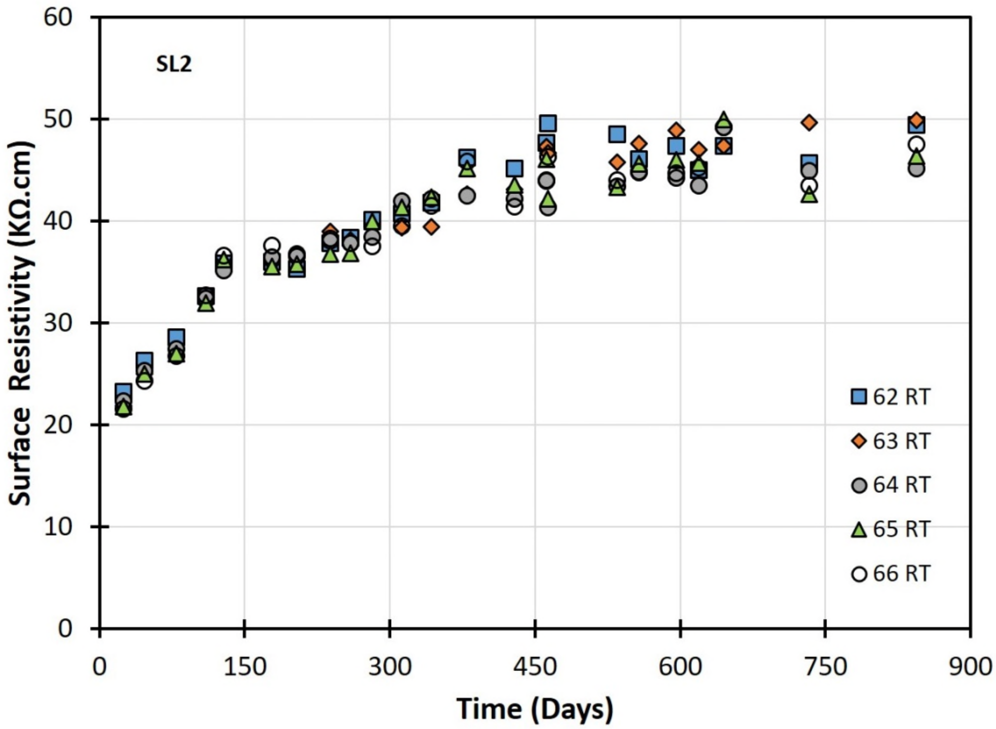


Figure 84. Surface resistivity vs. time measured on selected SL2 concrete cylinders exposed to high humidity.

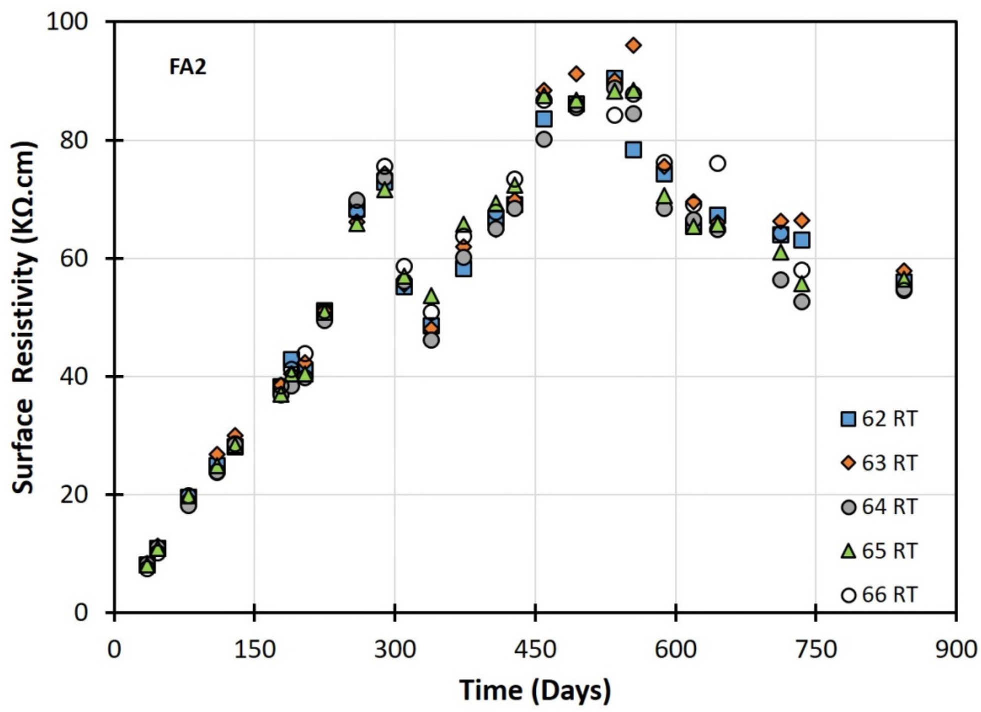


Figure 85. Surface resistivity vs. time measured on selected FA2 concrete cylinders exposed to high humidity.

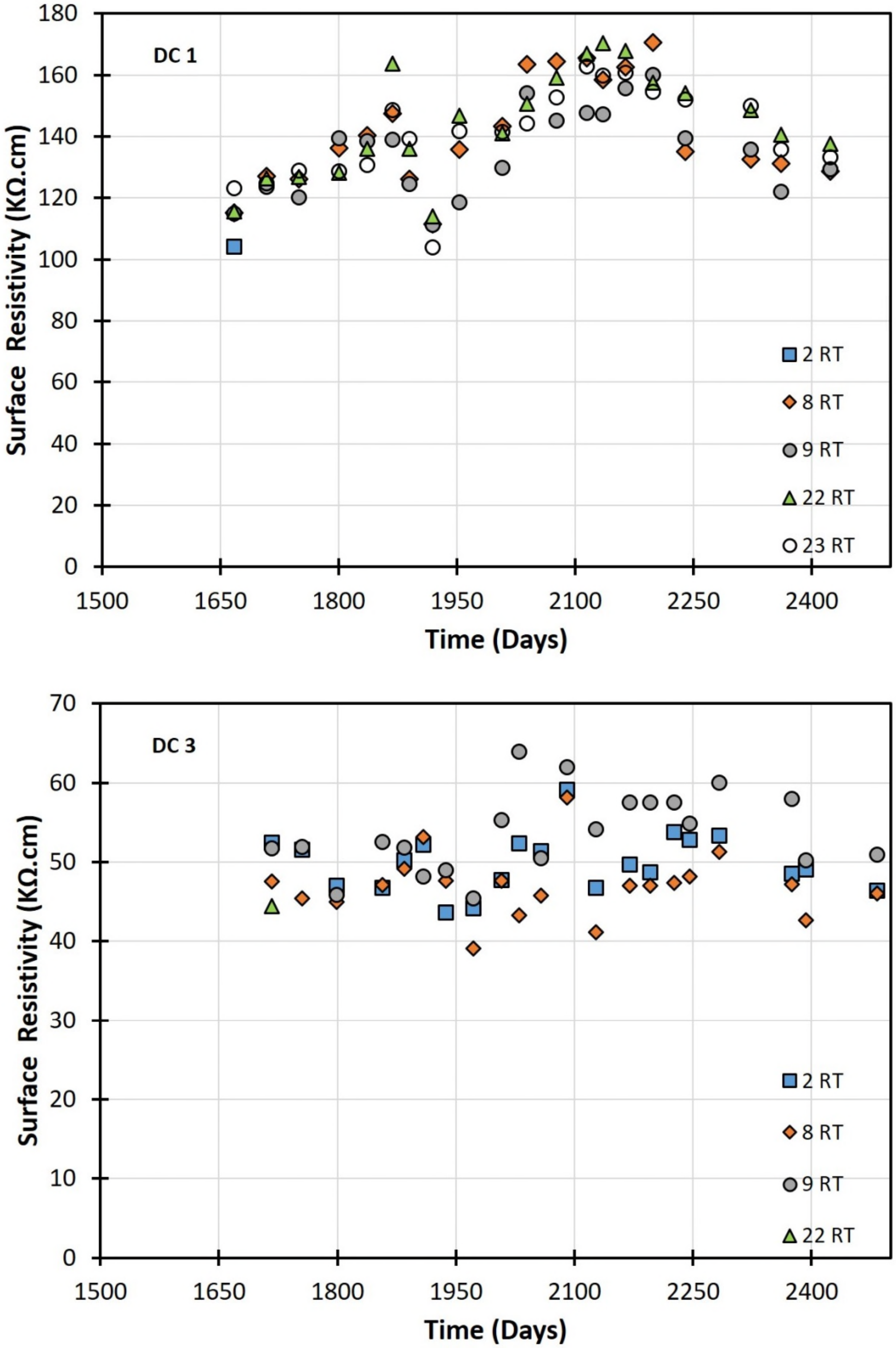


Figure 86. Surface resistivity vs. time measured on selected DCL1, and DCL3 concrete cylinders exposed to high humidity.

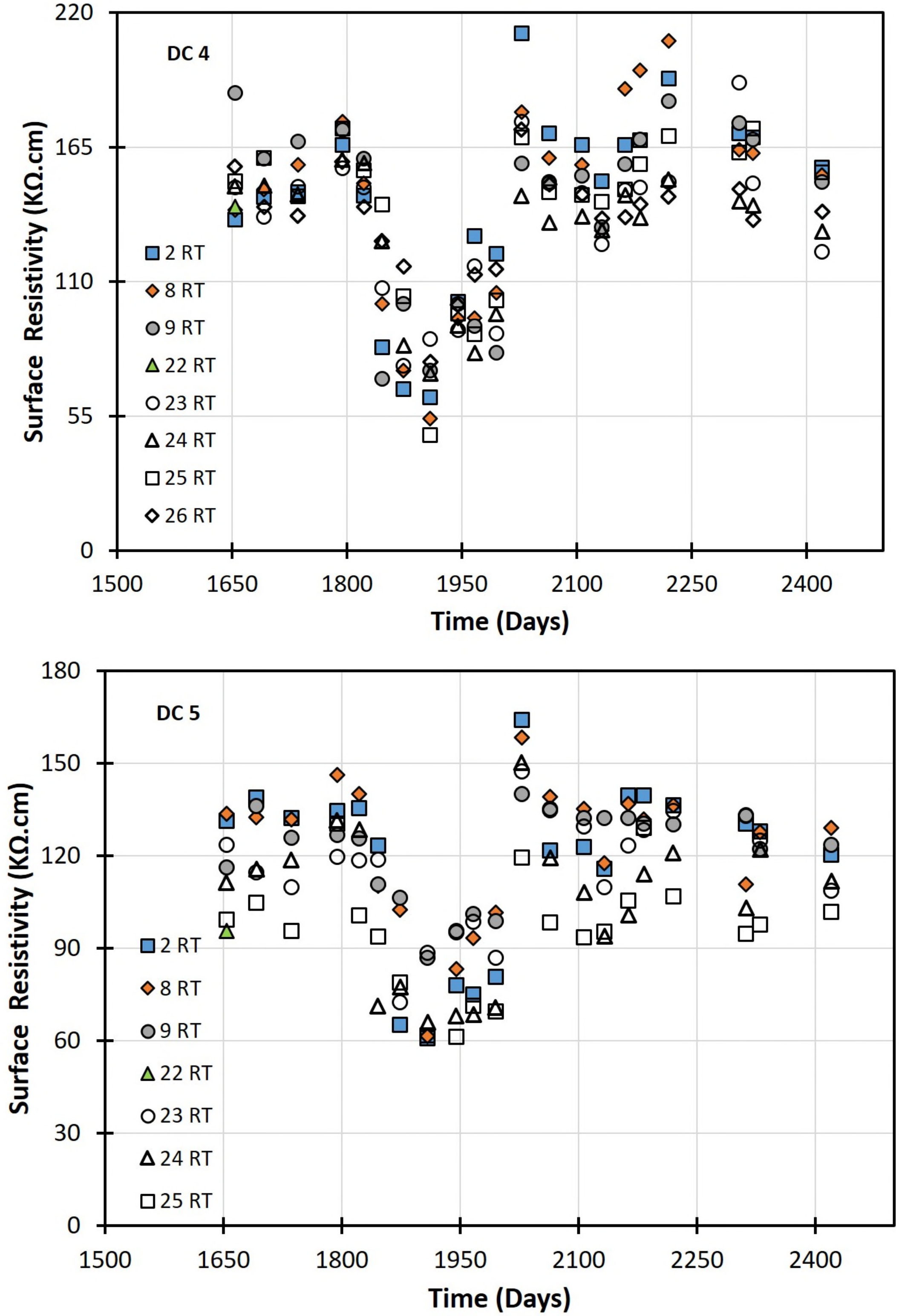


Figure 87. Surface resistivity vs. time measured on selected DCL4 and DCL5 concrete cylinders exposed to high humidity.

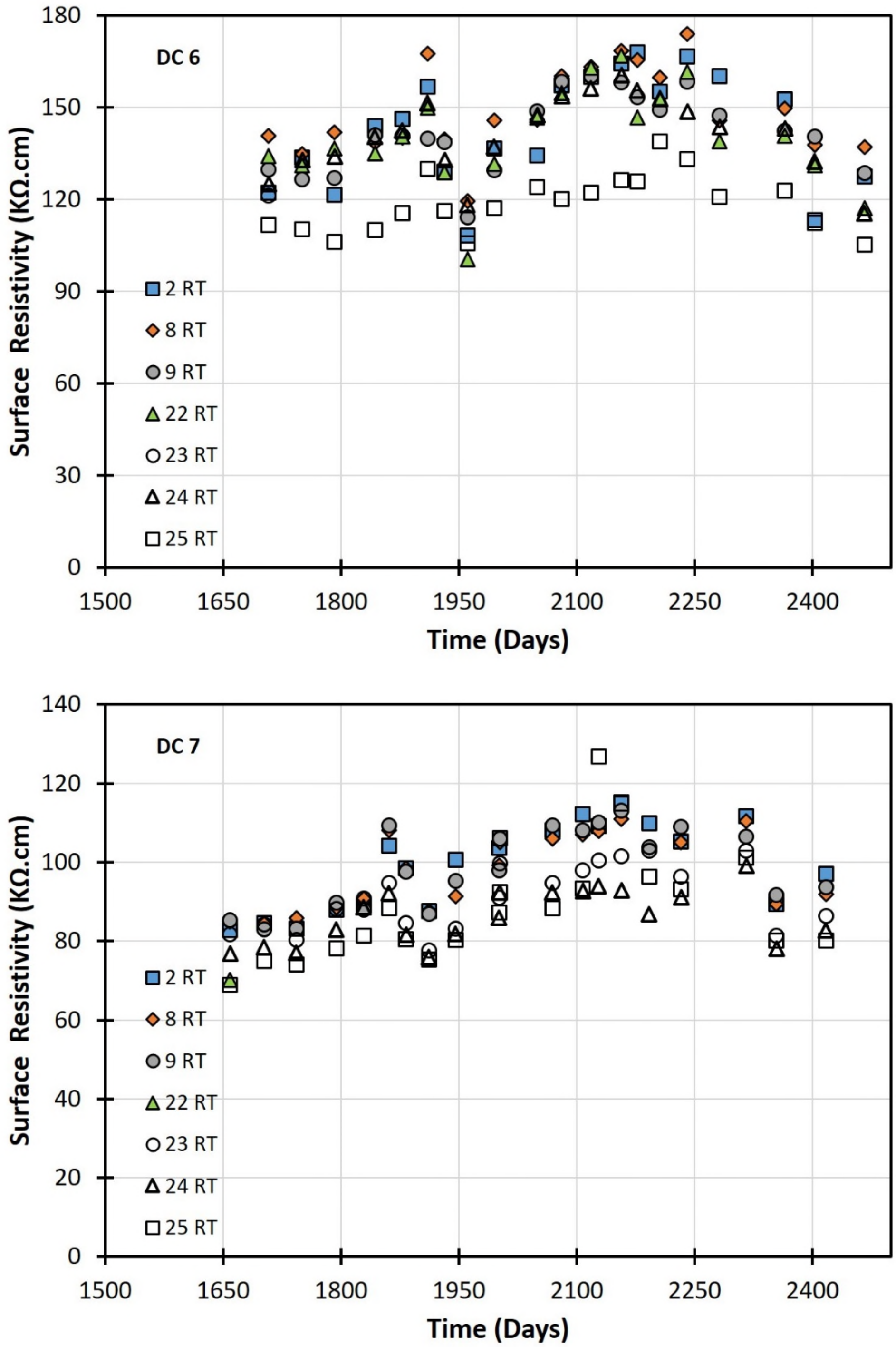
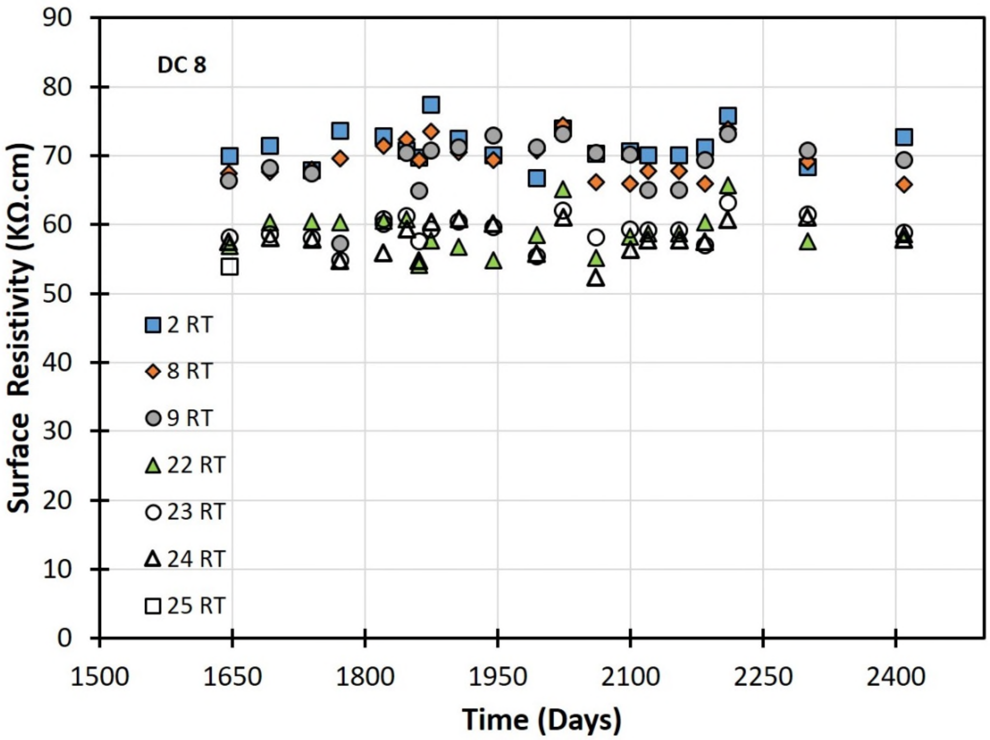


Figure 88. Surface resistivity vs. time measured on selected DCL6 and DCL7 concrete cylinders exposed to high humidity.



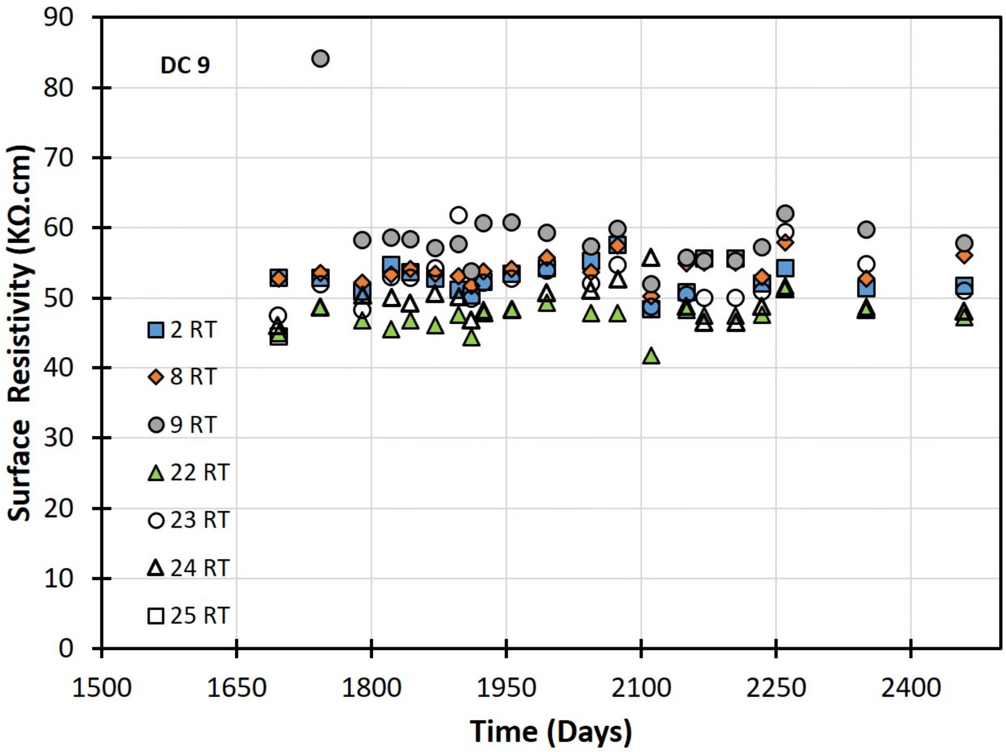
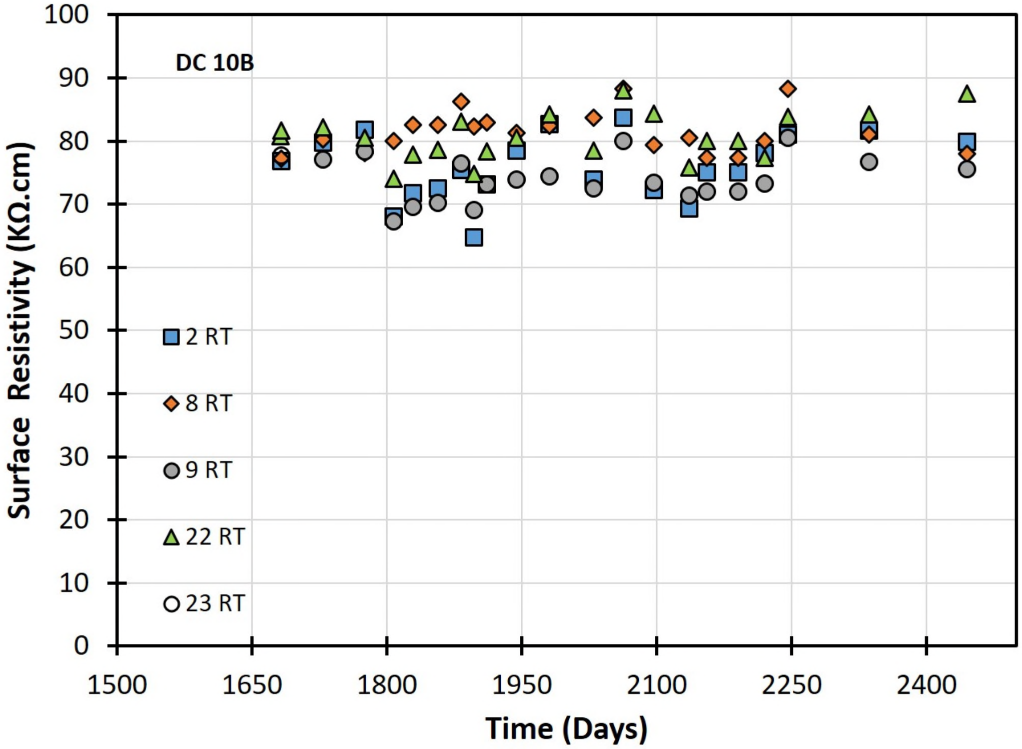


Figure 89. Surface resistivity vs. time measured on selected DCL8 and DCL9 concrete cylinders exposed to high humidity.



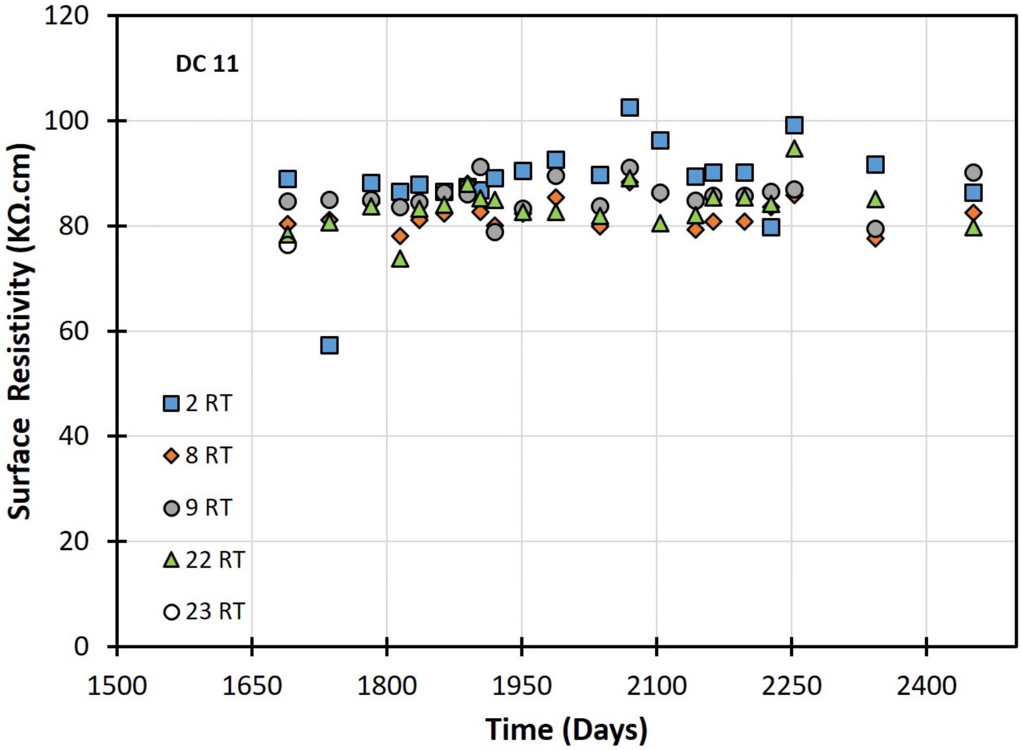


Figure 90. Surface resistivity vs. time measured on selected DCL10b and DCL11 concrete cylinders exposed to high humidity.

Appendix E – Sorptivity on DCL Specimens

Sorptivity plots showing water absorption vs. time $s^{1/2}$.

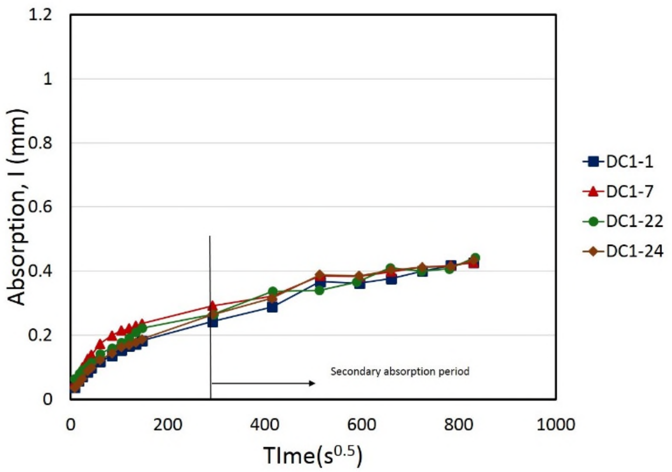


Figure 91. Water absorption vs. time (DC1).

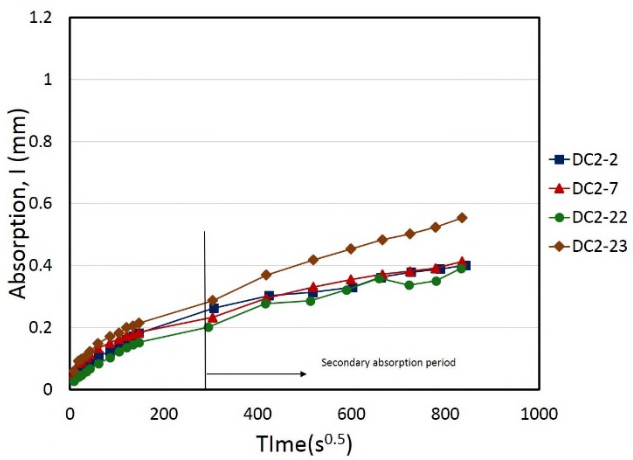


Figure 92. Water absorption vs. time (DC2).

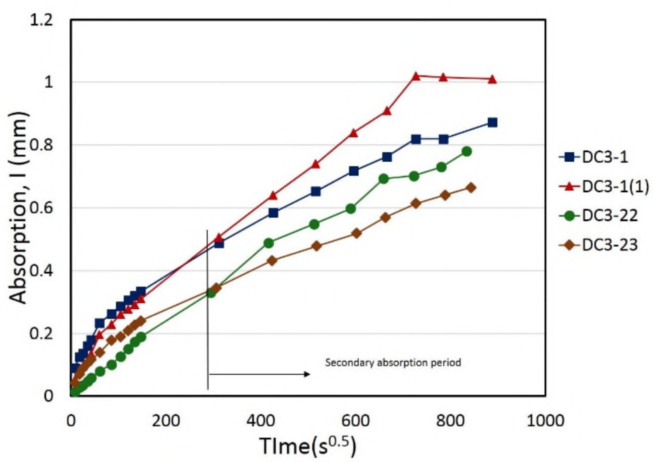


Figure 93. Water absorption vs. time (DC3).

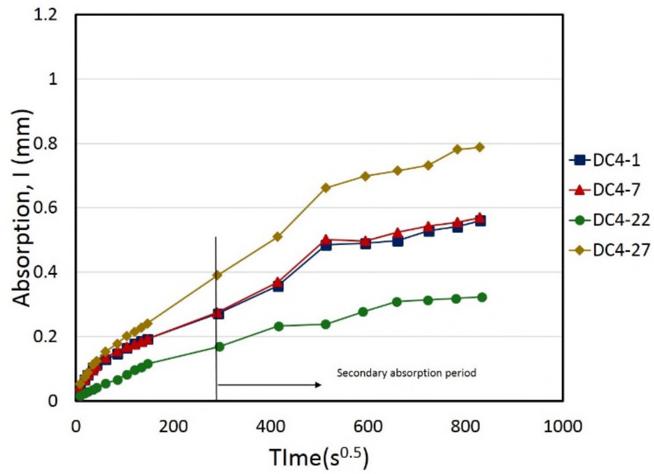


Figure 94. Water absorption vs. time (DC4).

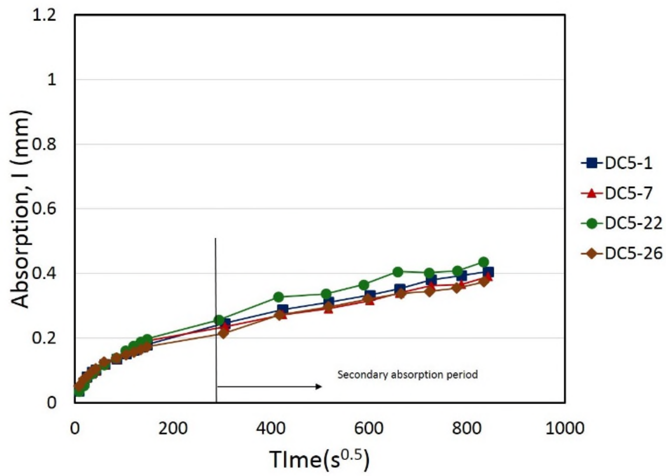


Figure 95. Water absorption vs. time (DC5).

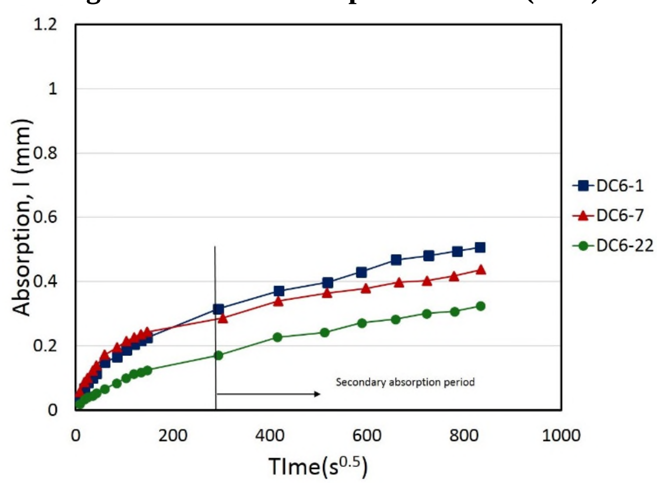


Figure 96. Water absorption vs. time (DC6 specimens).

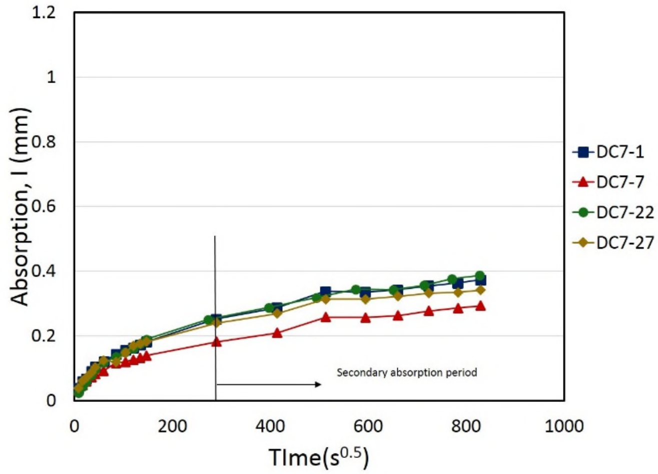


Figure 97. Water absorption vs. time (DC7).

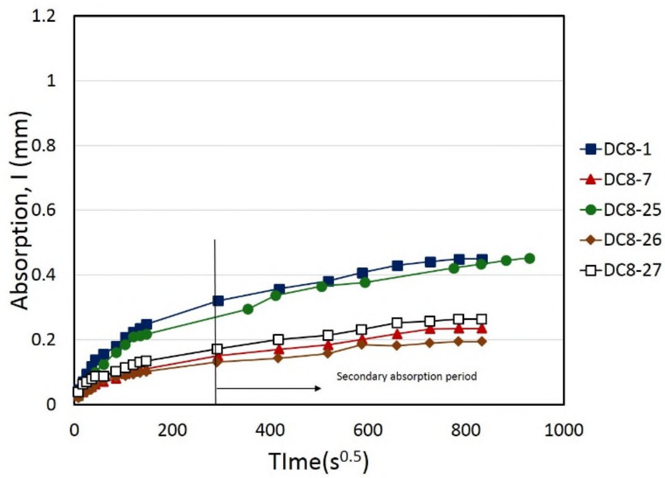


Figure 98. Water absorption vs. time (DC8).

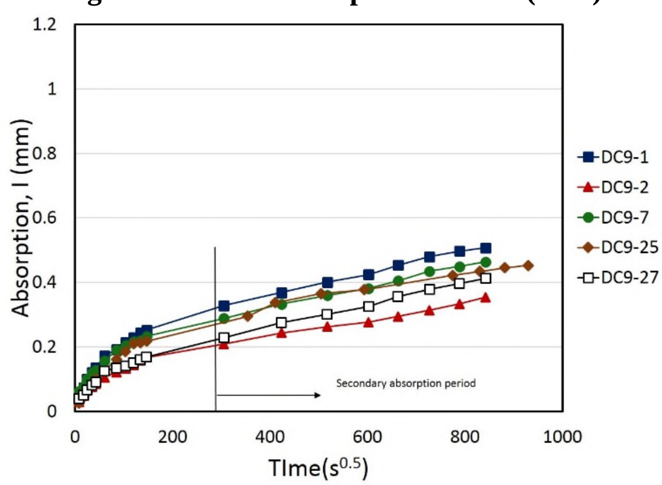


Figure 99. Water absorption vs. time (DC9).

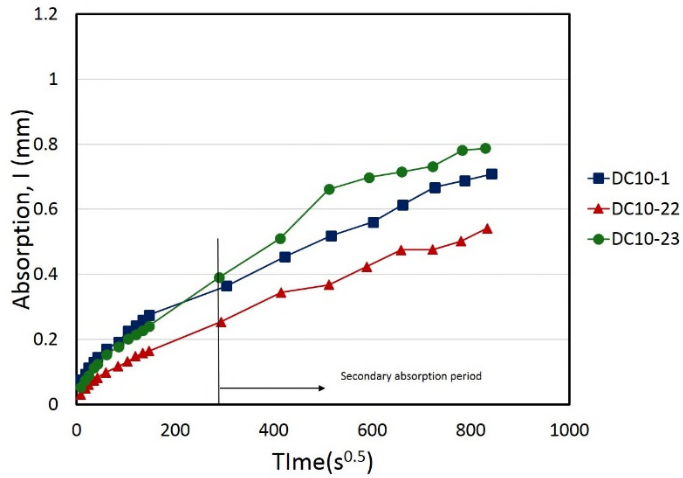


Figure 100. Water absorption vs. time (DC10).

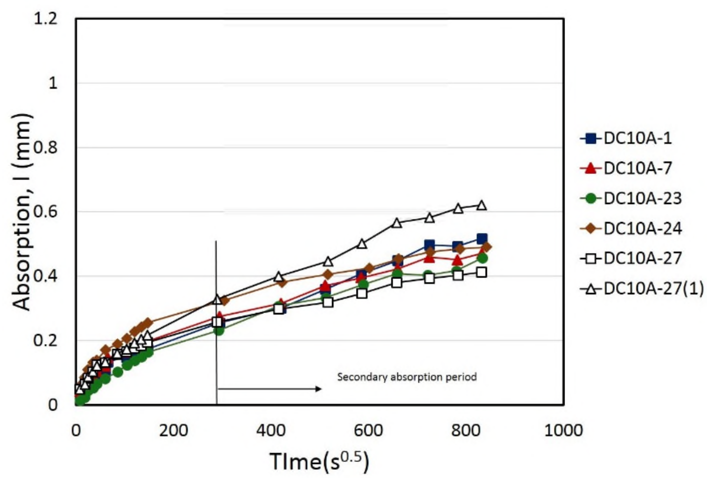


Figure 101. Water absorption vs. time (DC10A).

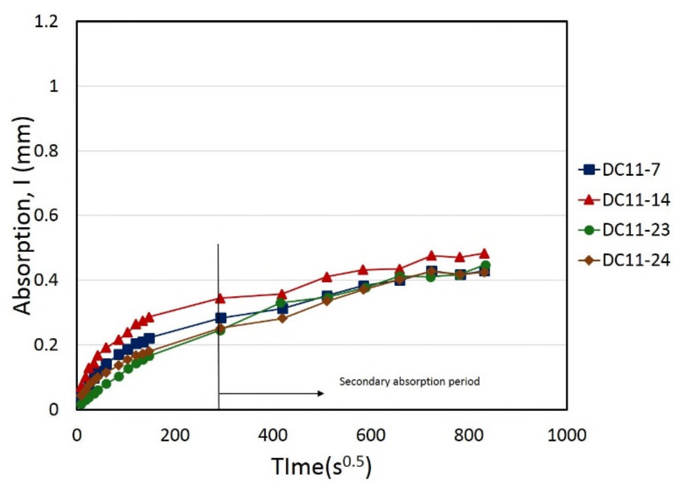


Figure 102. Water absorption vs. time (DC11).

Appendix F – Sorptivity for Mixes A to L and CRA Mix: Plots Showing Water Absorption vs. Time $s^{1/2}$.

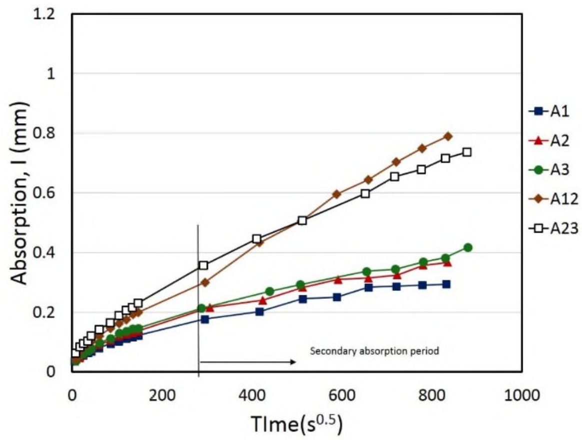


Figure 103. Water absorption vs. time (A).

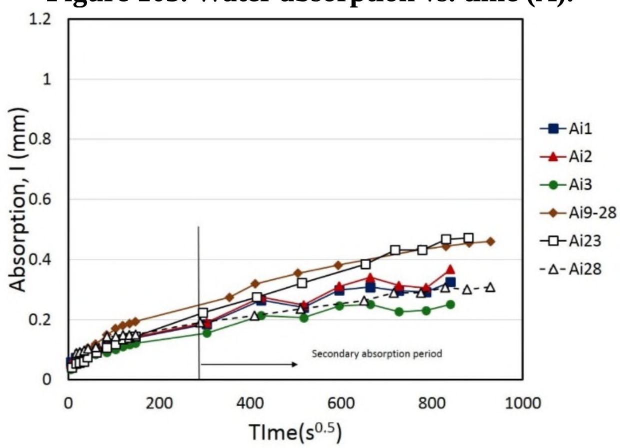


Figure 104. Water absorption vs. time (Ai).

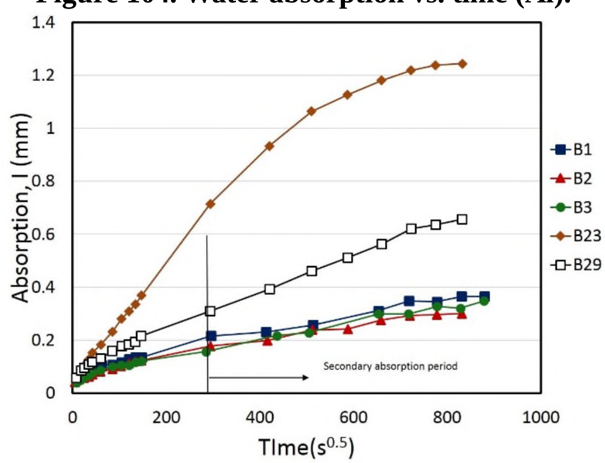


Figure 105. Water absorption vs. time (B).

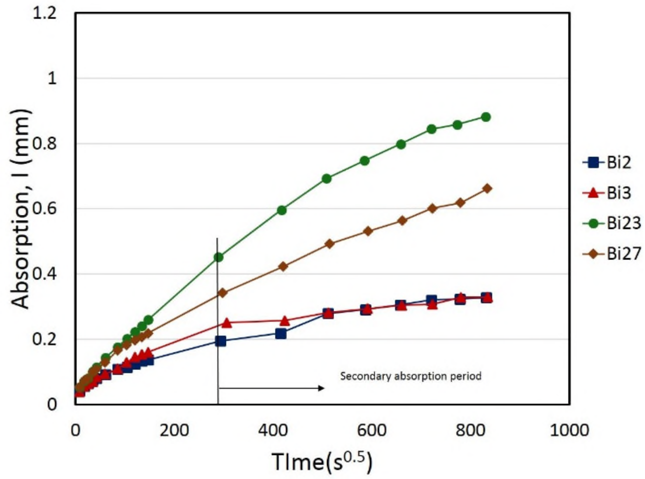


Figure 106. Water absorption vs. time (Bi/BB).

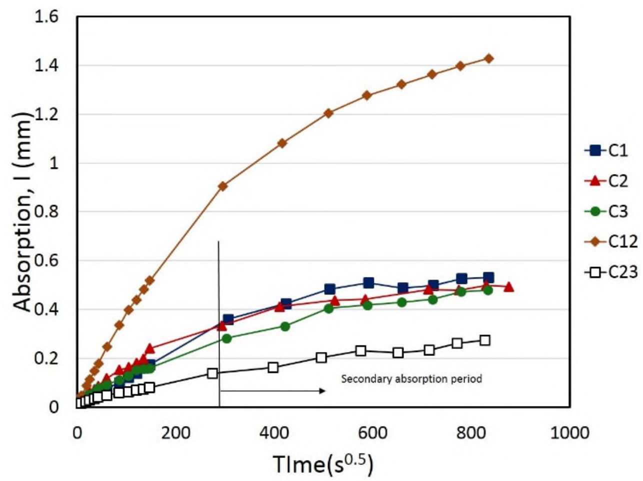


Figure 107. Water absorption vs. time (C).

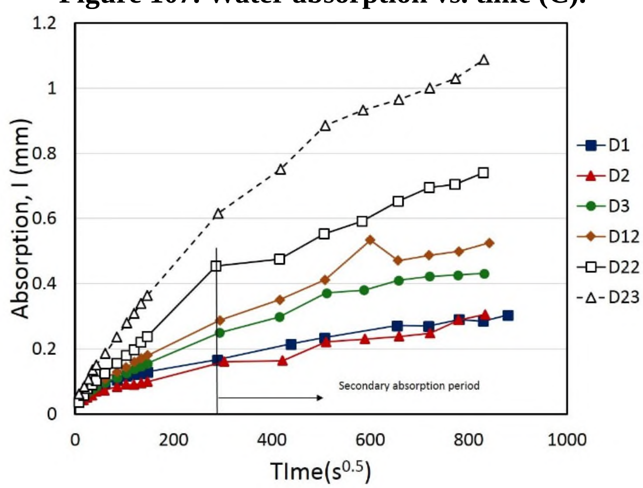


Figure 108. Water absorption vs. time (D).

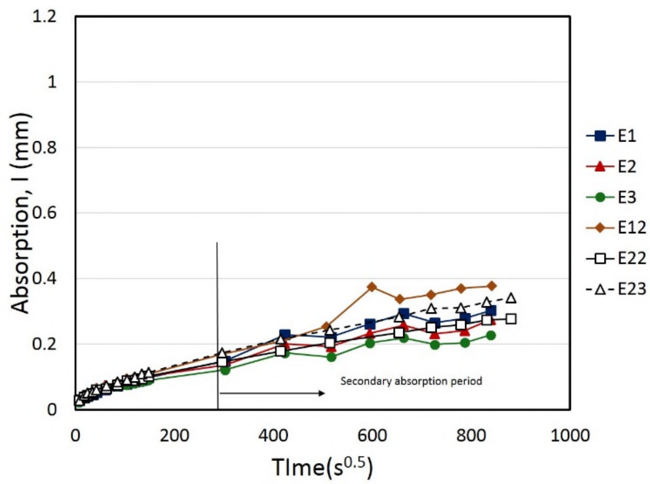


Figure 109. Water absorption vs. time (E specimens).

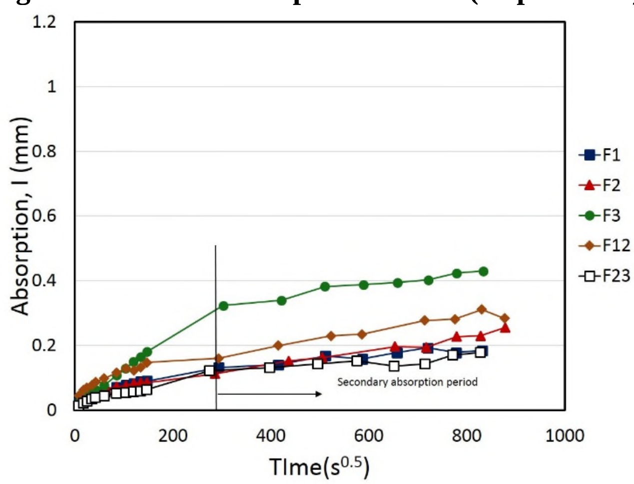


Figure 110. Water absorption vs. time (F).

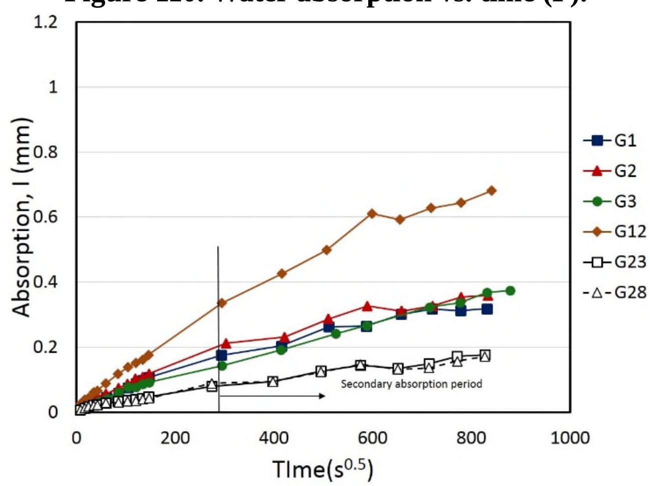


Figure 111. Water absorption vs. time (G).

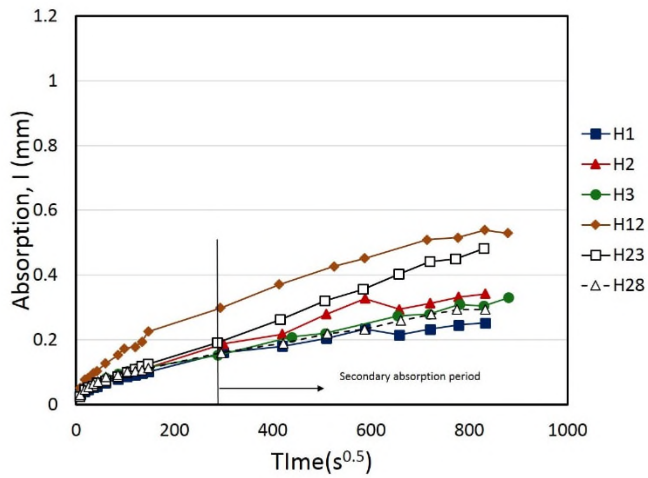


Figure 112. Water absorption vs. time (H).

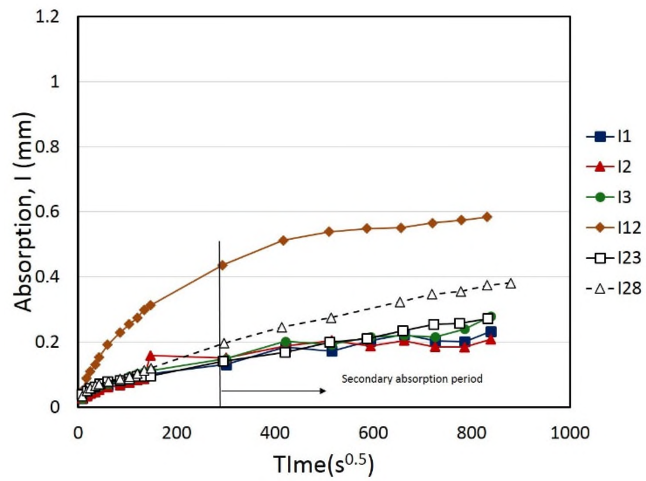


Figure 113. Water absorption vs. time (I).

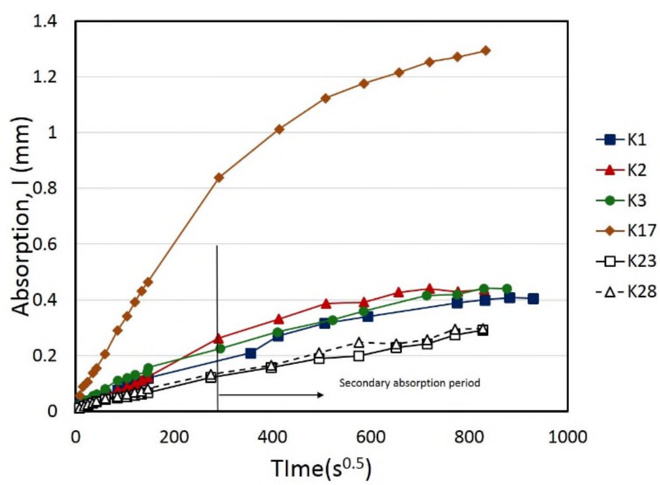


Figure 114. Water absorption vs. time (K).

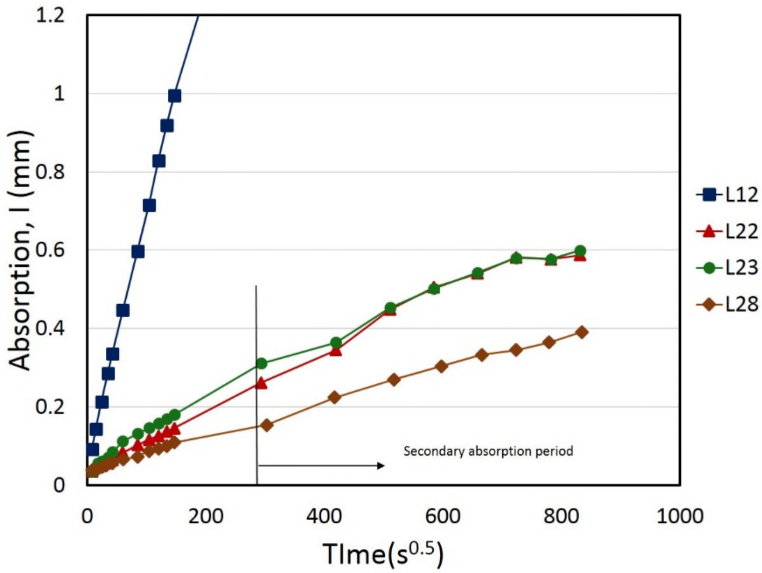


Figure 115. Water absorption vs. time (L).

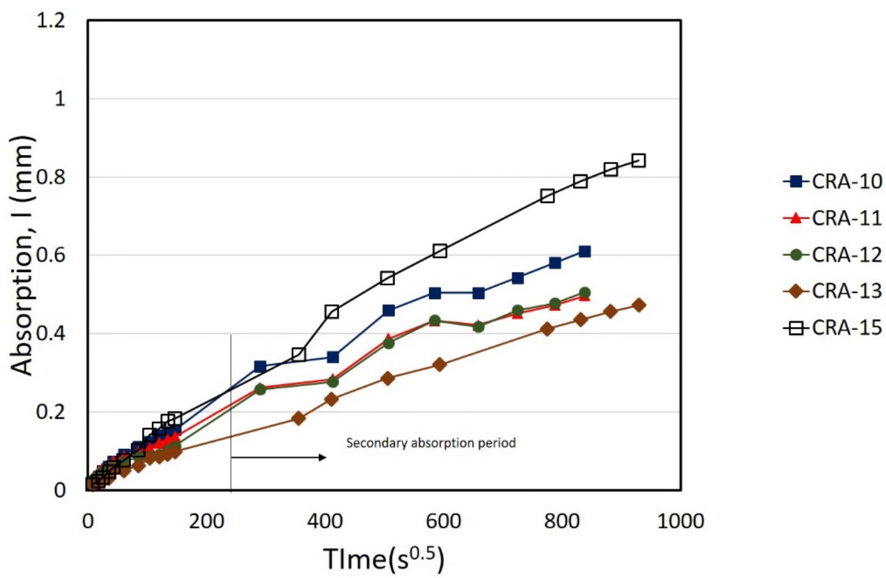
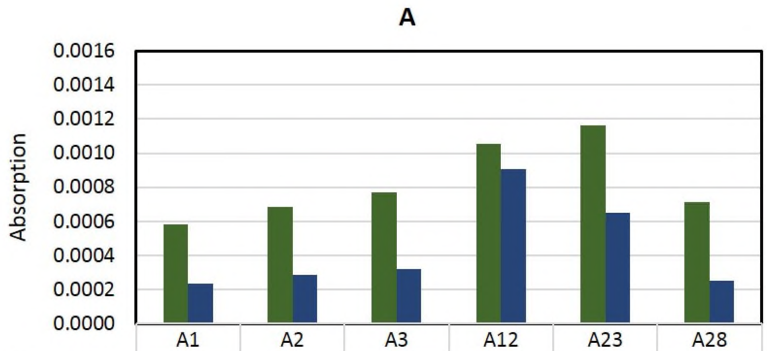


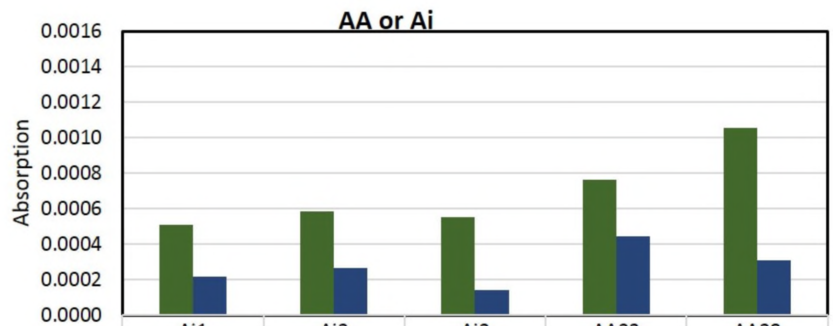
Figure 116. Water absorption vs. time (CRA_10% FA specimens).

Appendix G – Primary and Secondary water Absorption A to L mixes



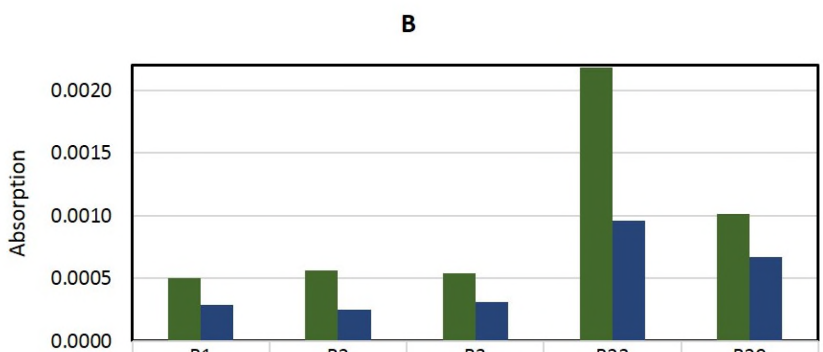
	A1	A2	A3	A12	A23	A28
Initial	0.00058	0.00068	0.00077	0.00105	0.00116	0.00072
Secondary	0.00023	0.00029	0.00032	0.00090	0.00065	0.00025

Figure 117. Primary and secondary absorption rate for A specimens.



	Ai1	Ai2	Ai3	AA23	AA28
Initial	0.00051	0.00058	0.00055	0.00076	0.00106
Secondary	0.00021	0.00026	0.00014	0.00044	0.00031

Figure 118. Primary and secondary absorption rate for AA (or Ai) specimens.



	B1	B2	B3	B23	B29
initial	0.00051	0.00056	0.00054	0.00218	0.00101
secondary	0.00029	0.00025	0.00031	0.00096	0.00067

Figure 119. Primary and secondary absorption rate for B specimens.

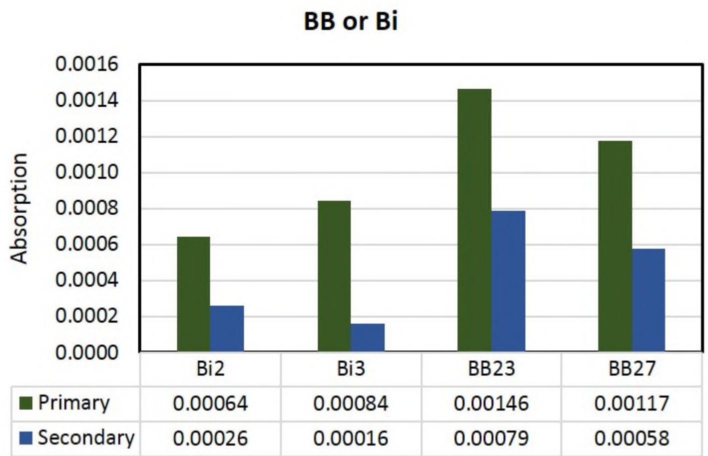


Figure 120. Primary and secondary absorption rate for B specimens.

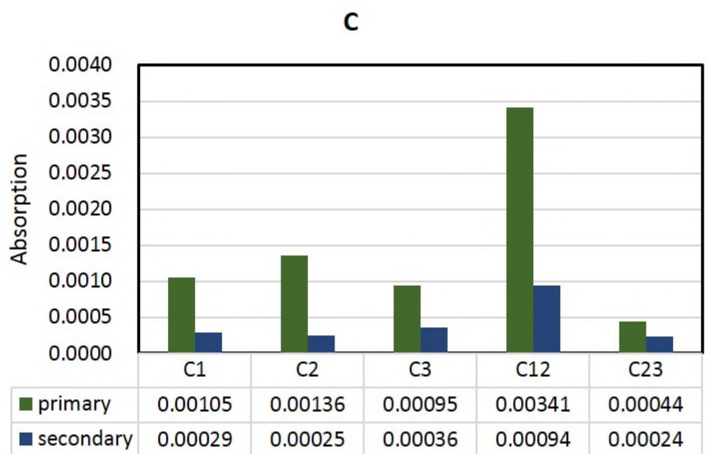


Figure 121. Primary and secondary absorption rate for C specimens

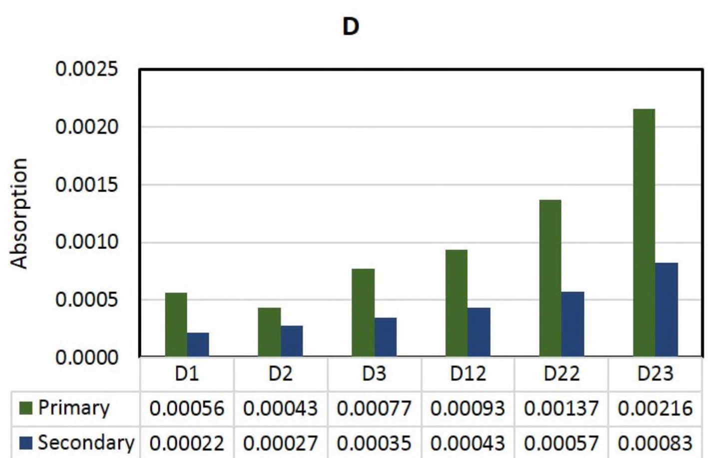
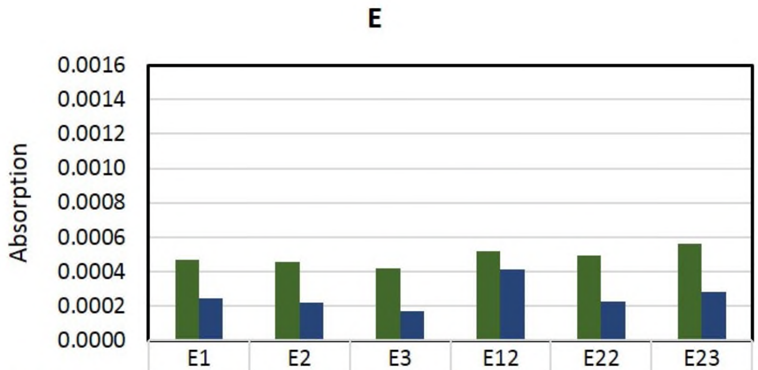
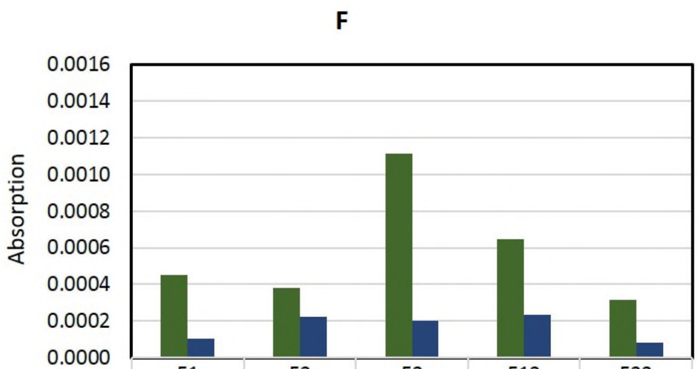


Figure 122. Primary and secondary absorption rate for D specimens.



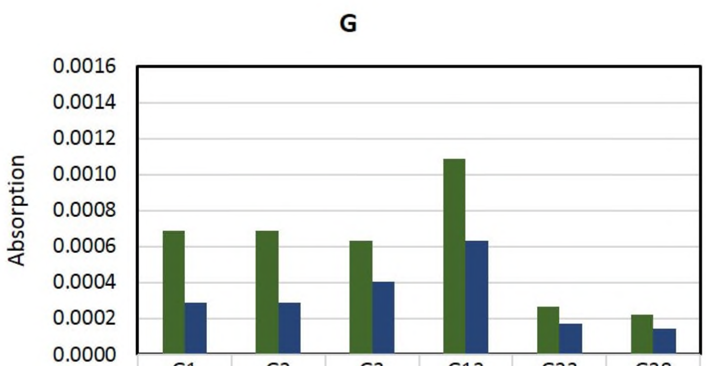
	E1	E2	E3	E12	E22	E23
Primary	0.00047	0.00045	0.00042	0.00052	0.00050	0.00056
Secondary	0.00025	0.00022	0.00017	0.00041	0.00023	0.00028

Figure 123. Primary and secondary absorption rate for E specimens.



	F1	F2	F3	F12	F23
Primary	0.00045	0.00038	0.00111	0.00065	0.00032
Secondary	0.00011	0.00022	0.00020	0.00024	0.00008

Figure 124. Primary and secondary absorption rate for F specimens.



	G1	G2	G3	G12	G23	G28
Primary	0.00069	0.00069	0.00063	0.00109	0.00027	0.00022
Secondary	0.00029	0.00029	0.00041	0.00063	0.00017	0.00014

Figure 125. Primary and secondary absorption rate for G specimens.

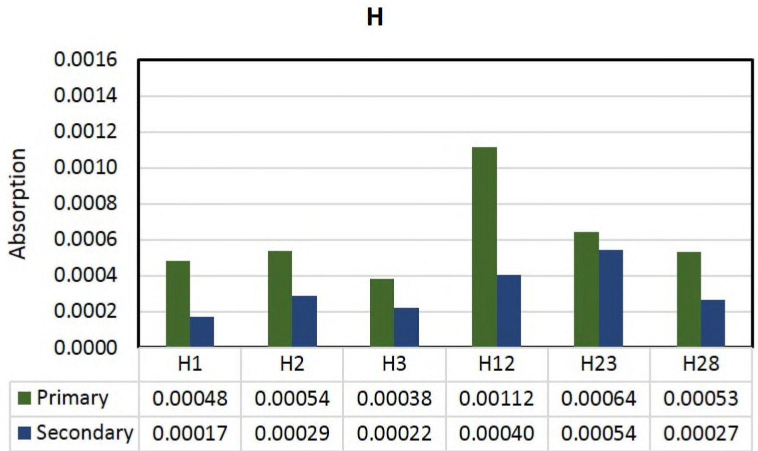


Figure 126. Primary and secondary absorption rate for H specimens.

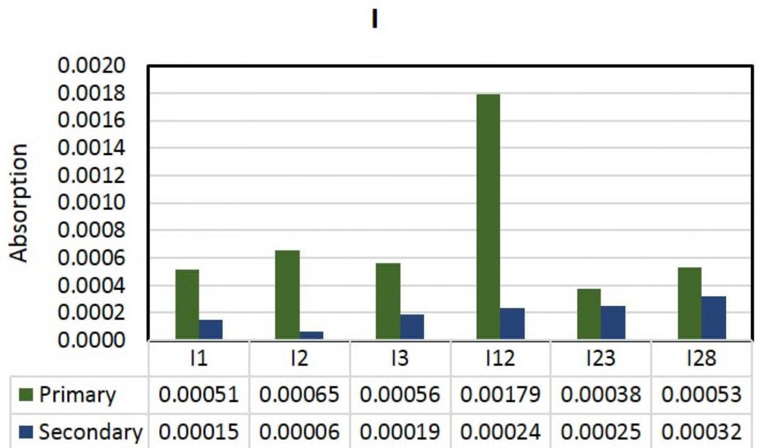


Figure 127. Primary and secondary absorption rate for I specimens.

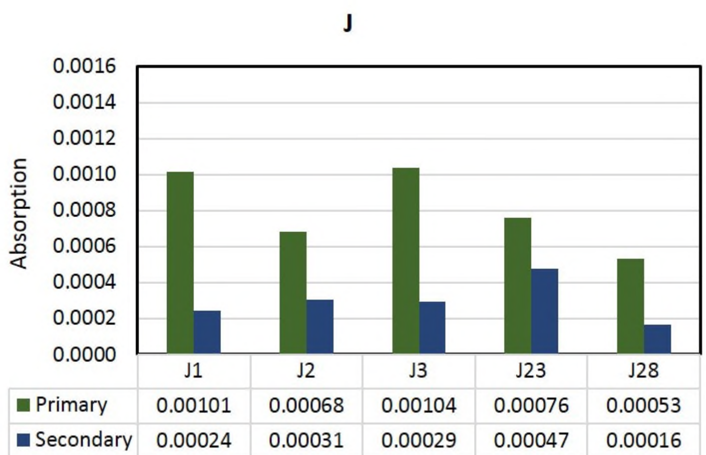


Figure 128. Primary and secondary absorption rate for J specimens.

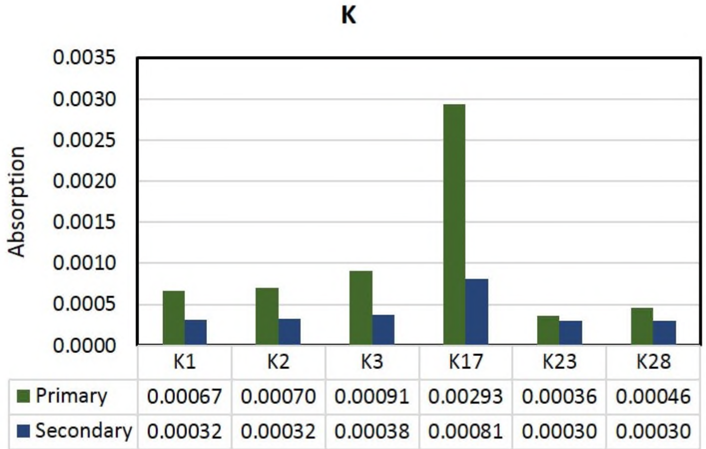


Figure 129. Primary and secondary absorption rate for K specimens.

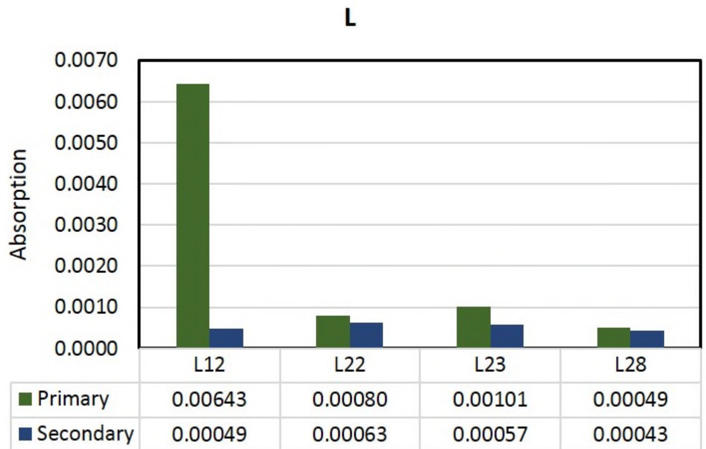


Figure 130. Primary and secondary absorption rate for L specimens.

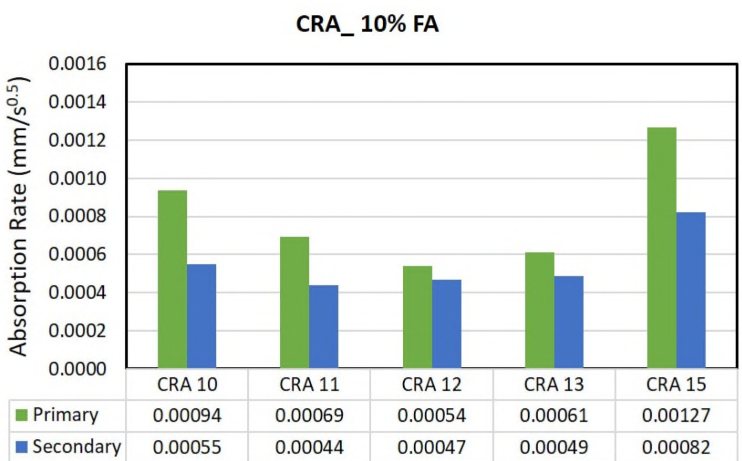


Figure 131. Primary and secondary absorption rate for CRA specimens (10% FA).

Appendix H – Tables of Primary and Secondary Absorption Rate

Table 53. Table – SL specimens primary and secondary absorption rate.

Specimen	Primary	Secondary	Tested on
SL1-4	0.00084	0.00053	7/11/16-7/19/16
SL1-5	0.00086	0.00050	7/11/16-7/19/16
SL1-6	0.00097	0.00051	7/11/16-7/19/16
SL1-7	0.00134	0.00060	7/11/16-7/19/16
SL1-8	0.00076	0.00040	11/22/16-11/30/16
SL1-9	0.00060	0.00033	11/22/16-11/30/16
SL1-35	0.00065	0.00028	3/21/17-3/29/17
SL1-36	0.00102	0.00057	6/22/16-7/1/16
SL1-38	0.00053	0.00023	11/9/16-11/18/16
SL1-39	0.00089	0.00026	8/8/16-8/18/16
SL1-40	0.00040	0.00003	6/14/17-6/23/17
SL1-41	0.00092	0.00028	6/14/17-6/23/17
SL1-45	0.00112	0.00042	12/5/17-12/17/17
SL2-4	0.00157	0.00063	7/11/16-7/19/16
SL2-5	0.00103	0.00056	7/11/16-7/19/16
SL2-6	0.00112	0.00068	7/11/16-7/19/16
SL2-7	0.00143	0.00055	7/11/16-7/19/16
SL2-8	0.00119	0.00055	11/22/16-11/30/16
SL2-9	0.00099	0.00032	11/22/16-11/30/16
SL2-51	0.00057	0.00008	6/14/17-6/23/17
SL2-53	0.00064	0.00042	11/9/16-11/18/16
SL2-54	0.00092	0.00055	6/22/16-7/1/16
SL2-55	0.00081	0.00029	8/8/16-8/18/16
SL2-56	0.00050	0.00022	3/21/17-3/29/17
SL2-58	0.00068	0.00031	6/14/17-6/23/17
SL2-60	0.00101	0.00047	12/5/17-12/17/17

NOTE: The date format is mm/dd/yyyy for all tables in Appendix H

Table 54. FA specimens primary and secondary absorption rate.

Specimen	Primary	Secondary	Tested on
FA1-4	0.00187	0.00090	7/13/16-7/21/16
FA1-5	0.00195	0.00098	7/13/16-7/21/16
FA1-6	0.00173	0.00087	7/13/16-7/21/16
FA1-7	0.00184	0.00080	7/13/16-7/21/16
FA1-8	0.00113	0.00063	11/22/16-11/30/16
FA1-9	0.00109	0.00061	11/22/16-11/30/16
FA1-35	0.00085	0.00026	6/14/17-6/23/17
FA1-36	0.00100	0.00052	3/21/17-3/29/17
FA1-37	0.00139	0.00101	7/25/16-8/2/16
FA1-38	0.00100	0.00061	11/9/16-11/18/16
FA1-40	0.00121	0.00068	9/13/16-9/21/16
FA1-41	0.00123	0.00052	6/14/17-6/23/17
FA1-45	0.00140	0.00051	12/5/17-12/17/17
FA2-4	0.00174	0.00085	7/13/16-7/21/16
FA2-5	0.00168	0.00094	7/11/16-7/19/16
FA2-6	0.00176	0.00080	7/13/16-7/21/16
FA2-7	0.00208	0.00081	7/13/16-7/21/16
FA2-8	0.00118	0.00065	11/23/16-12/1/16
FA2-9	0.00102	0.00061	11/23/16-12/1/16
FA2-51	0.00097	0.00047	3/21/17-3/29/17
FA2-53	0.00173	0.00098	7/25/16-8/2/16
FA2-54	0.00114	0.00066	11/9/16-11/18/16
FA2-55	0.00142	0.00053	8/8/16-8/18/16
FA2-56	0.00058	0.00029	6/14/17-6/23/17
FA2-58	0.00117	0.00055	6/14/17-6/23/17
FA2-60	0.00137	0.00067	12/5/17-12/17/17

Table 55. T1 and T2 specimens primary and secondary absorption rate.

	Primary	Secondary	Tested on
T1-4	0.00116	0.00054	4/11/17-4/19/17
T1-5	0.00103	0.00071	4/11/17-4/19/17
T1-6	0.00125	0.00067	3/21/17-3/29/17
T1-7	0.00094	0.00064	11/9/16-11/18/16
T1-8	0.00161	0.00090	3/21/17-3/29/17
T1-9	0.00142	0.00071	3/21/17-3/29/17
T1-10	0.00120	0.00048	6/14/17-6/23/17
T1-11	0.00121	0.00059	12/5/17-12/17/17
	Primary	Secondary	Tested on
T2-4	0.00050	0.00043	4/11/17-4/19/17
T2-5	0.00054	0.00040	4/11/17-4/19/17
T2-6	0.00057	0.00040	3/21/17-3/29/17
T2-7	0.00060	0.00049	11/9/16-11/18/16
T2-8	0.00060	0.00050	3/21/17-3/29/17
T2-9	0.00060	0.00036	6/14/17-6/23/17
T2-11	0.00063	0.00053	3/21/17-3/29/17
T2-12	0.00061	0.00043	12/5/17-12/17/17

Table 56. DCL specimens primary and secondary absorption rate.

	Primary	Secondary	Tested on
DC1-1	0.00099	0.00033	3/22/17-3/30/17
DC1-7	0.00126	0.00025	3/22/17-3/30/17
DC1-22	0.00109	0.00029	10/18/16-10/26/16
DC1-24	0.00107	0.00029	3/22/17-3/30/17
DC1-27	0.00101	0.00019	5/9/17-5/18/17
DC2-2	0.00099	0.00026	4/24/17-5/2/17
DC2-7	0.00086	0.00032	4/11/17-4/19/17
DC2-22	0.00090	0.00031	10/18/16-10/26/16
DC2-23	0.00104	0.00048	4/11/17-4/19/17
DC3-1	0.00171	0.00068	5/9/17-5/18/17
DC3-7	0.00185	0.00097	5/9/17-5/18/17
DC3-22	0.00123	0.00079	10/18/16-10/26/16
DC3-23	0.00133	0.00060	4/24/17-5/2/17

Table 56. Continues

	Primary	Secondary	Tested on
DC4-1	0.00102	0.00051	3/22/17-3/30/17
DC4-7	0.00100	0.00052	3/22/17-3/30/17
DC4-22	0.00070	0.00029	10/18/16-10/26/16
DC4-27	0.00074	0.00025	3/22/17-3/30/17
DC5-2	0.00092	0.00030	4/24/17-5/2/17
DC5-8	0.00101	0.00028	4/24/17-5/2/17
DC5-22	0.00110	0.00031	10/18/16-10/26/16
DC5-26	0.00080	0.00028	4/11/17-4/19/17
DC5-27	0.00102	0.00029	7/20/17 - 8/1/17
DC6-1	0.00127	0.00036	4/25/17-5/3/17
DC6-7	0.00129	0.00026	4/11/17-4/19/17
DC6-22	0.00075	0.00027	10/18/16-10/26/16
DC6-26	0.00090	0.00019	5/9/17-5/18/17
DC7-1	0.00097	0.00021	3/22/17-3/30/17
DC7-2	0.00071	0.00020	
DC7-7	0.00133	0.00020	4/25/17-5/3/17
DC7-22	0.00109	0.00024	9/14/16-9/22/16
DC7-27	0.00096	0.00018	3/22/17-3/30/17
DC8-1	0.00137	0.00025	4/25/17-5/3/17
DC8-7	0.00058	0.00017	4/25/17-5/3/17
DC8-25	0.00143	0.00025	8/8/16-8/18/16
DC8-26	0.00055	0.00013	4/25/17-5/3/17
DC8-27	0.00059	0.00018	4/25/17-5/3/17
DC9-1	0.00141	0.00034	4/24/17-5/2/17
DC9-2	0.00091	0.00026	4/24/17-5/2/17
DC9-7	0.00121	0.00033	4/24/17-5/2/17
DC9-25	0.00122	0.00047	8/8/16-8/18/16
DC9-27	0.00090	0.00034	4/24/17-5/2/17

Table 56. Continues

	Primary	Secondary	Tested on
DC10-1	0.00139	0.00065	4/24/17-5/2/17
DC10-22	0.00091	0.00051	10/18/16-10/26/16
DC10-23	0.00130	0.00072	3/22/17-3/30/17
DC10-27	0.00114	0.00057	4/25/17-5/3/17
DC10A-1	0.00096	0.00052	4/10/17-4/18/17
DC10A-7	0.00106	0.00038	4/10/17-4/18/17
DC10a-23	0.00103	0.00038	10/18/16-10/26/16
DC10a-24	0.00129	0.00031	4/24/17-5/2/17
DC10A-27	0.00098	0.00030	4/25/17-5/3/17
DC10B-1	0.00095	0.00044	4/10/17-4/18/17
DC10B-7	0.00085	0.00041	4/10/17-4/18/17
DC10b-23	0.00093	0.00036	10/18/16-10/26/16
DC10b-24	0.00109	0.00034	4/10/17-4/18/17
DC11-7	0.00126	0.00029	4/10/17-4/18/17
DC11-14	0.00144	0.00028	4/10/17-4/18/17
DC11-23	0.00107	0.00034	10/18/16-10/26/16
DC11-24	0.00095	0.00036	4/10/17-4/18/17

Table 57. A to L specimens primary and secondary absorption rate.

Specimen	Primary	Secondary	Tested on
A1	0.00058	0.00023	7/25/16-8/2/16
A2	0.00068	0.00029	7/27/16-8/4/16
A3	0.00077	0.00032	6/7/16-6/16/16
A12	0.00105	0.00090	5/27/16-6/4/16
A23	0.00116	0.00065	6/22/16-7/1/16
A28	0.00072	0.00025	6/22/16-7/1/16
Ai1	0.00051	0.00021	9/13/16-9/21/16
Ai2	0.00058	0.00026	9/13/16-9/21/16
Ai3	0.00055	0.00014	9/13/16-9/21/16
AA23	0.00076	0.00044	6/22/16-7/1/16
AA28	0.00106	0.00031	6/22/16-7/1/16
Bi2	0.00064	0.00026	7/25/16-8/2/16
Bi3	0.00084	0.00016	7/27/16-8/4/16
BB23	0.00146	0.00079	6/27/16-7/5/16
BB27	0.00117	0.00058	7/11/16-7/19/16
BB28	0.00120	0.00069	11/22/16-11/30/16
B1	0.00051	0.00029	6/22/16-7/1/16
B2	0.00056	0.00025	7/25/16-8/2/16
B3	0.00054	0.00031	6/7/16-6/16/16
B23	0.00218	0.00096	6/27/16-7/5/16
B29	0.00101	0.00067	6/27/16-7/5/16
C1	0.00105	0.00029	7/27/16-8/4/16
C2	0.00136	0.00025	6/6/16-6/15/16
C3	0.00095	0.00036	7/27/16-8/4/16
C12	0.00341	0.00094	5/27/16-6/4/16
C22	0.00071	0.00037	11/22/16-11/30/16
C23	0.00044	0.00024	9/14/16-9/22/16
C28	0.00038	0.00025	11/23/16-12/1/16
D1	0.00056	0.00022	6/7/16-6/16/16
D2	0.00043	0.00027	7/27/16-8/4/16
D3	0.00077	0.00035	7/25/16-8/2/16
D12	0.00093	0.00043	5/18/16-5/26/16
D22	0.00137	0.00057	6/27/16-7/5/16
D23	0.00216	0.00083	6/27/16-7/5/16
D27	0.00071	0.00040	5/9/17-5/18/17

Table 57. Continues

	Primary	Secondary	Tested on
E1	0.00047	0.00025	9/13/16-9/21/16
E2	0.00045	0.00022	9/13/16-9/21/16
E3	0.00042	0.00017	9/13/16-9/21/16
E12	0.00052	0.00041	5/18/16-5/26/16
E22	0.00050	0.00023	6/22/16-7/1/16
E23	0.00056	0.00028	6/22/16-7/1/16
E28	0.00054	0.00020	11/23/16-12/1/16
F1	0.00045	0.00011	7/25/16-8/2/16
F2	0.00038	0.00022	6/7/16-6/16/16
F3	0.00111	0.00020	7/27/16-8/4/16
F12	0.00065	0.00024	6/6/16-6/15/16
F23	0.00032	0.00008	9/14/16-9/22/16
F27	0.00036	0.00011	5/9/17-5/18/17
G1	0.00069	0.00029	7/25/16-8/2/16
G2	0.00069	0.00029	7/27/16-8/4/16
G3	0.00063	0.00041	6/6/16-6/15/16
G12	0.00109	0.00063	5/18/16-5/26/16
G22	0.00034	0.00017	11/23/16-12/1/16
G23	0.00027	0.00017	9/14/16-9/22/16
G28	0.00022	0.00014	9/14/16-9/22/16
H1	0.00048	0.00017	7/27/16-8/4/16
H2	0.00054	0.00029	7/27/16-8/4/16
H3	0.00038	0.00022	6/7/16-6/16/16
H12	0.00112	0.00040	6/6/16-6/15/16
H23	0.00064	0.00054	6/27/16-7/5/16
H28	0.00053	0.00027	6/27/16-7/5/16
I1	0.00051	0.00015	9/13/16-9/21/16
I2	0.00065	0.00006	9/13/16-9/21/16
I3	0.00056	0.00019	9/13/16-9/21/16
I12	0.00179	0.00024	7/13/16-7/21/16
I22	0.00027	0.00032	5/9/17-5/18/17
I23	0.00038	0.00025	6/27/16-7/5/16
I28	0.00053	0.00032	6/22/16-7/1/16
J1	0.00101	0.00024	7/25/16-8/2/16
J2	0.00068	0.00031	6/7/16-6/16/16
J3	0.00104	0.00029	8/8/16-8/18/16
J23	0.00076	0.00047	6/27/16-7/5/16
J28	0.00053	0.00016	6/27/16-7/5/16

Table 57. Continues

	Primary	Secondary	Tested on
K1	0.00067	0.00032	8/8/16-8/18/16
K2	0.00070	0.00032	7/25/16-8/2/16
K3	0.00091	0.00038	6/6/16-6/15/16
K17	0.00293	0.00081	5/27/16-6/4/16
K23	0.00036	0.00030	9/14/16-9/22/16
K28	0.00046	0.00030	9/14/16-9/22/16
L1	0.00083	0.00051	7/20/17 - 8/1/17
L3	0.00071	0.00041	7/20/17 - 8/1/17
L10	0.00653	0.00063	
L12	0.00643	0.00049	5/27/16-6/4/16
L22	0.00080	0.00063	4/10/17-4/18/17
L23	0.00101	0.00057	4/10/17-4/18/17
L28	0.00049	0.00043	4/11/17-4/19/17
CRA 10	0.00094	0.00055	11/23/16-12/1/16
CRA 11	0.00069	0.00044	11/23/16-12/1/16
CRA 12	0.00054	0.00047	11/23/16-12/1/16
CRA 13	0.00061	0.00049	8/8/16-8/18/16
CRA 15	0.00127	0.00082	8/8/16-8/18/16

Appendix I – Chloride Profiles DCL Specimens

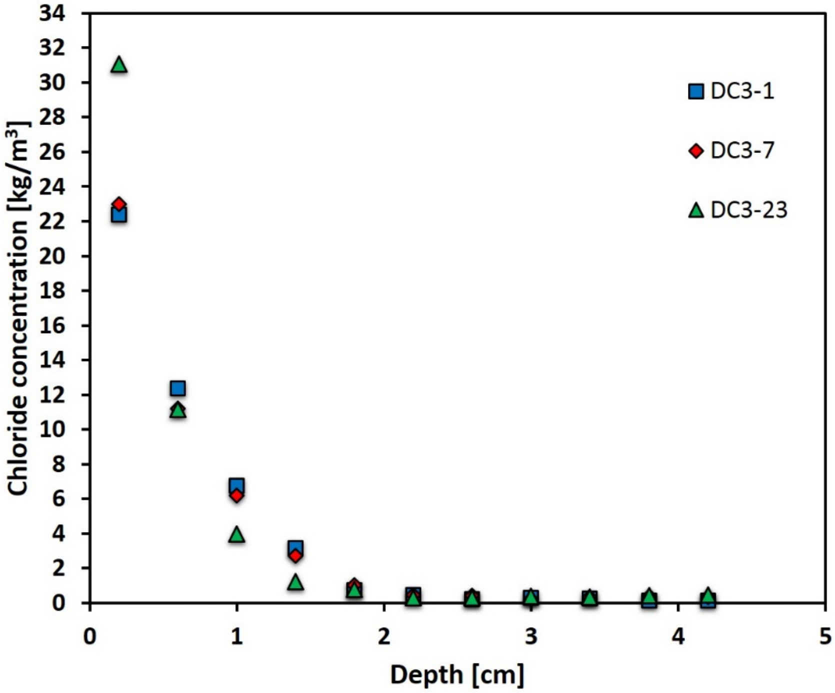


Figure 132. Chloride profile for DC3 specimens.

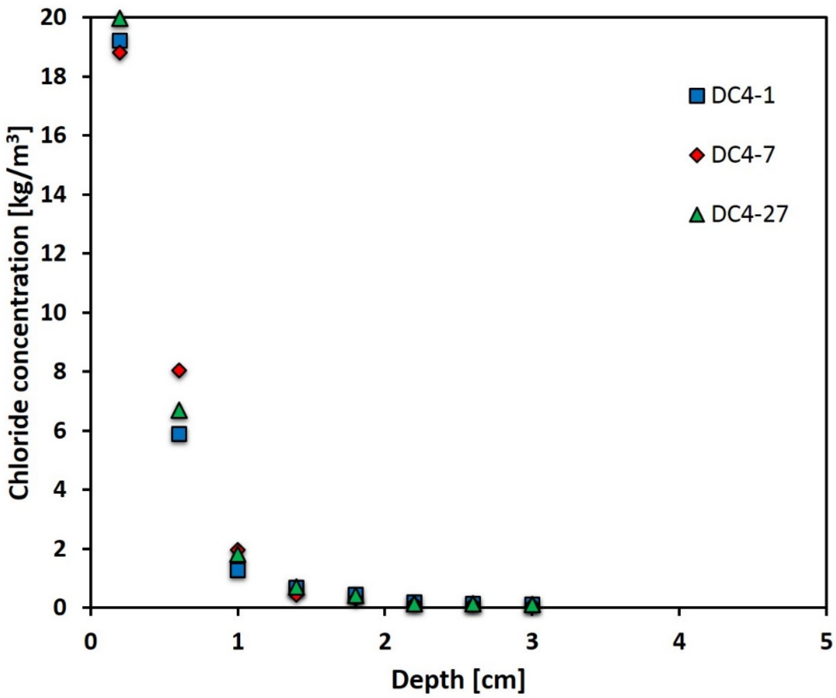


Figure 133. Chloride profile for DC4 specimens.

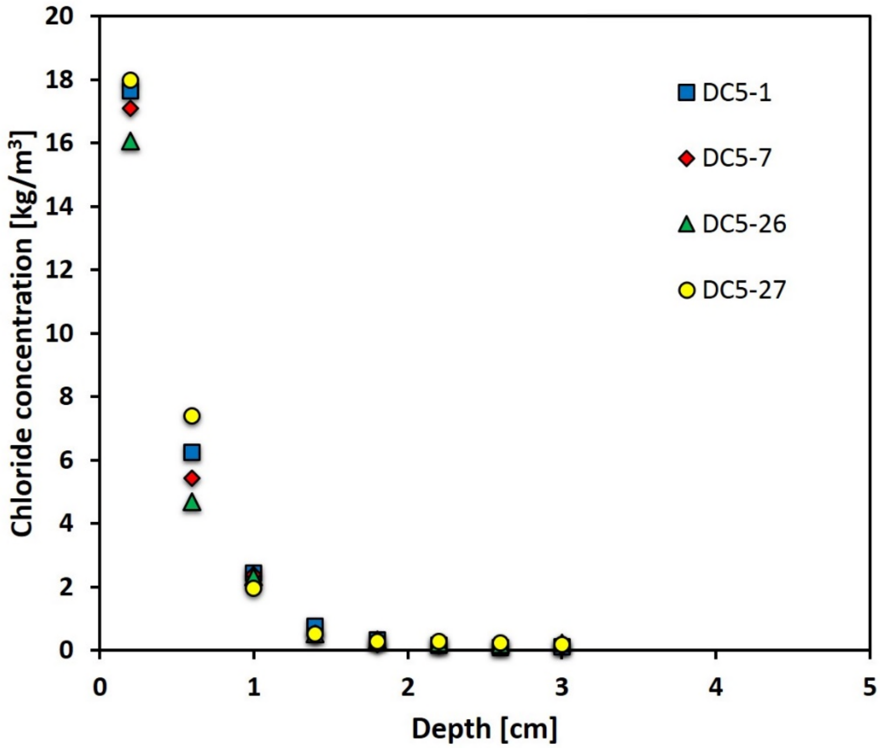


Figure 134. Chloride profile for DC5 specimens.

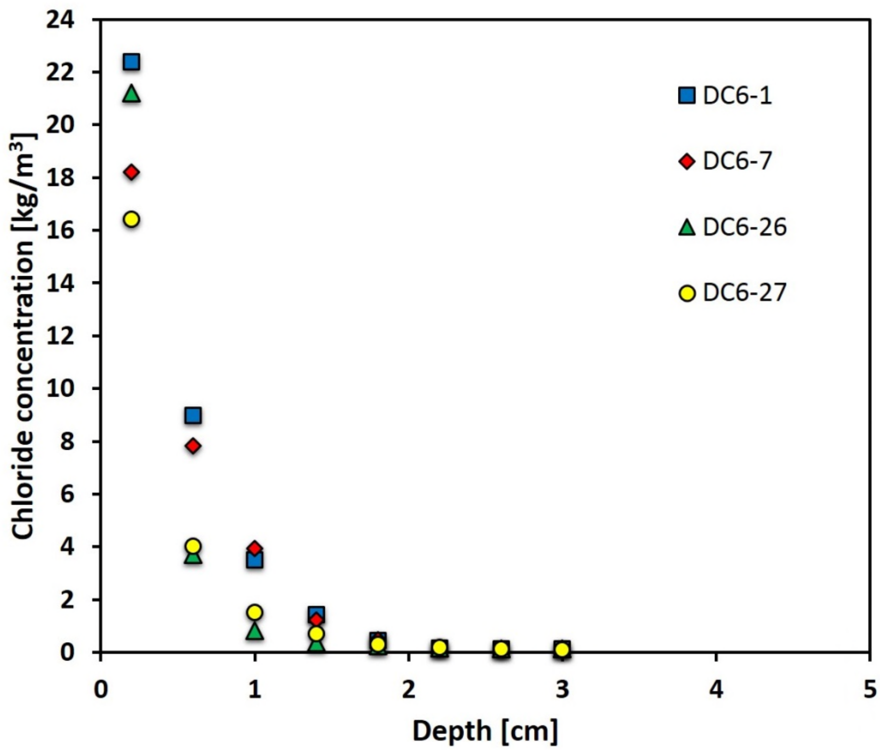


Figure 135. Chloride profile for DC6 specimens.

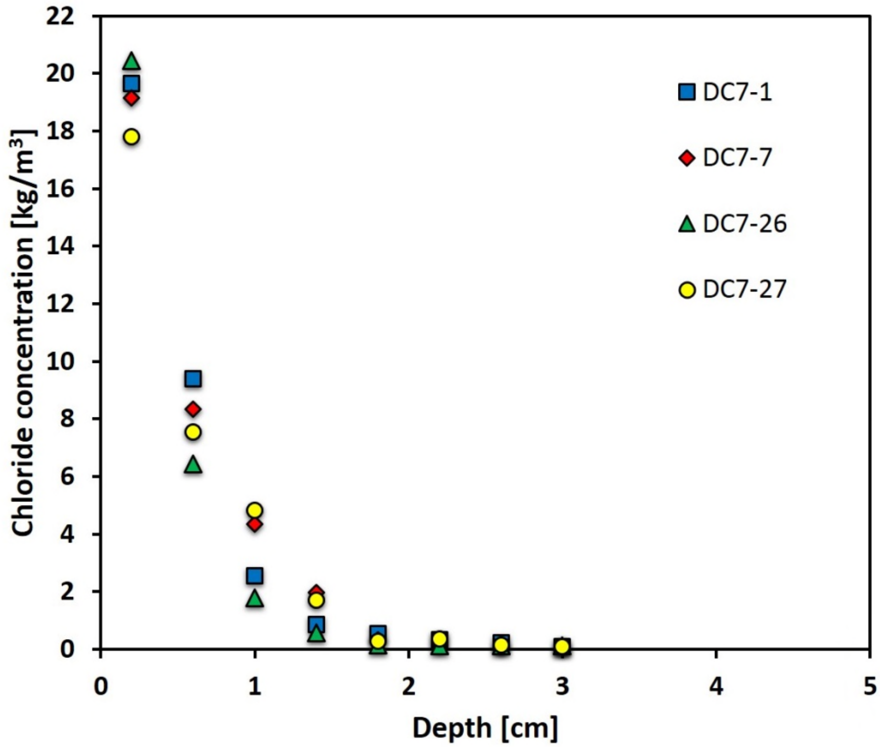


Figure 136. chloride profile for DC7 specimens.

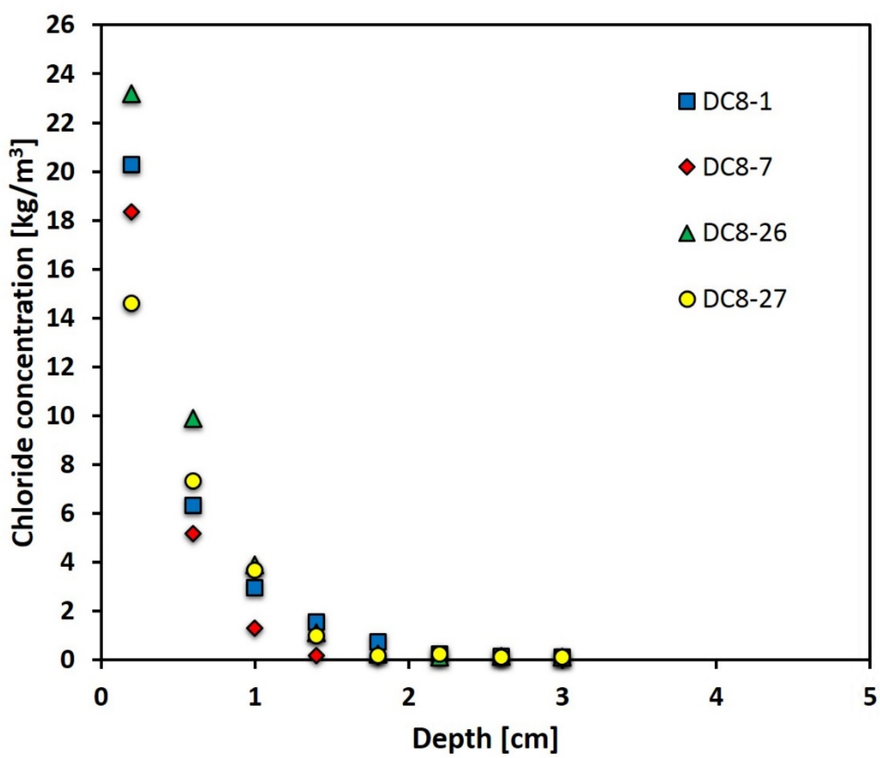


Figure 137. Chloride profile for DC8 specimens.

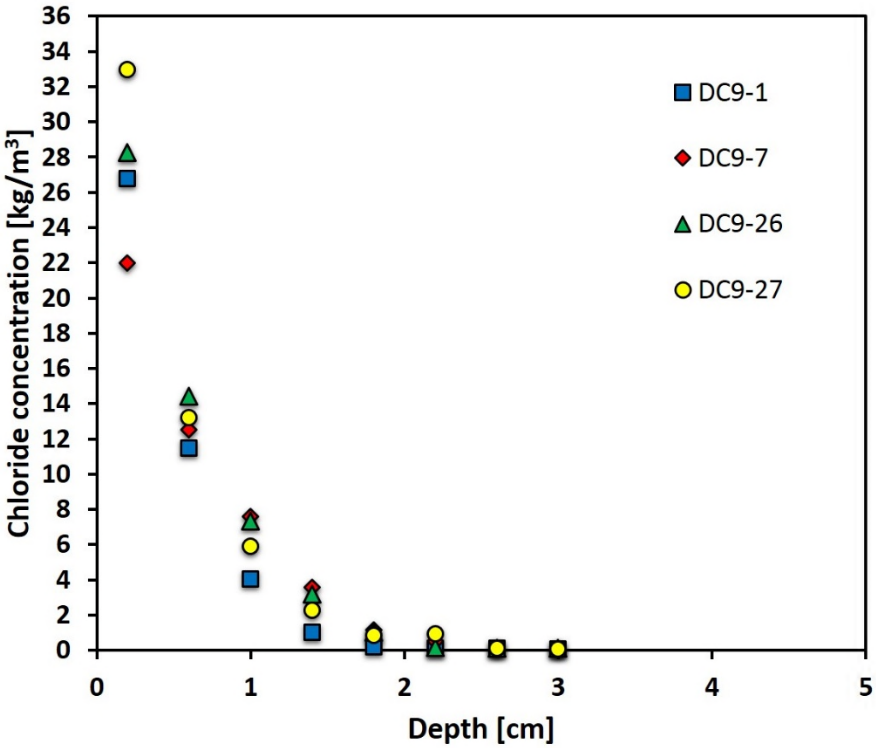


Figure 138. Chloride profile for DC9 specimens.

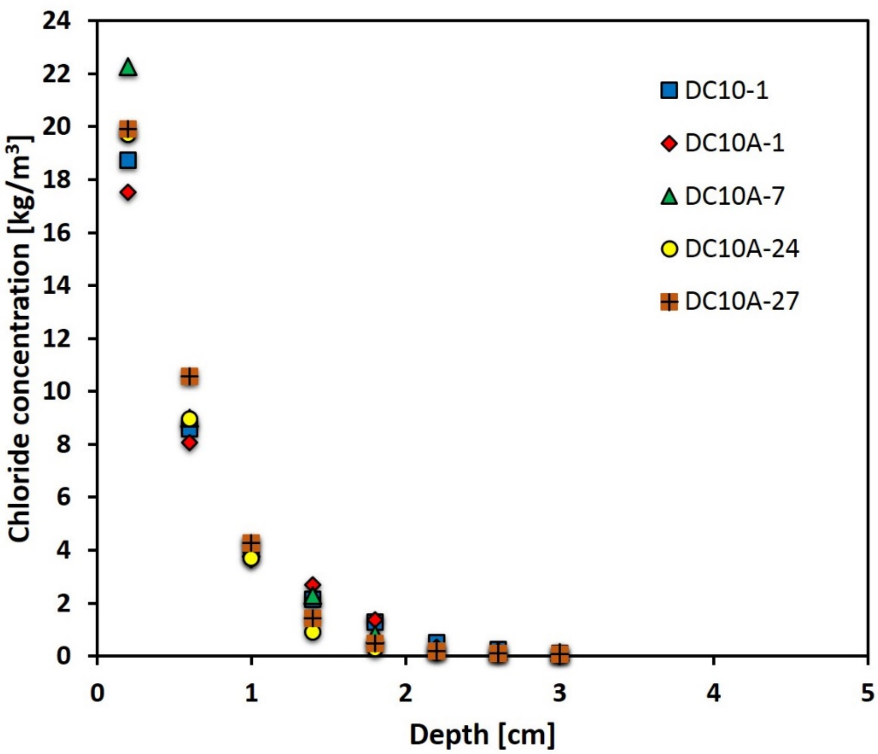


Figure 139. Chloride profile for DC10A specimens.

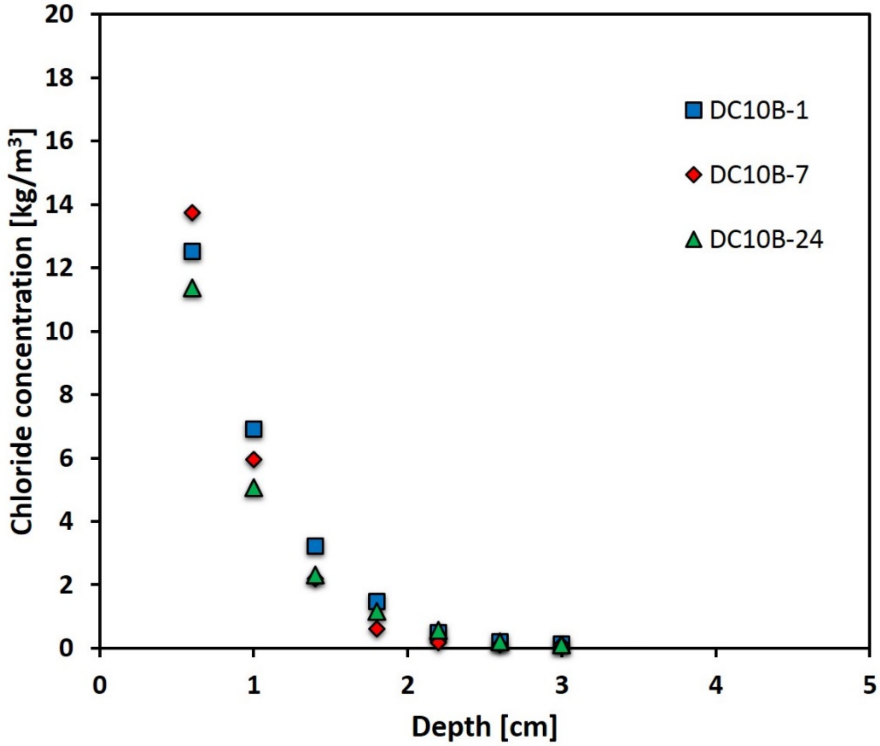


Figure 140. Chloride profile for DC10B specimens.

Appendix J – Chloride Profiles DCL Samples Immersed in Low Chloride

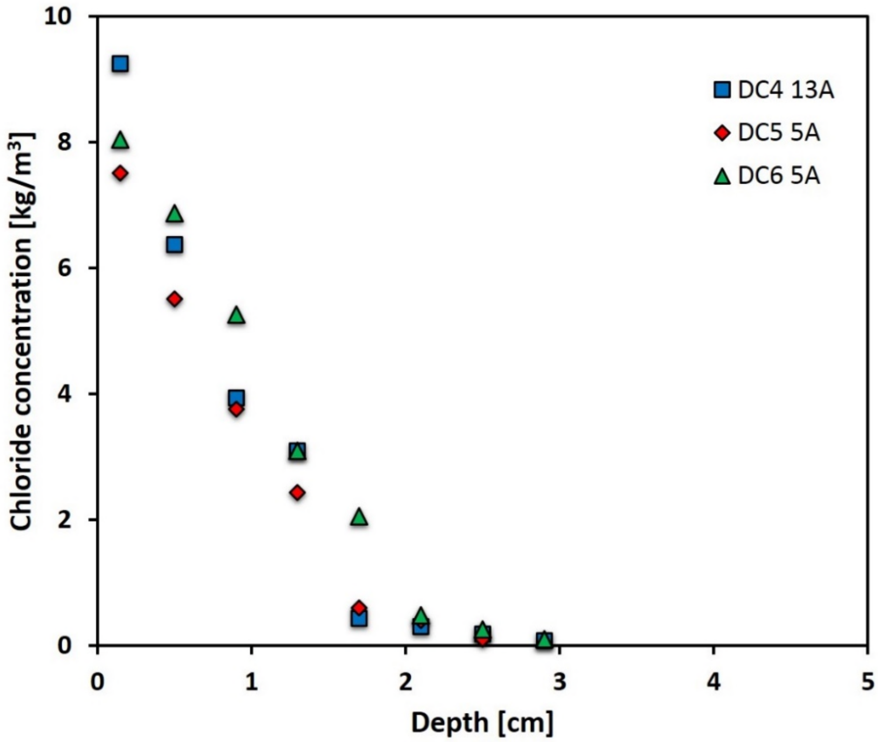


Figure 141. Chloride profile for DC4, 5, and 6 specimens immersed in low chloride solution

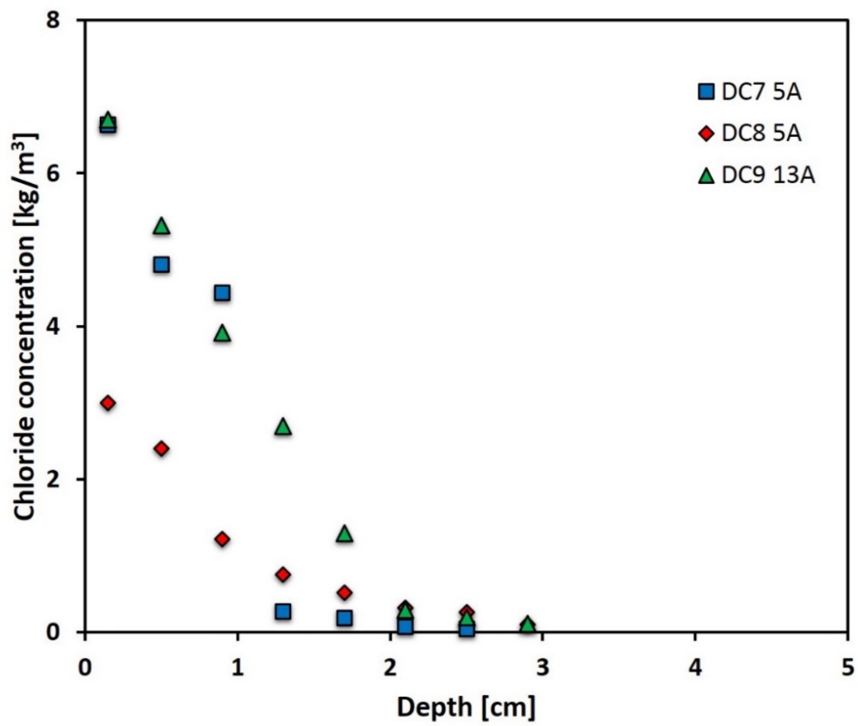


Figure 142. Chloride profile for DC 7, 8, and 9 specimens immersed in low chloride solution.

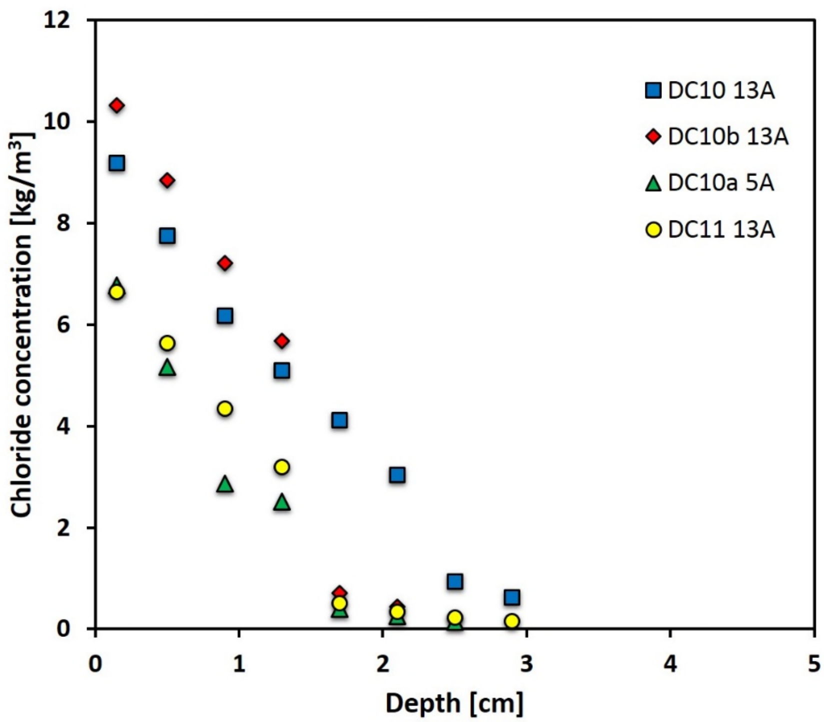


Figure 143. Chloride profile for DC10 and 11 immersed in low chloride solution.

Appendix K – Chloride Profiles SL, FA, T1 and T2 Samples

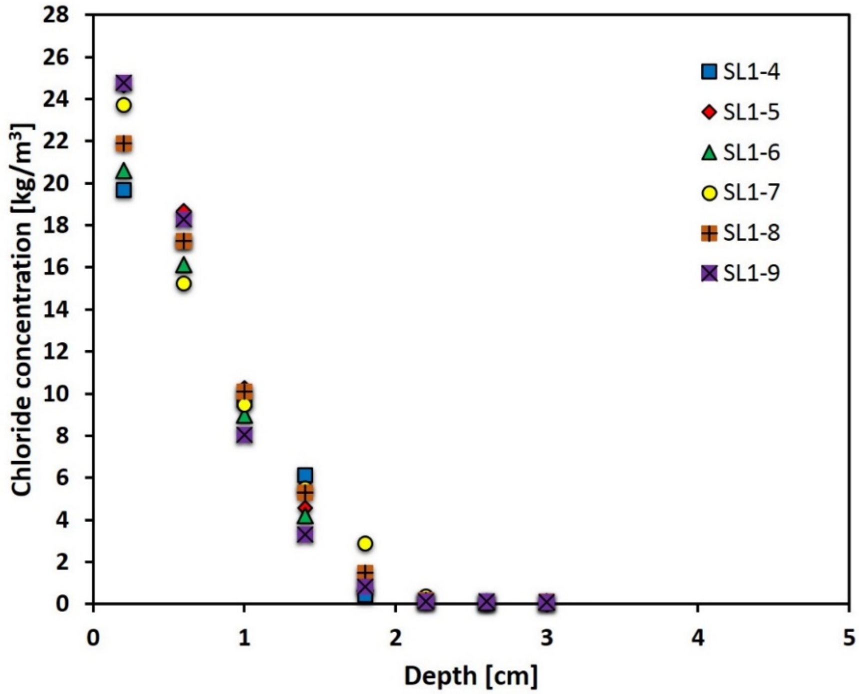


Figure 144. Chloride profile for SL1 specimens under different curing condition

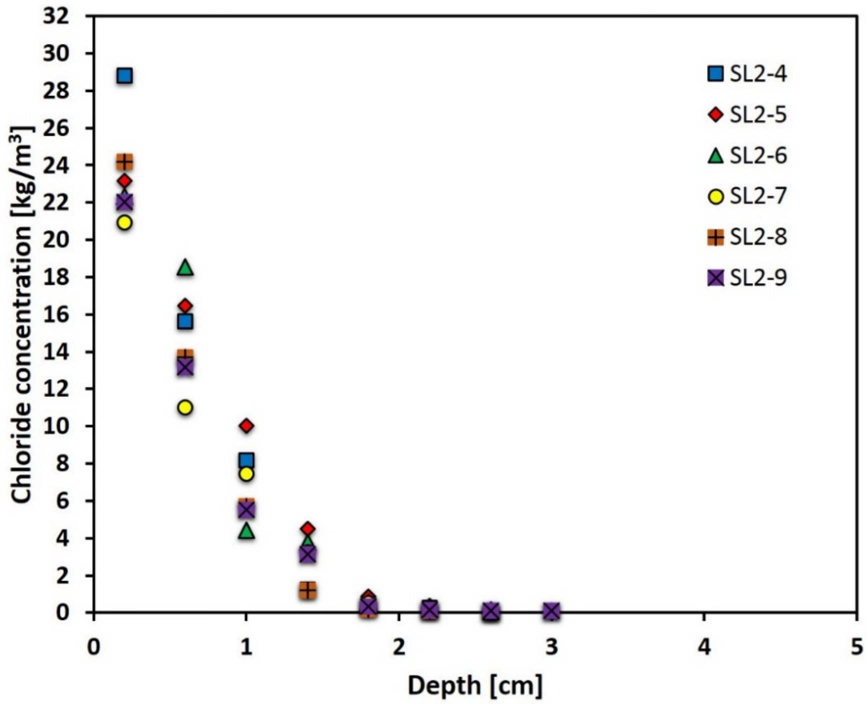


Figure 145. Chloride profile for SL2 specimens under different curing condition

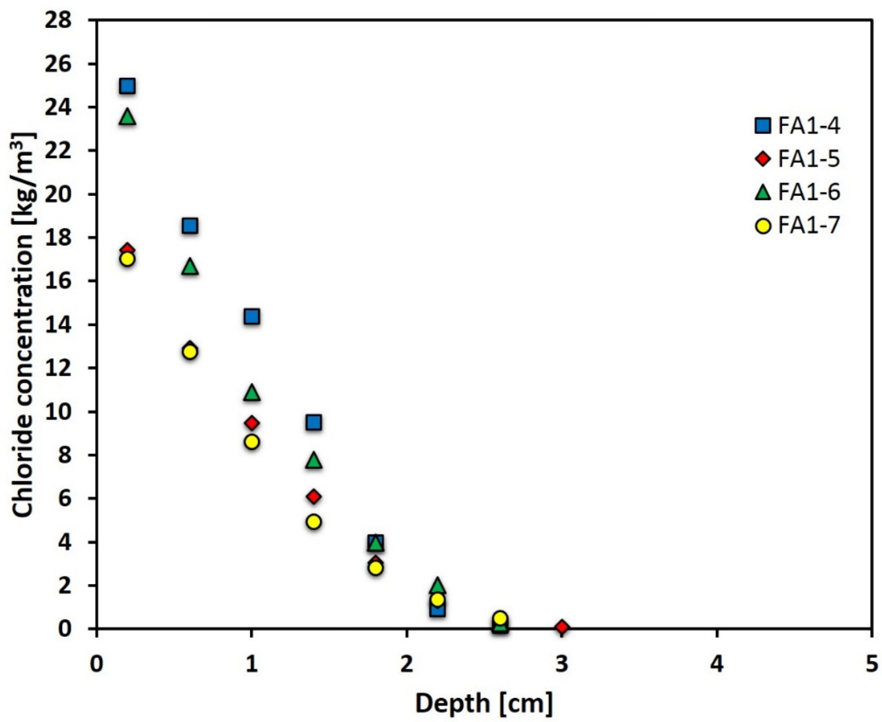


Figure 146. Chloride profile for FA1 specimens under different curing condition.

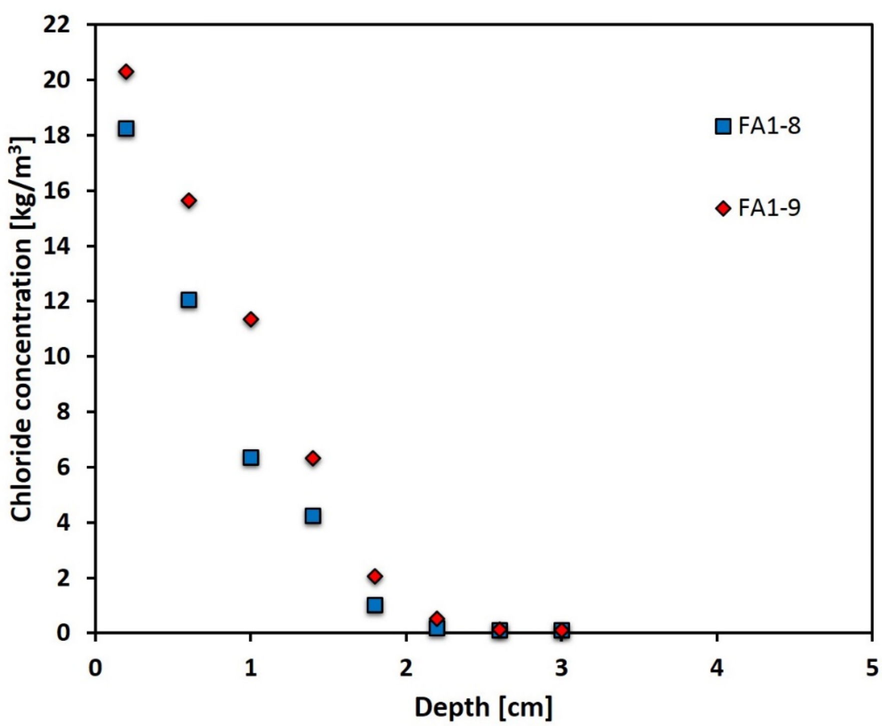


Figure 147. Chloride profile for FA specimens under different curing condition

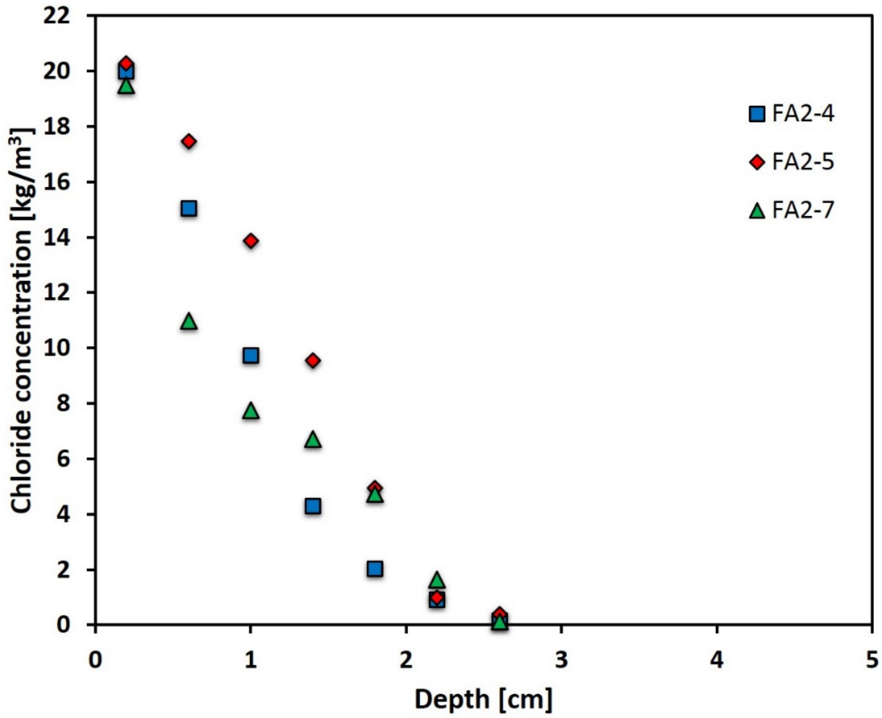


Figure 148. Chloride profile for FA2 specimens under different curing condition.

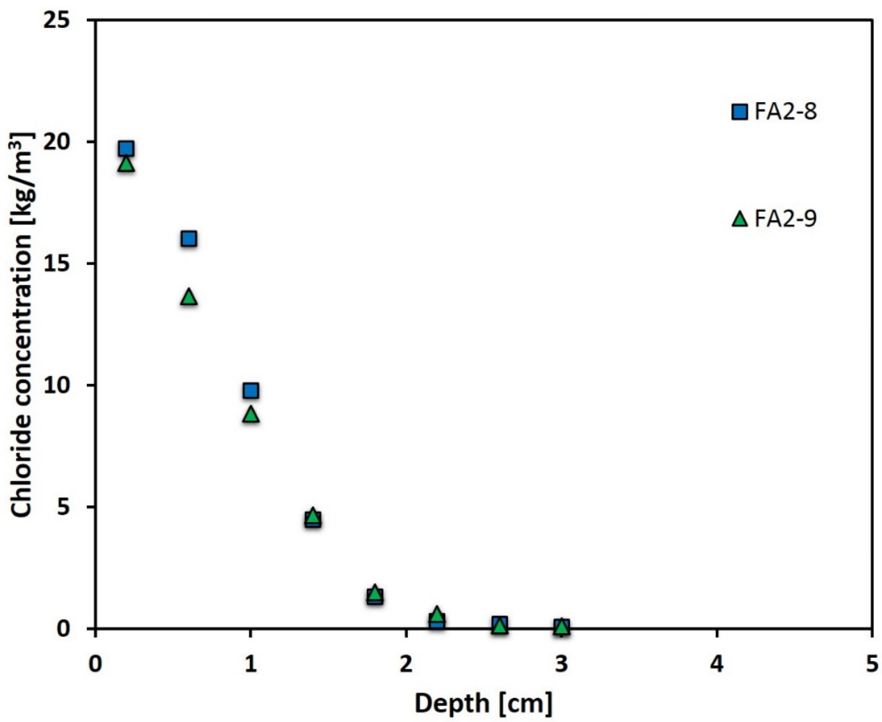


Figure 149. Chloride profile for FA specimens with respect to depth.

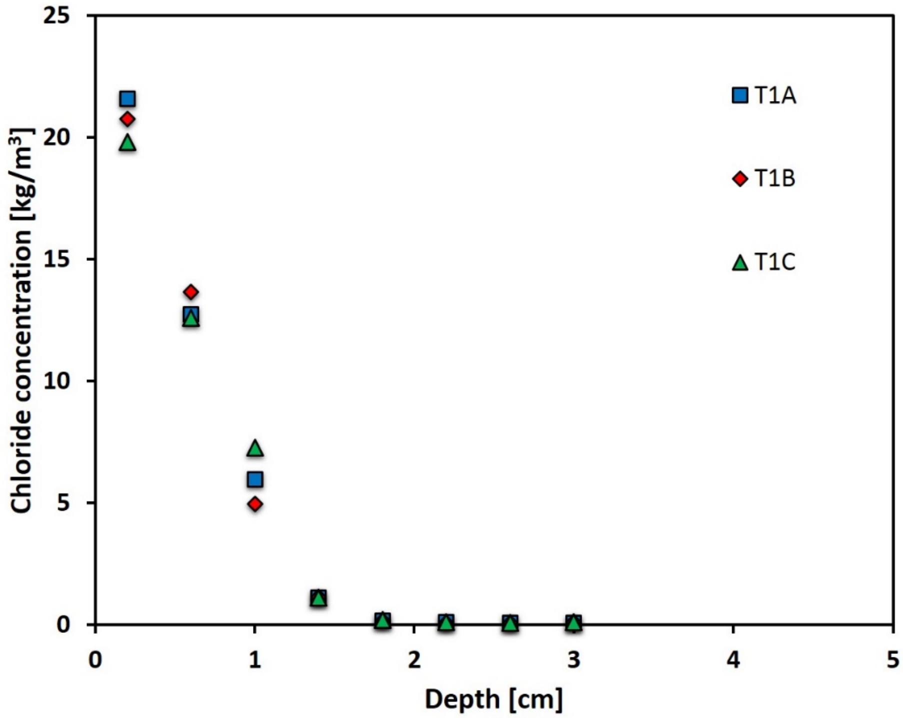


Figure 150. Chloride profile for T1 specimens with respect to depth.

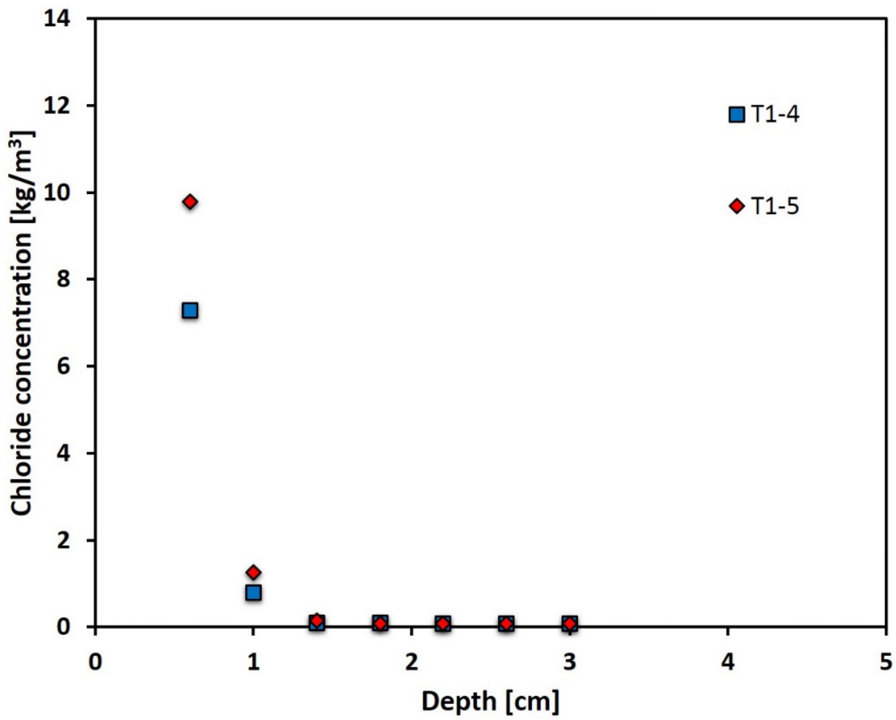


Figure 151. Chloride profile for T1 specimens with respect to depth.

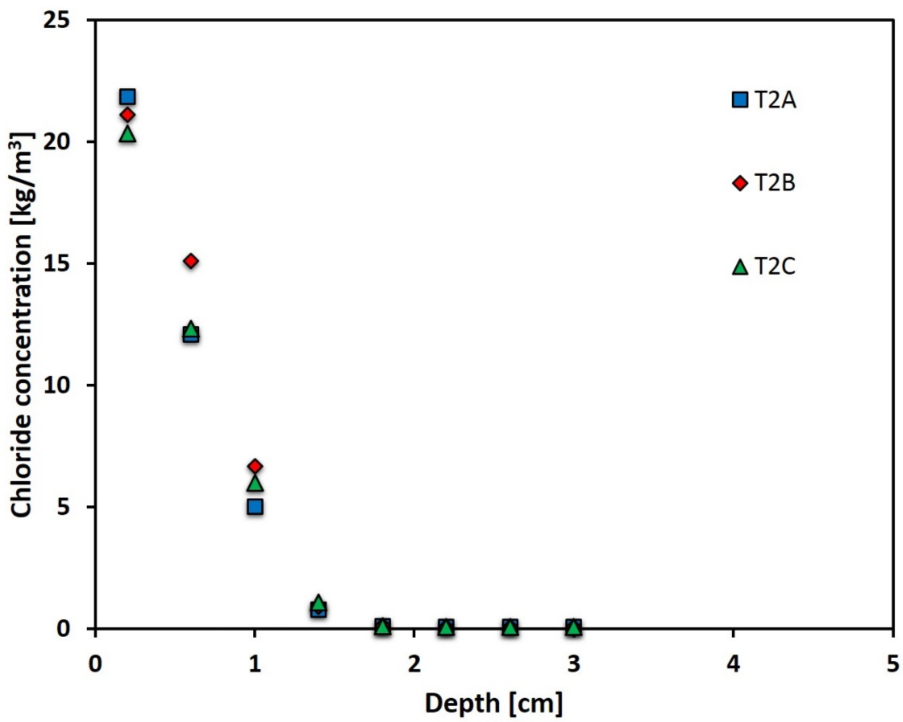


Figure 152. Chloride profile for T2 specimens with respect to depth.

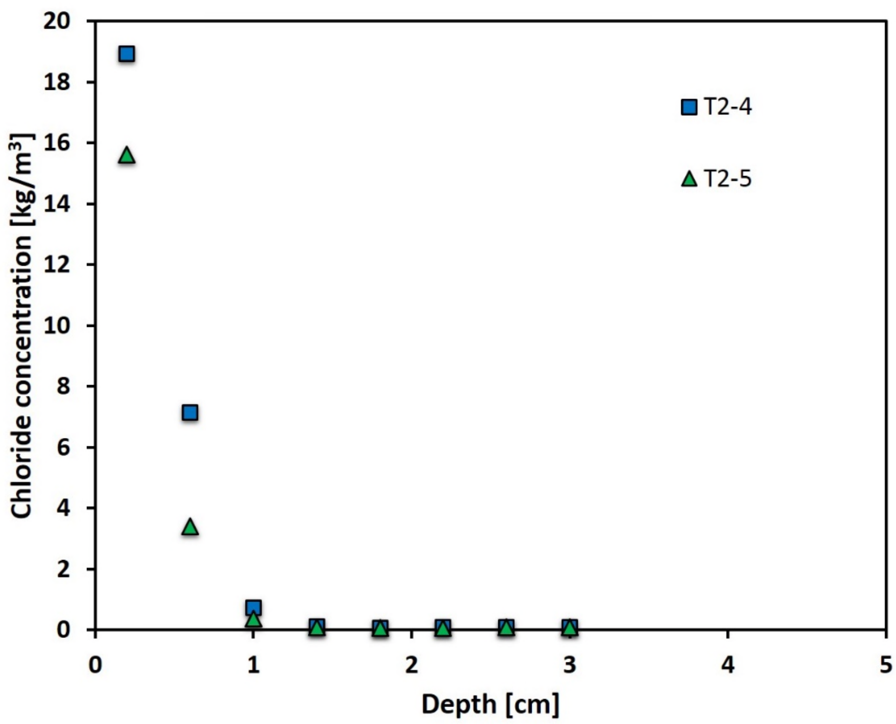


Figure 153. Chloride profile for T2 specimens with respect to depth.

Appendix L – Chloride Profiles A to L Samples

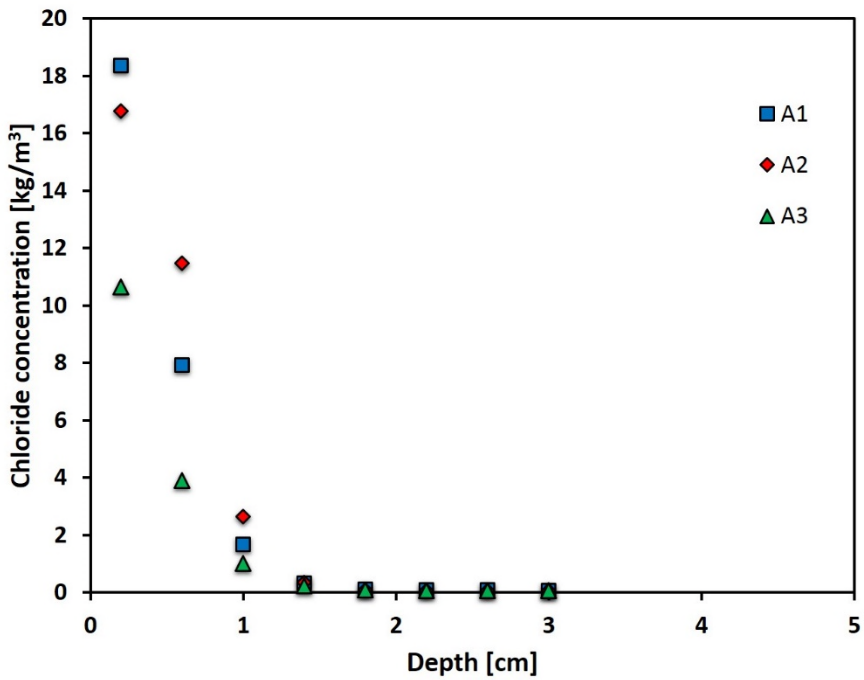


Figure 154. Chloride profile for A specimens with respect to depth.

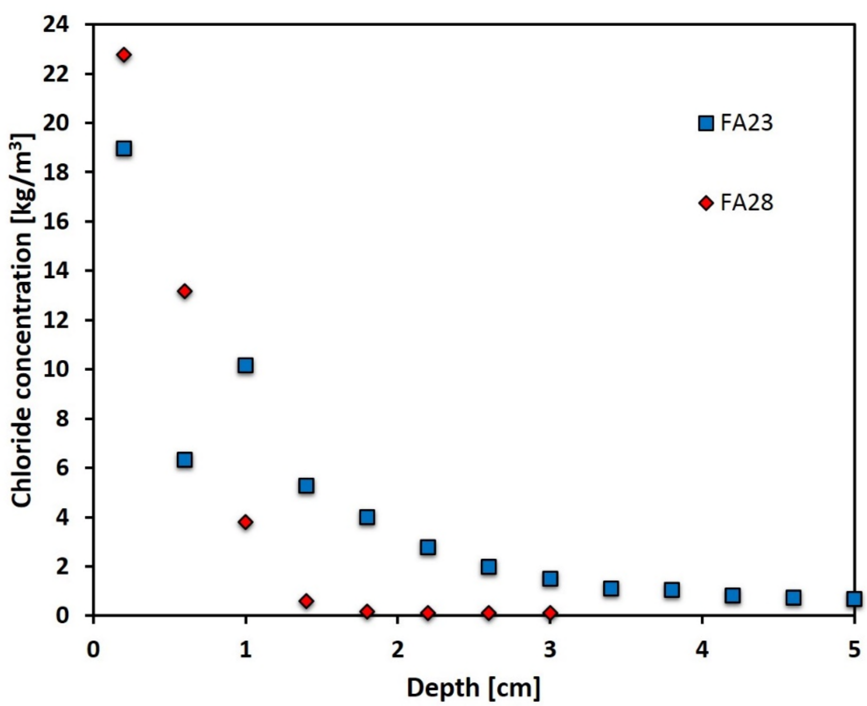


Figure 155. Chloride profile for FA2 specimens with respect to depth.

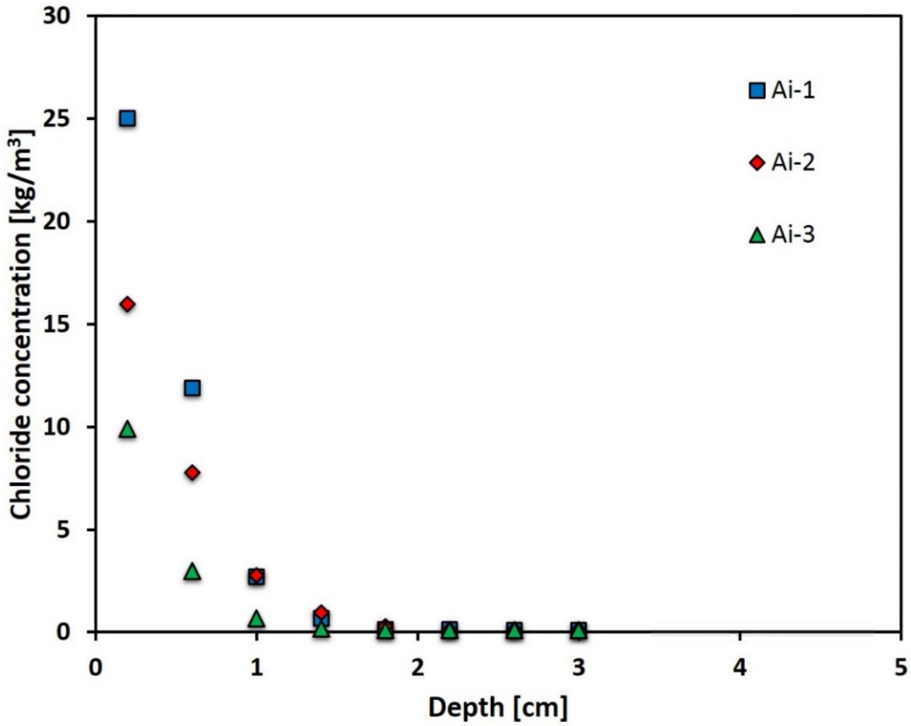


Figure 156. Chloride profile for Ai specimens with respect to depth.

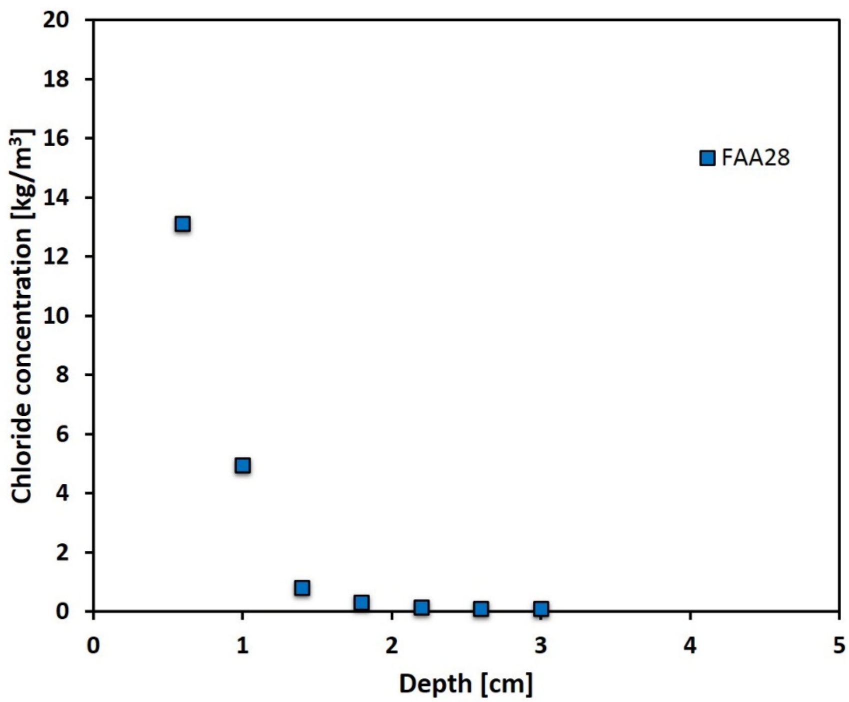


Figure 157. Chloride profile for FAA specimens with respect to depth.

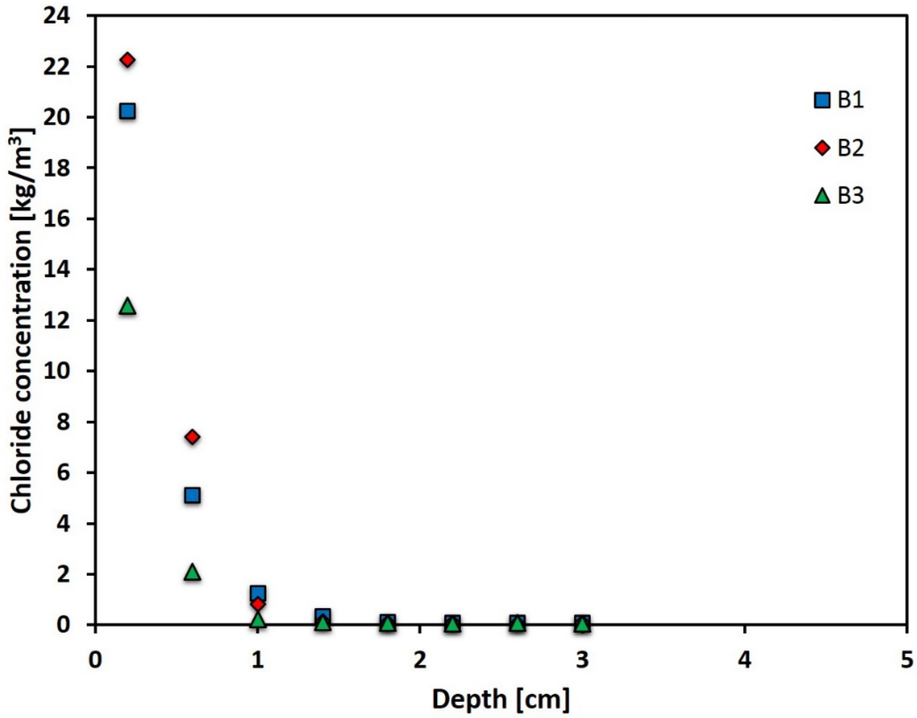


Figure 158. Chloride profile for B1 specimens with respect to depth.

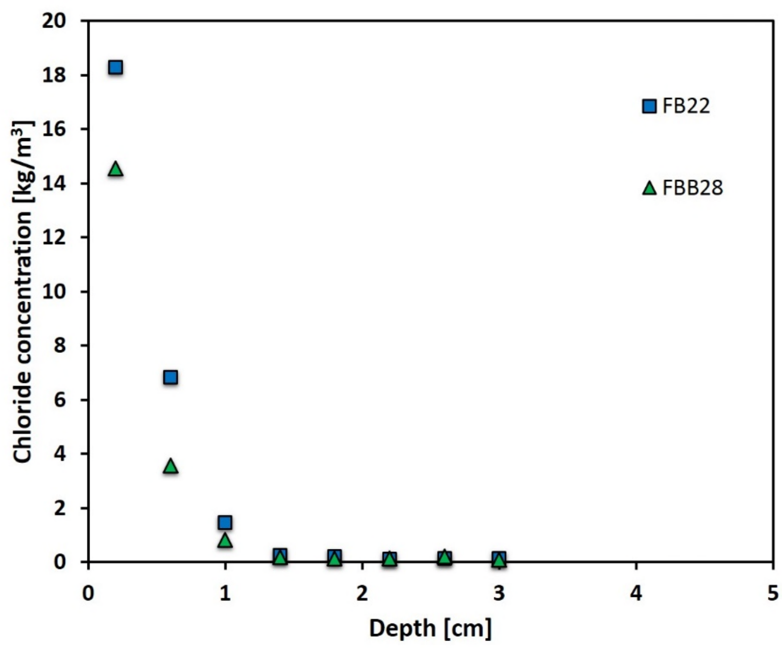


Figure 159. Chloride profile for FB specimens with respect to depth.

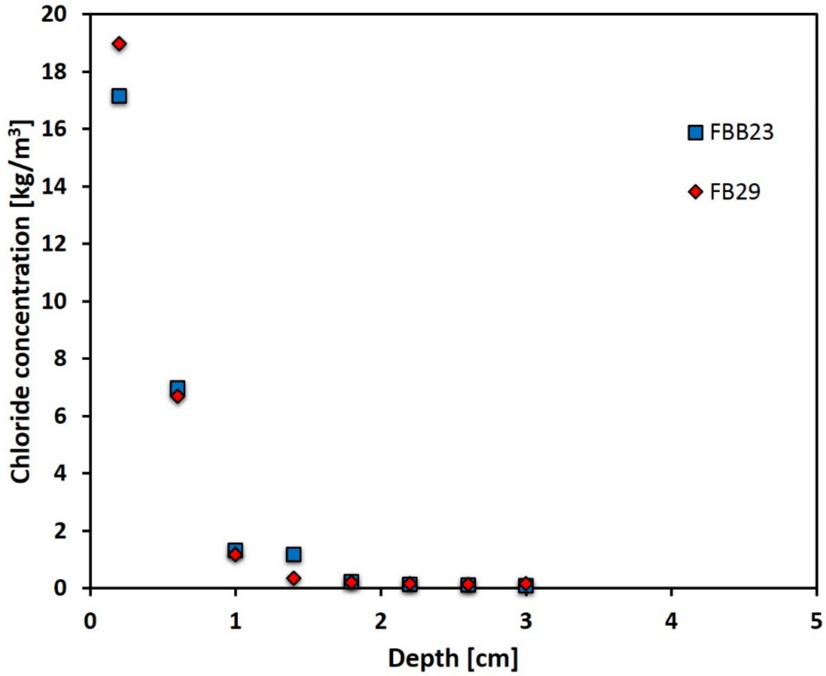


Figure 160. Chloride profile for FBB23 and FB29 specimens with respect to depth.

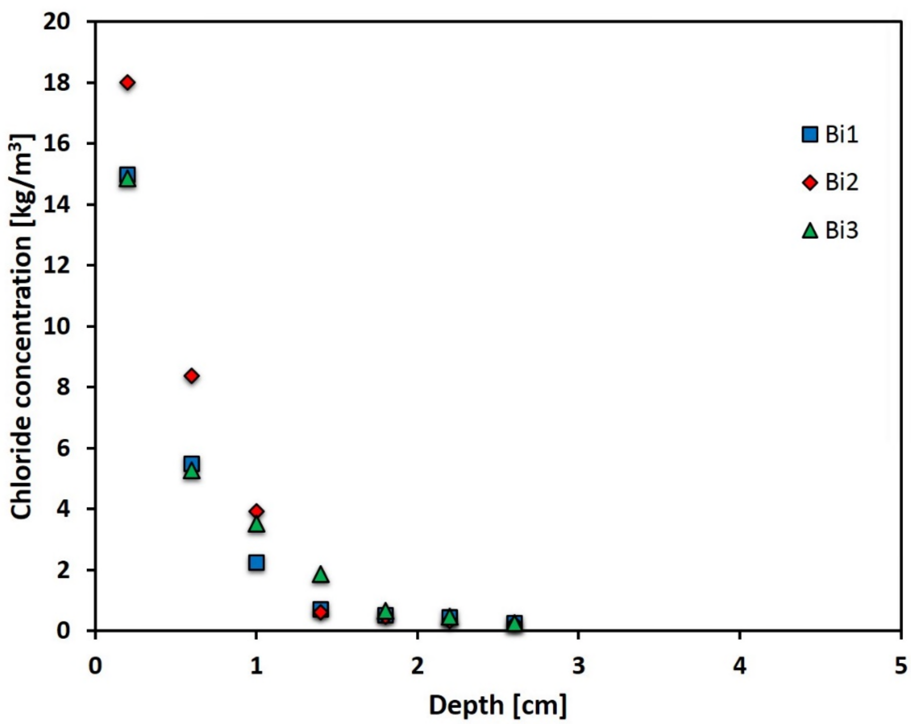


Figure 161. Chloride profile for Bi specimens with respect to depth.

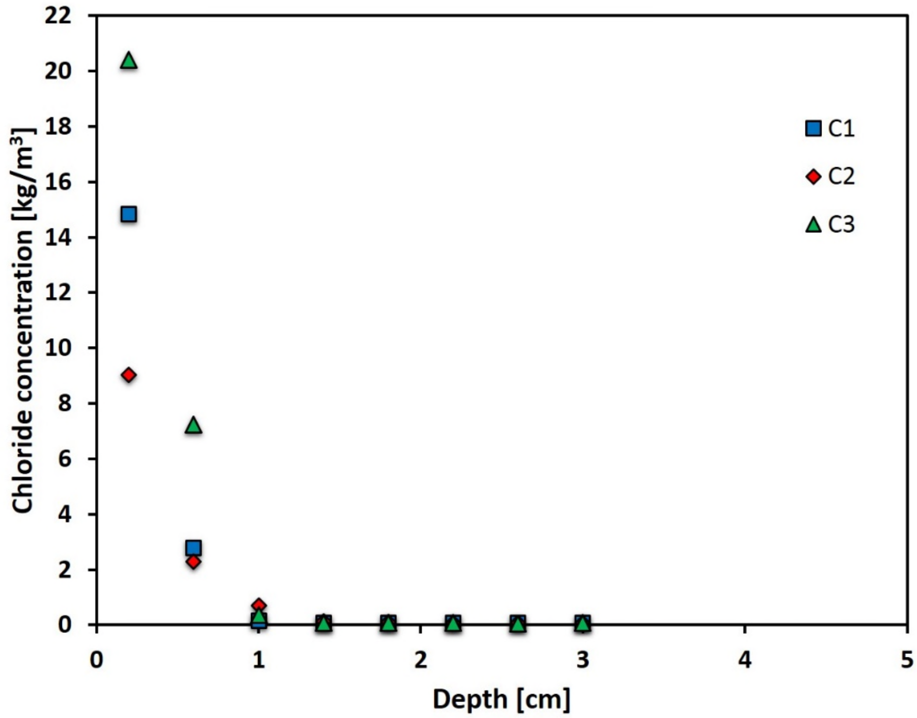


Figure 162. Chloride profile for C specimens with respect to depth.

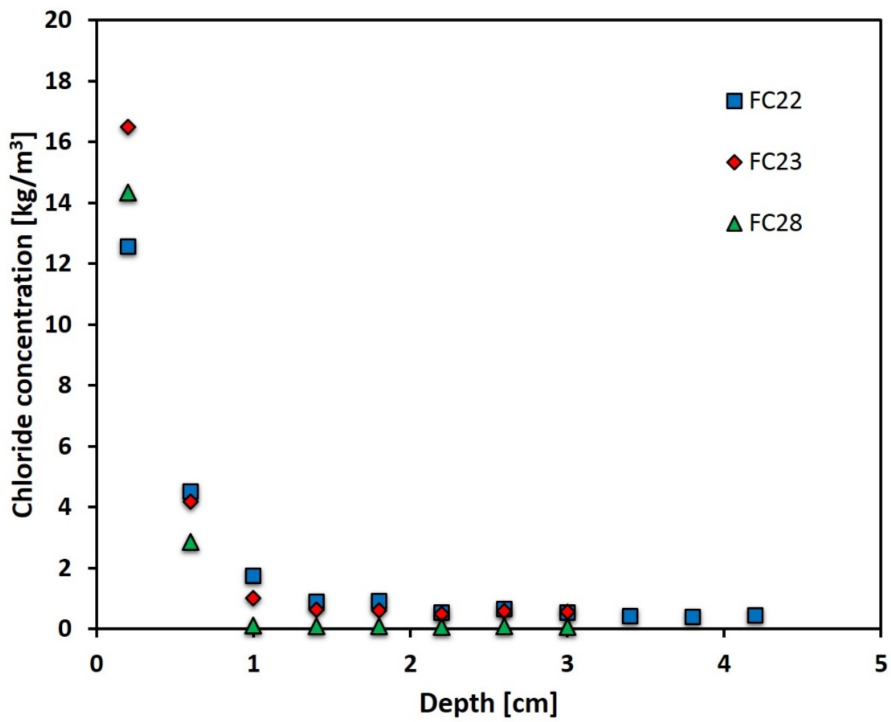


Figure 163. Chloride profile for FC specimens with respect to depth.

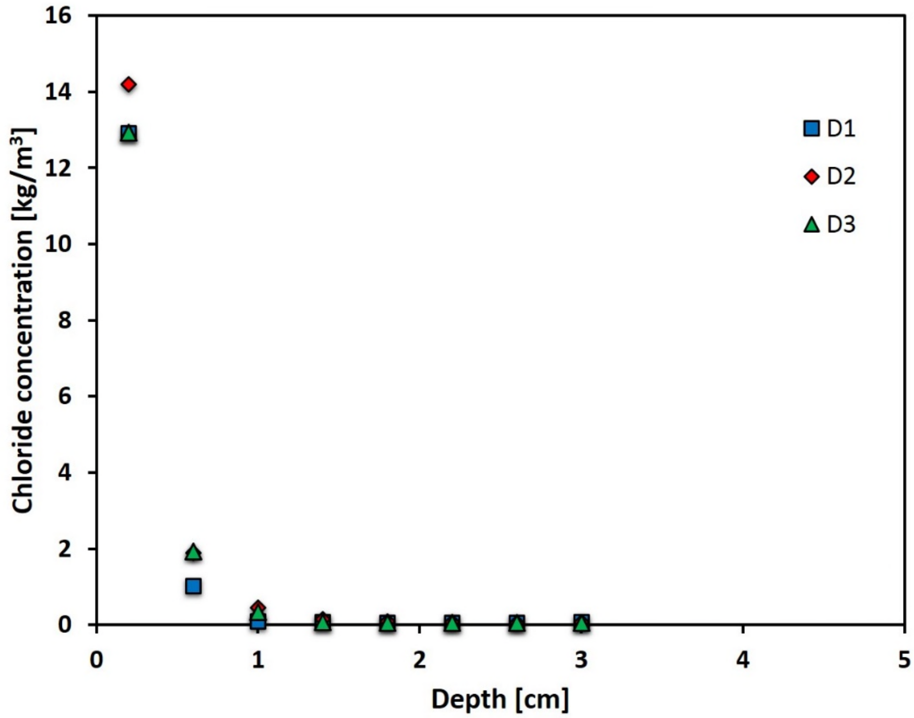


Figure 164. Chloride profile for FB specimens with respect to depth.

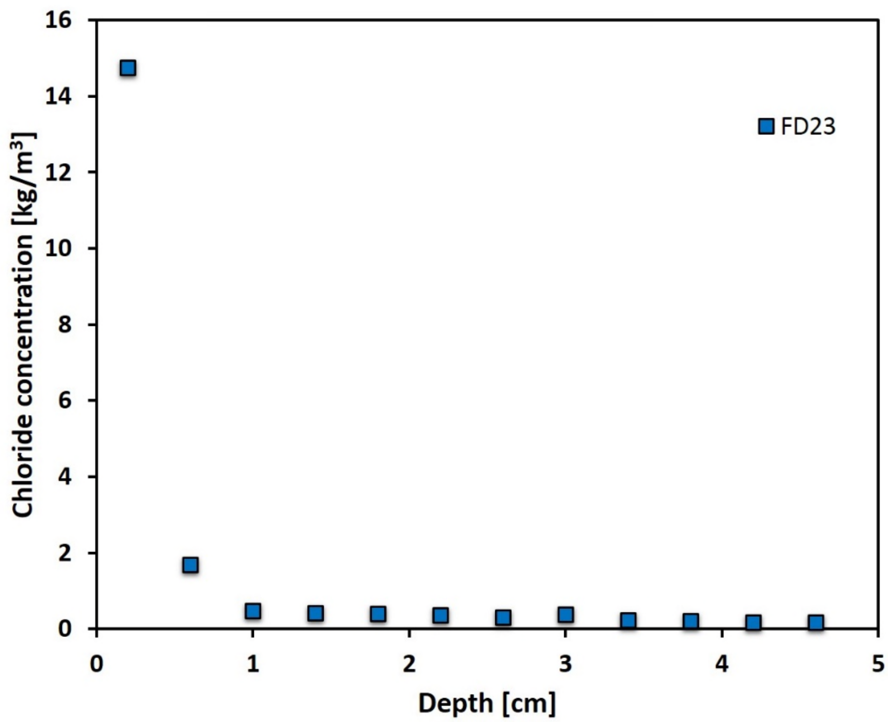


Figure 165. Chloride profile for FB specimens with respect to depth.

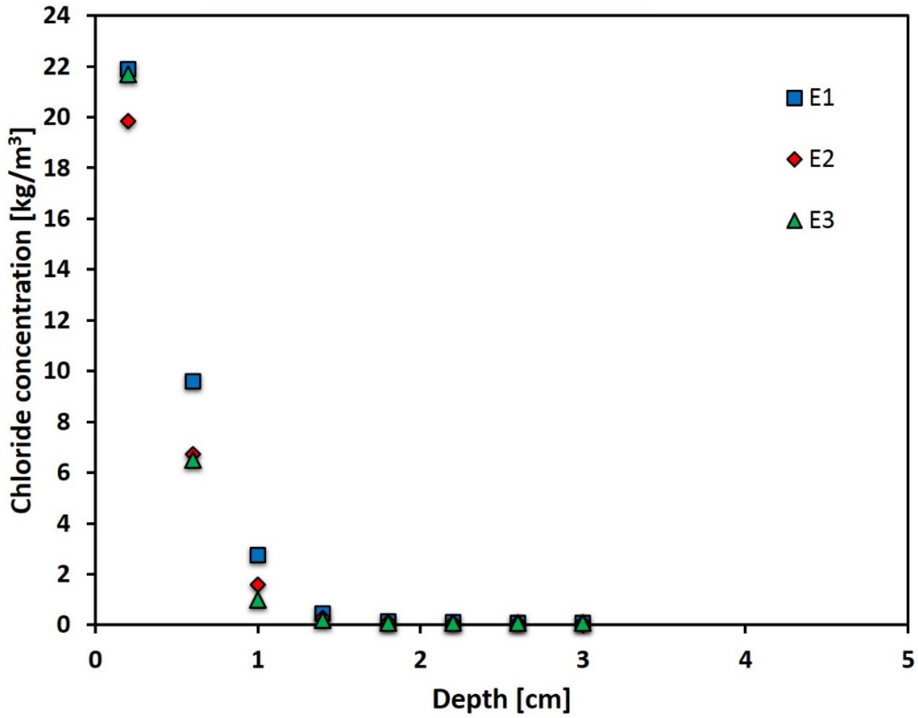


Figure 166. Chloride profile for E specimens with respect to depth.

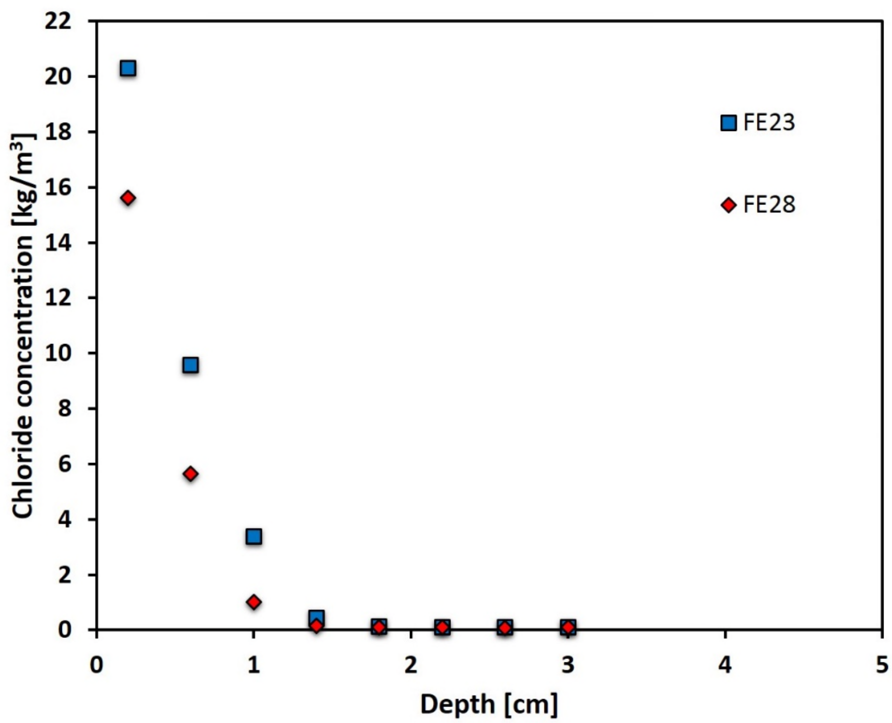


Figure 167. Chloride profile for FE23 and 28 specimens with respect to depth.

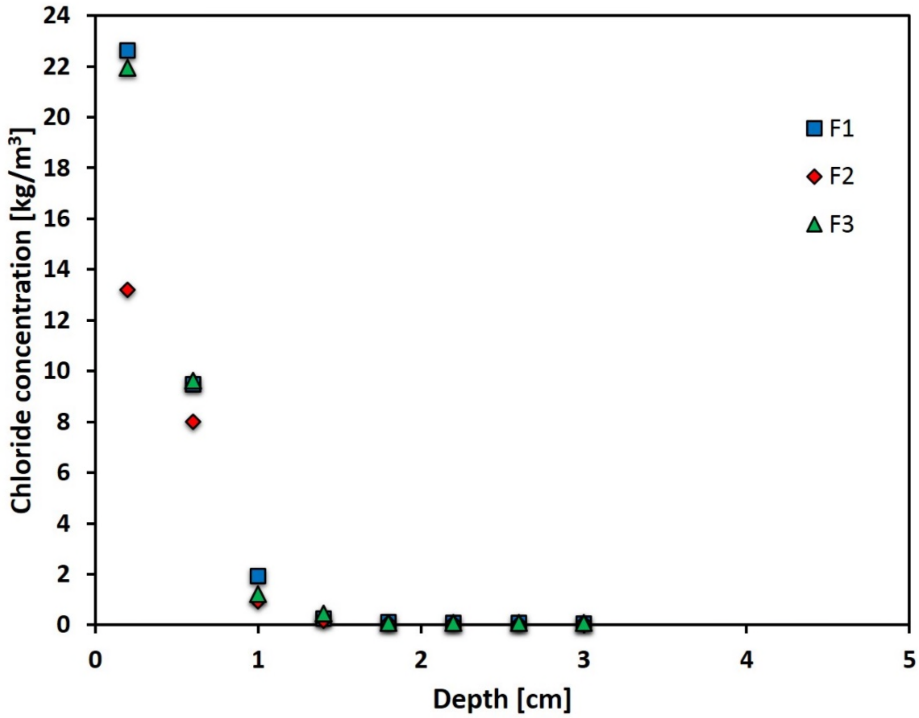


Figure 168. Chloride profile for F specimens with respect to depth.

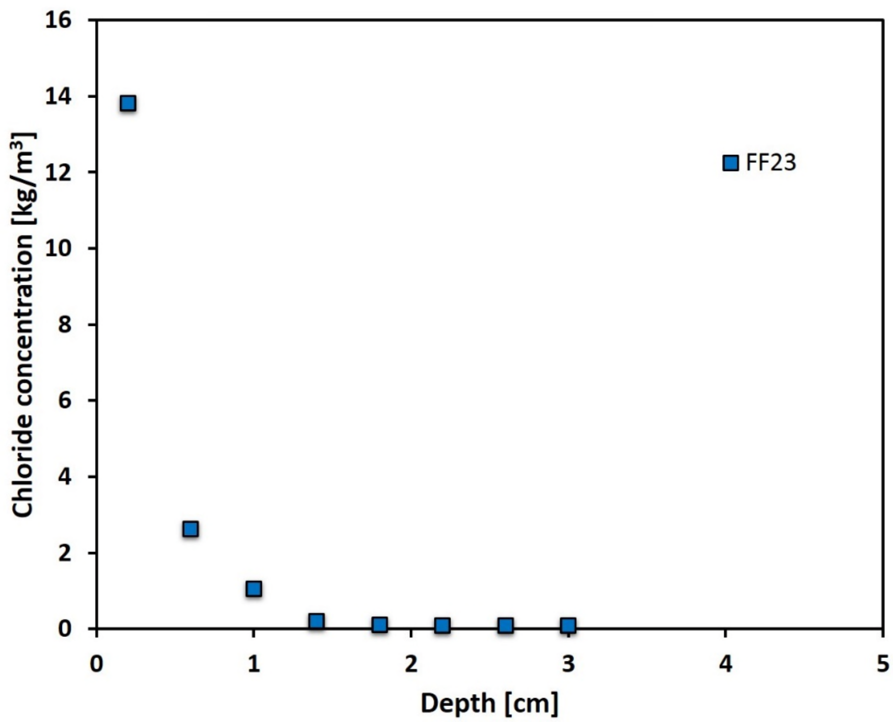


Figure 169. Chloride profile for FF specimens with respect to depth.

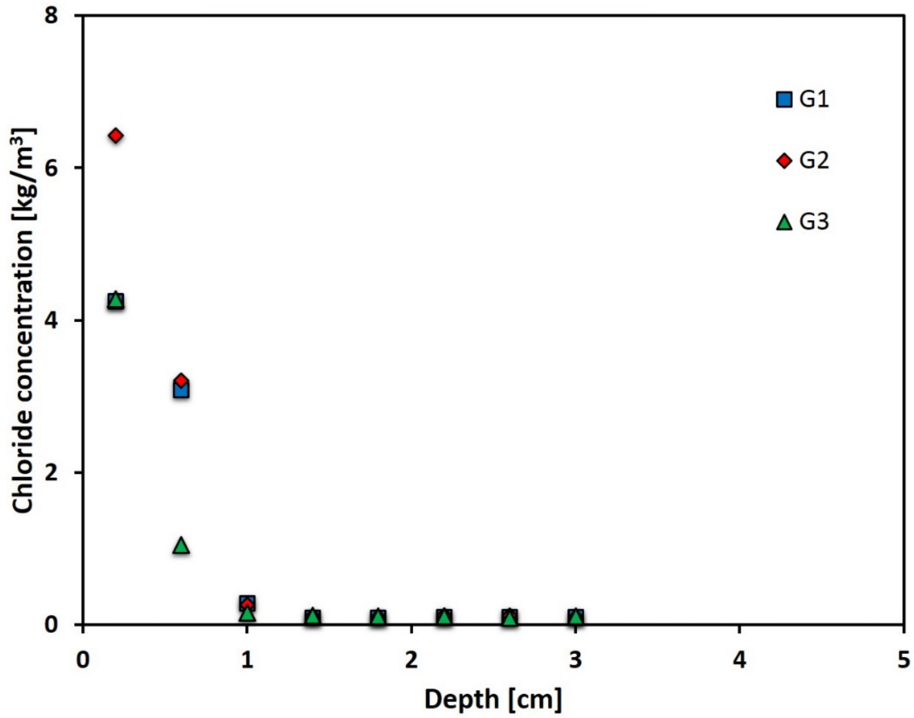


Figure 170. Chloride profile for G specimens with respect to depth.

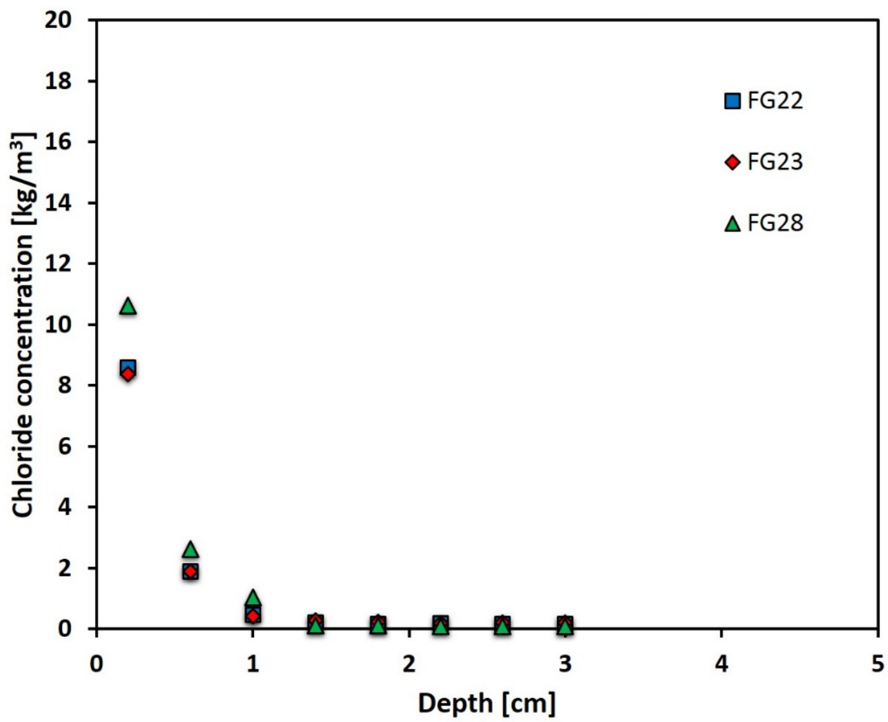


Figure 171. Chloride profile for FG specimens with respect to depth.

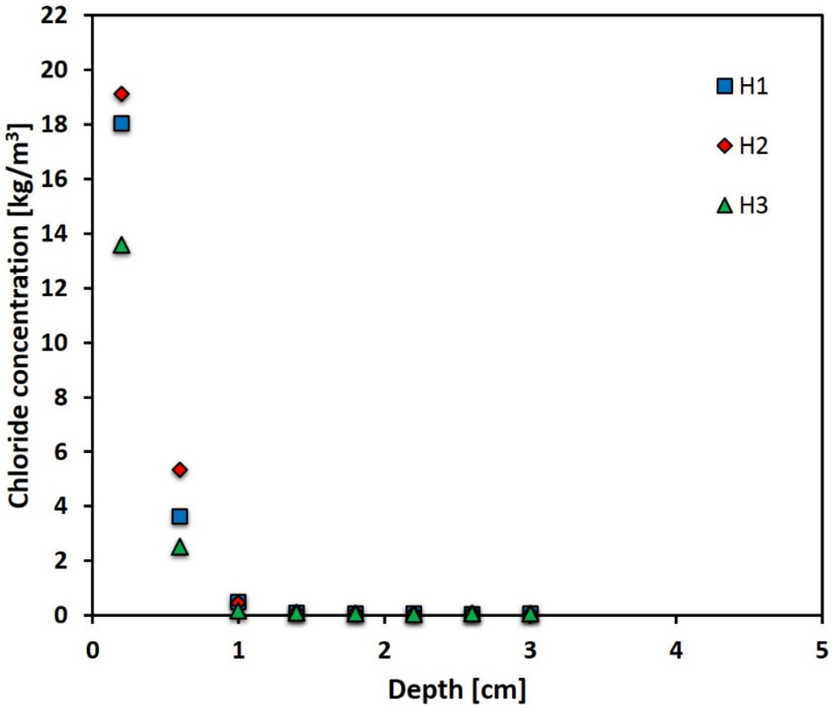


Figure 172. Chloride profile for H specimens with respect to depth.

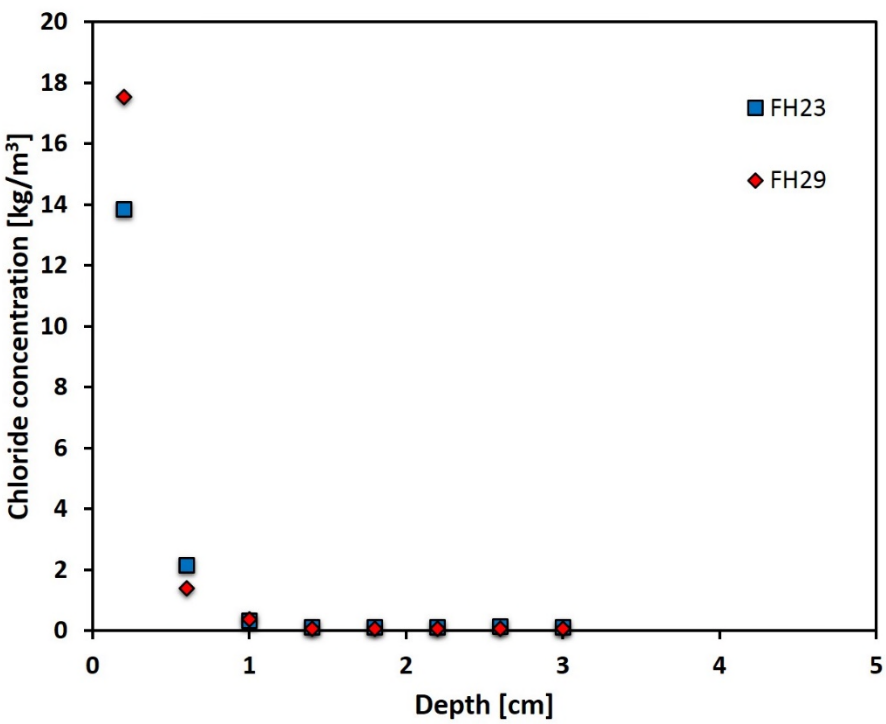


Figure 173. Chloride profile for FH specimens with respect to depth.

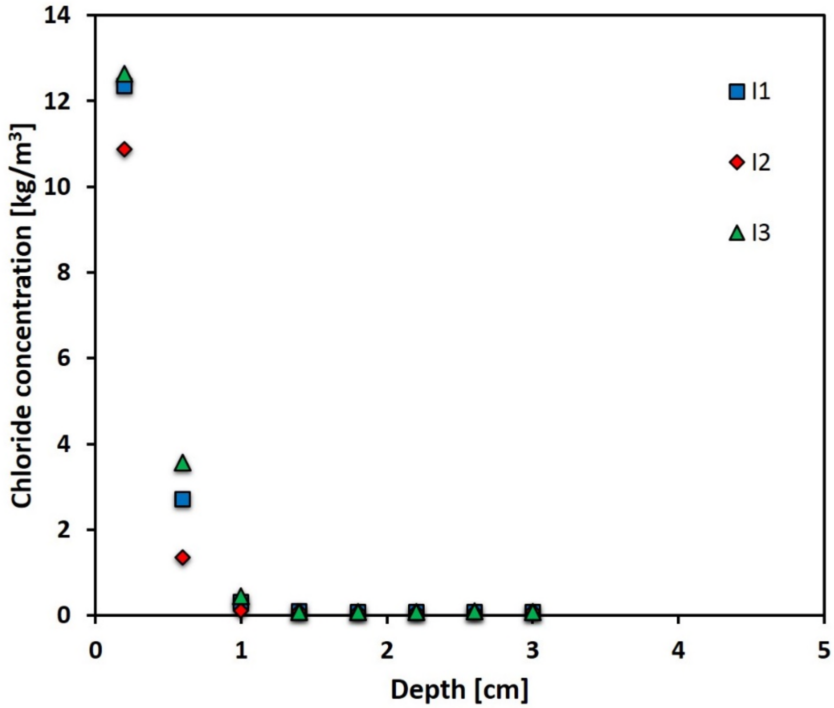


Figure 174. Chloride profile for I1 specimens with respect to depth.

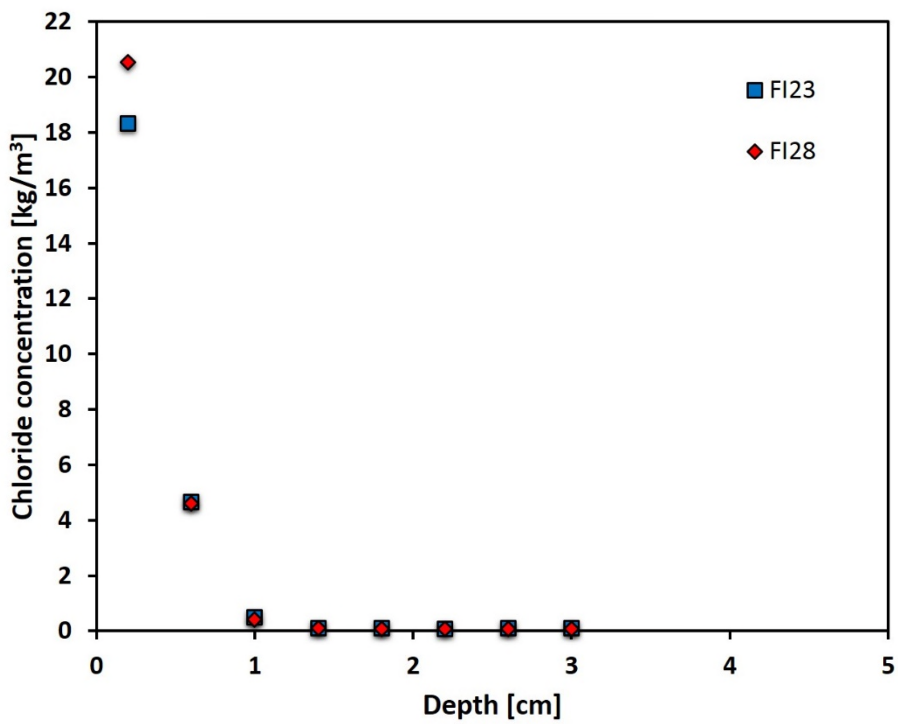


Figure 175. Chloride profile for F123 and 128 specimens with respect to depth.

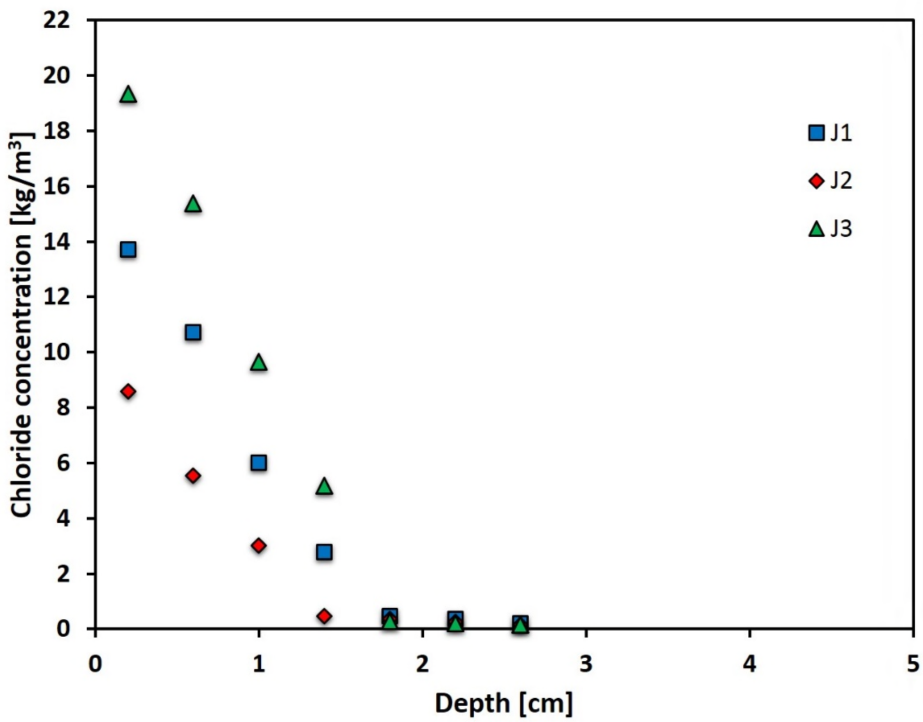


Figure 176. Chloride profile for J specimens with respect to depth.

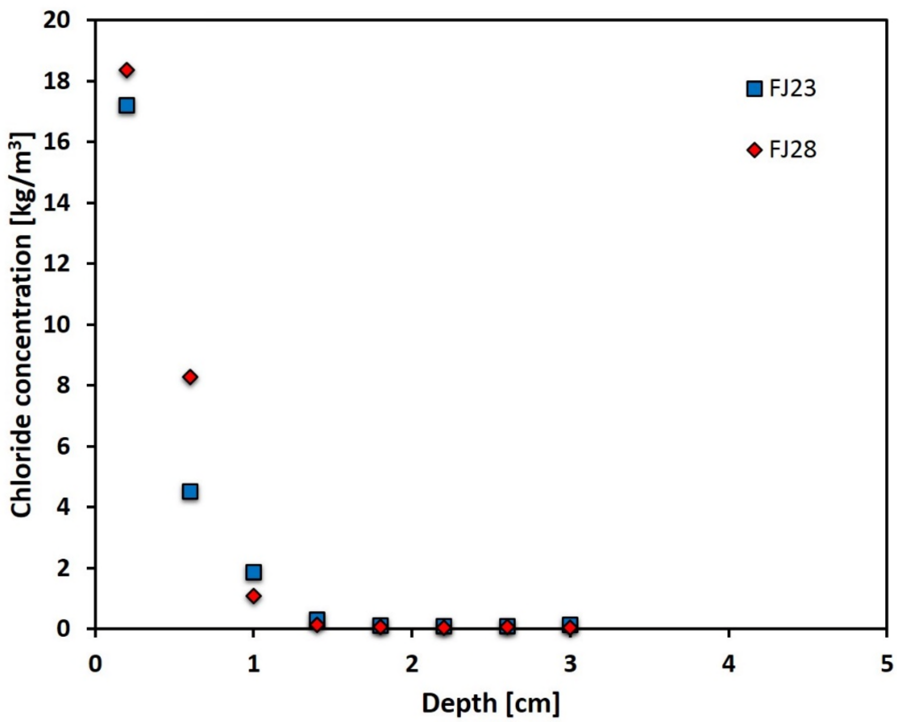


Figure 177. Chloride profile for FJ 23 and 28 specimens with respect to depth.

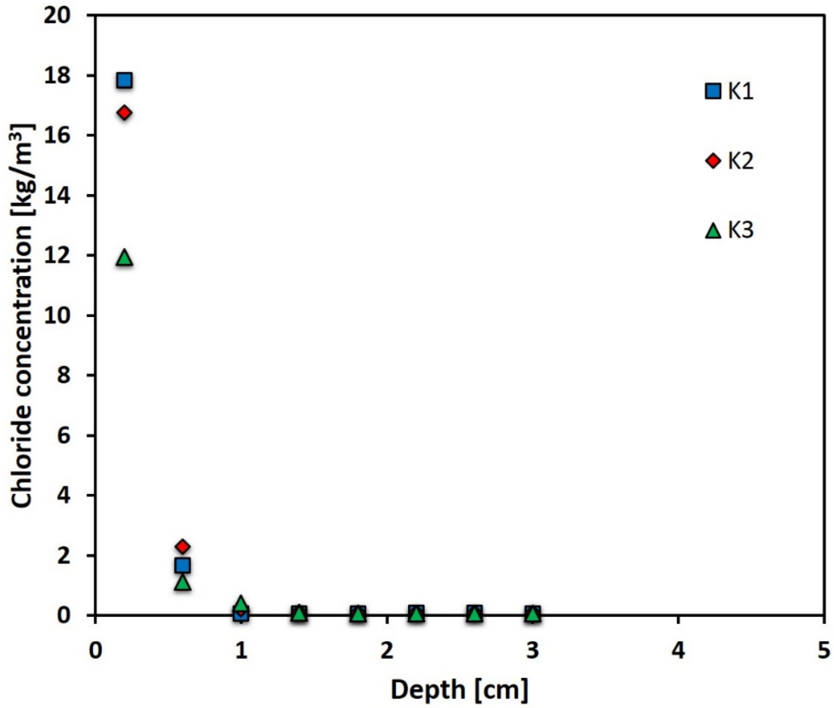


Figure 178. Chloride profile for K specimens with respect to depth.

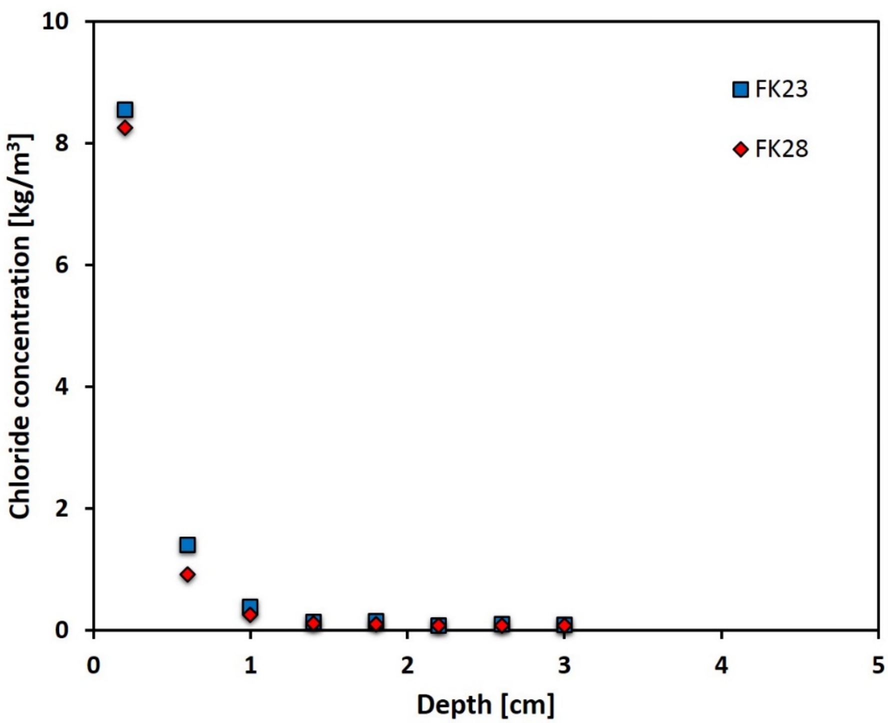


Figure 179. Chloride profile for FK specimens with respect to depth.

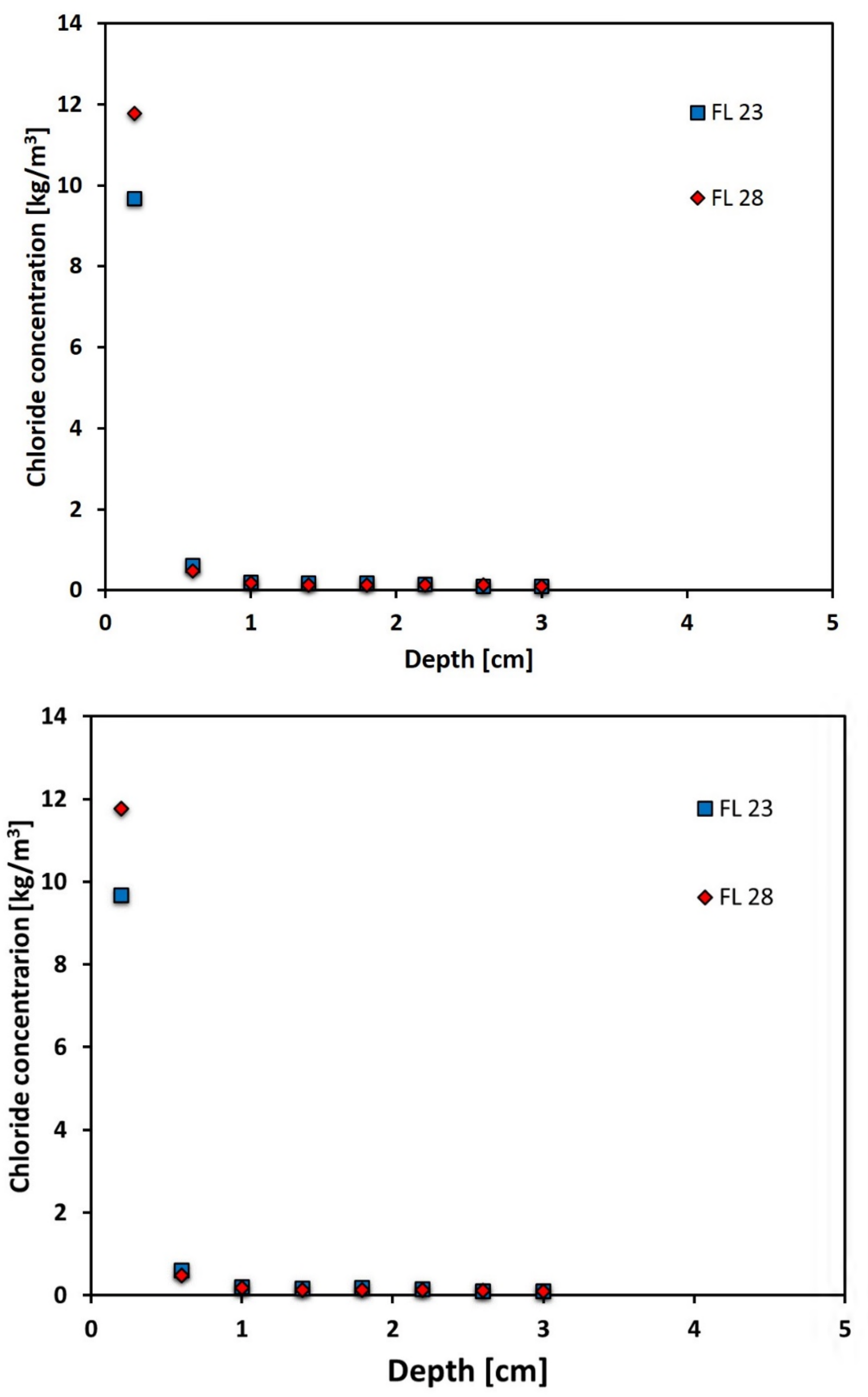


Figure 180. Chloride profile for FL specimens with respect to depth.

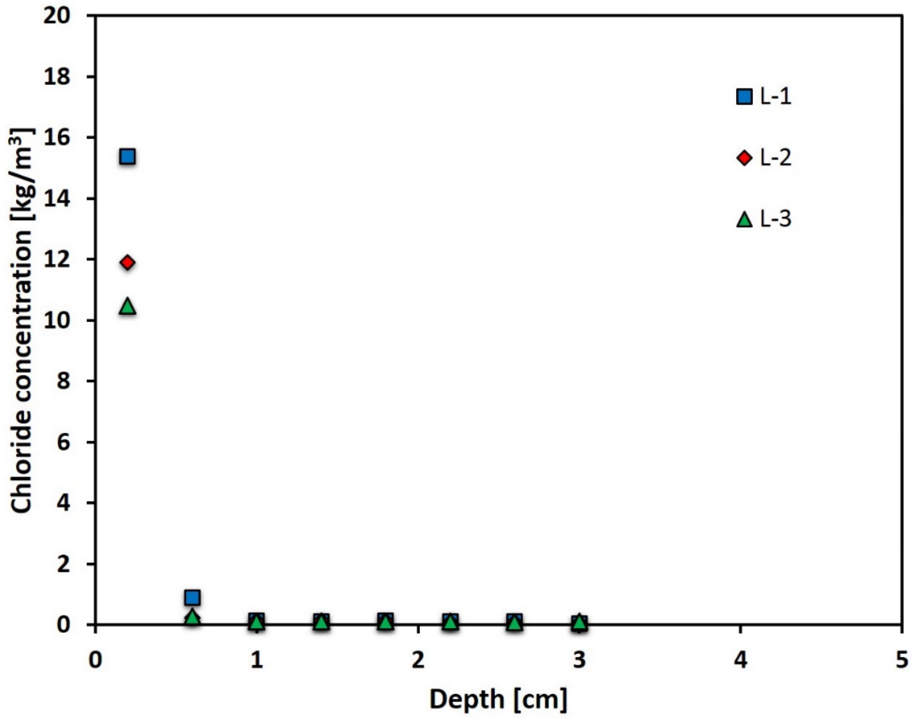


Figure 181. Chloride profile for L specimens with respect to depth.

Appendix M – Chloride Profiles Field Simulation Elevation A, B, C and D

M.1 Tidal simulation chloride profiles

M.1.1 Tidal: Elevation A

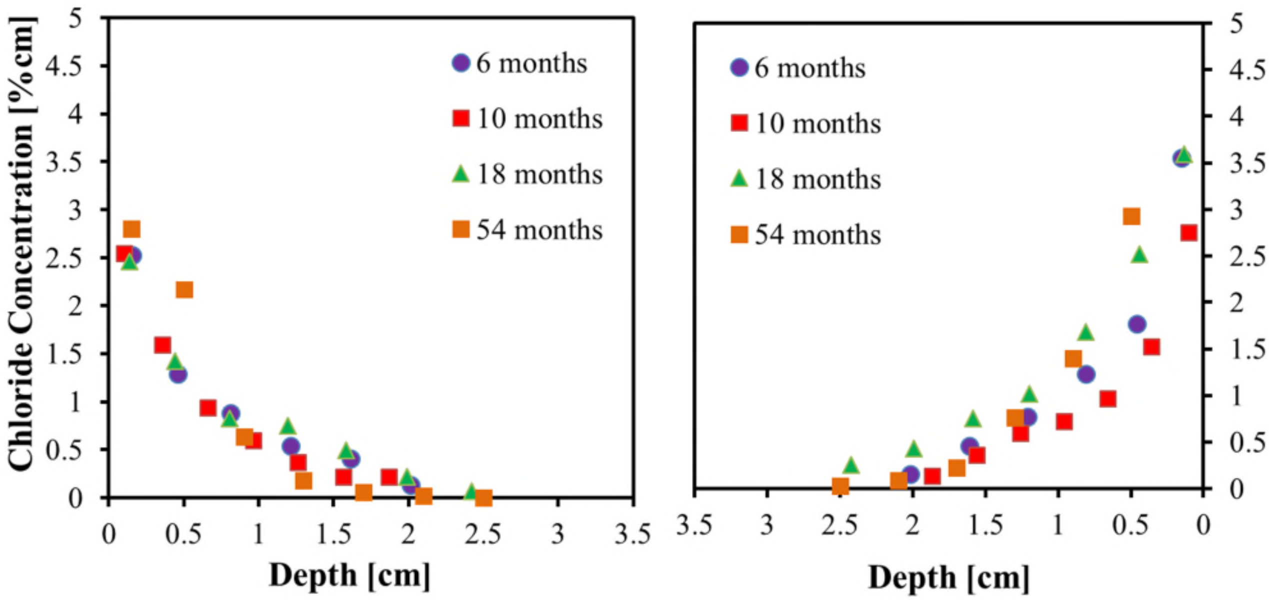


Figure 182. Chloride profile for tidal DCL1 at elevation A

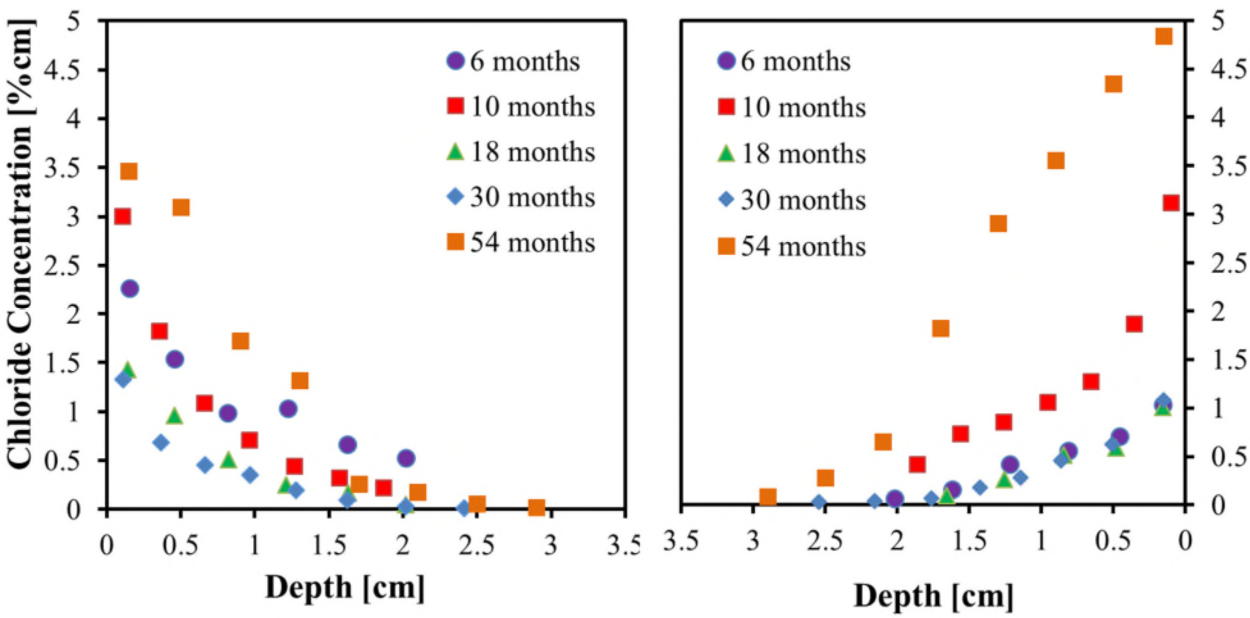


Figure 183. Chloride profile for tidal DCL2 at elevation A.

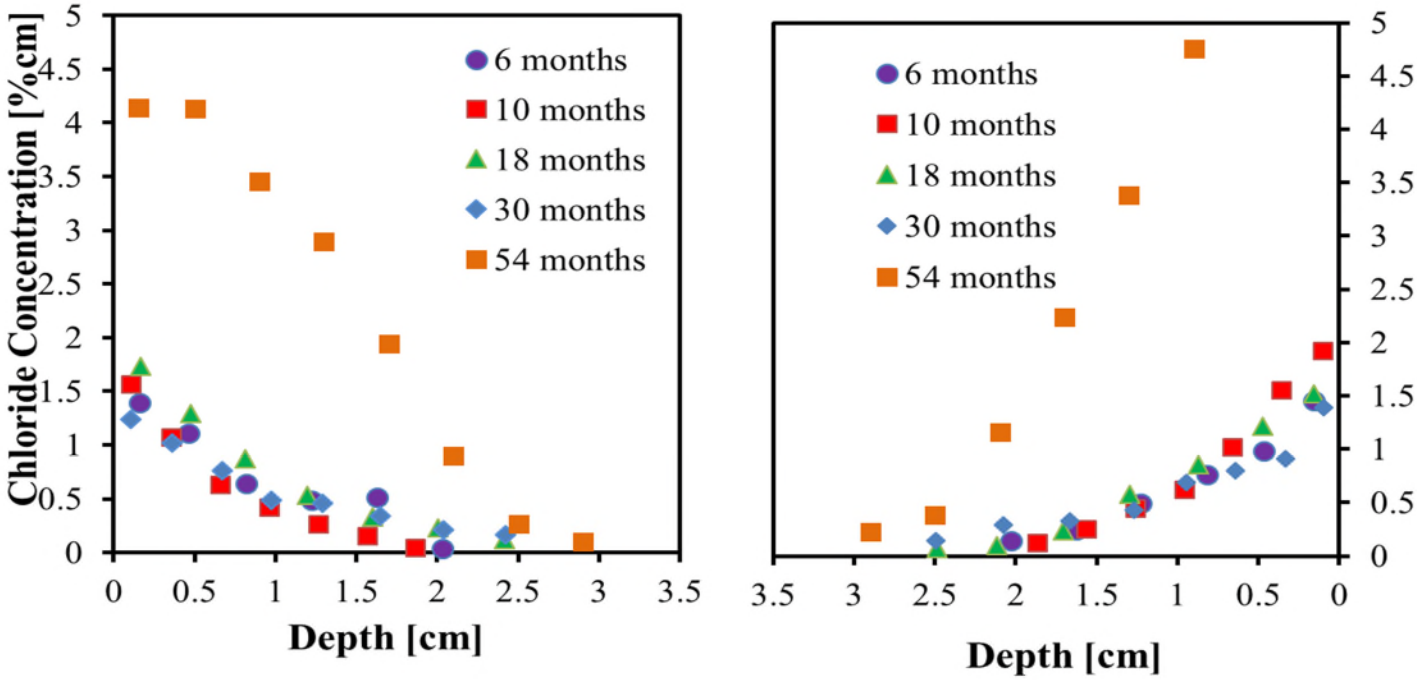


Figure 184. Chloride profile for tidal DCL3 at elevation A

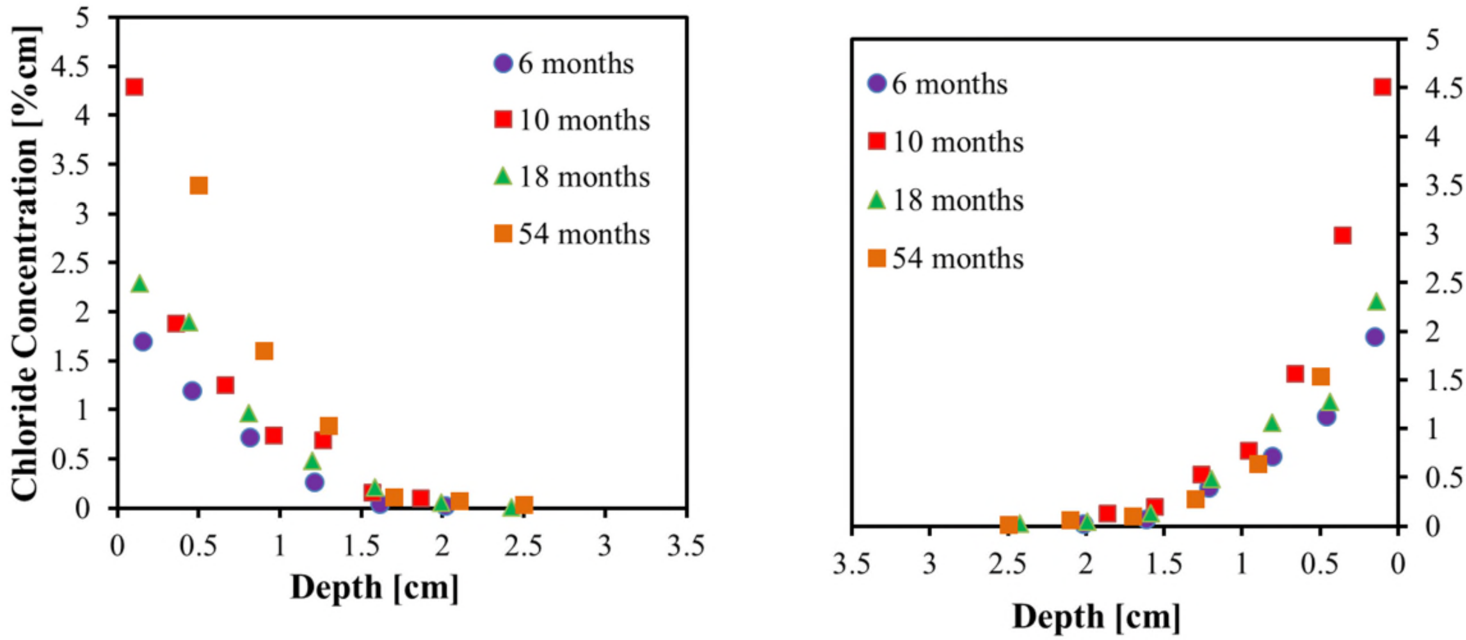


Figure 185. Chloride profile for tidal DCL4 at elevation A

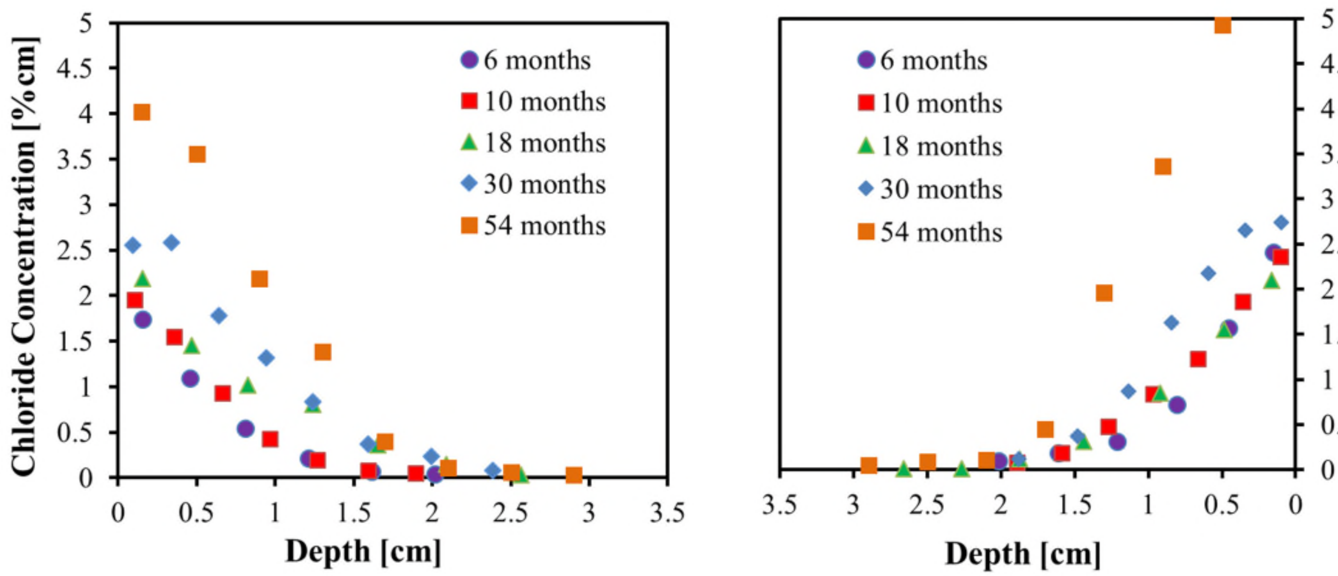


Figure 186. Chloride profile for tidal DCL5 at elevation A

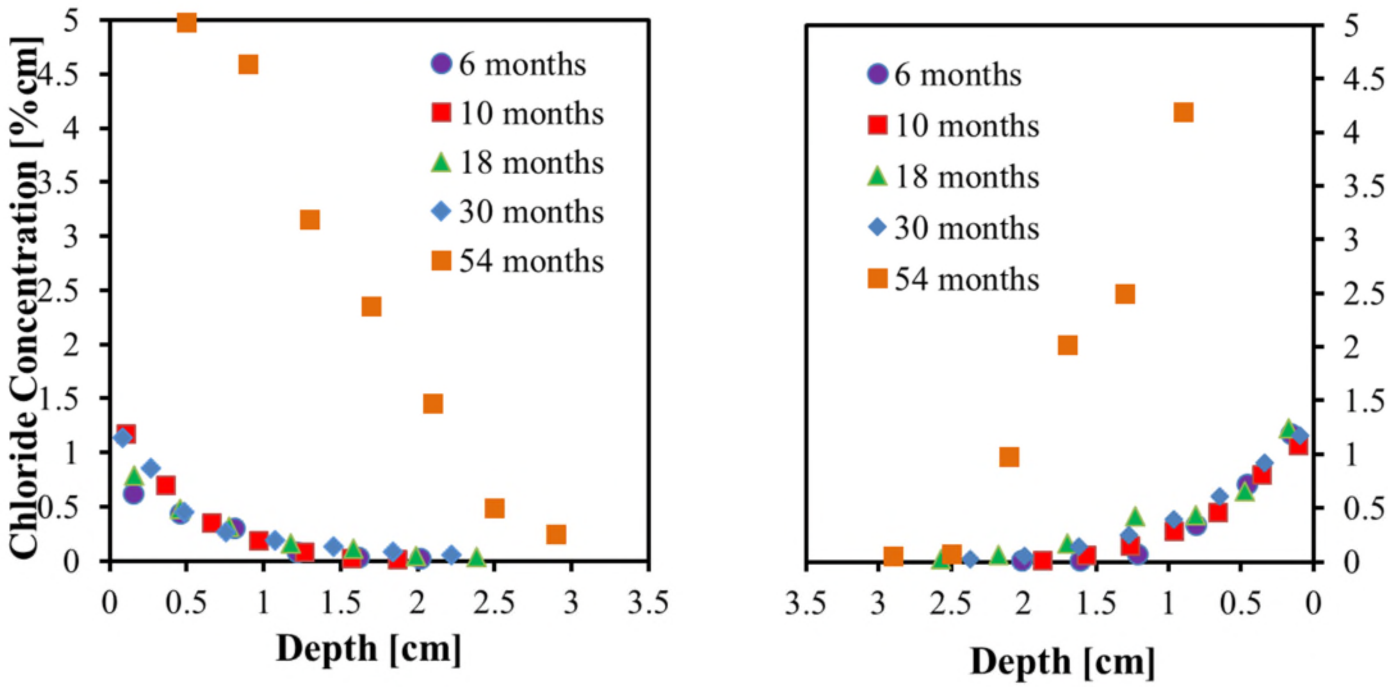


Figure 187. Chloride profile for tidal DCL6 at elevation A

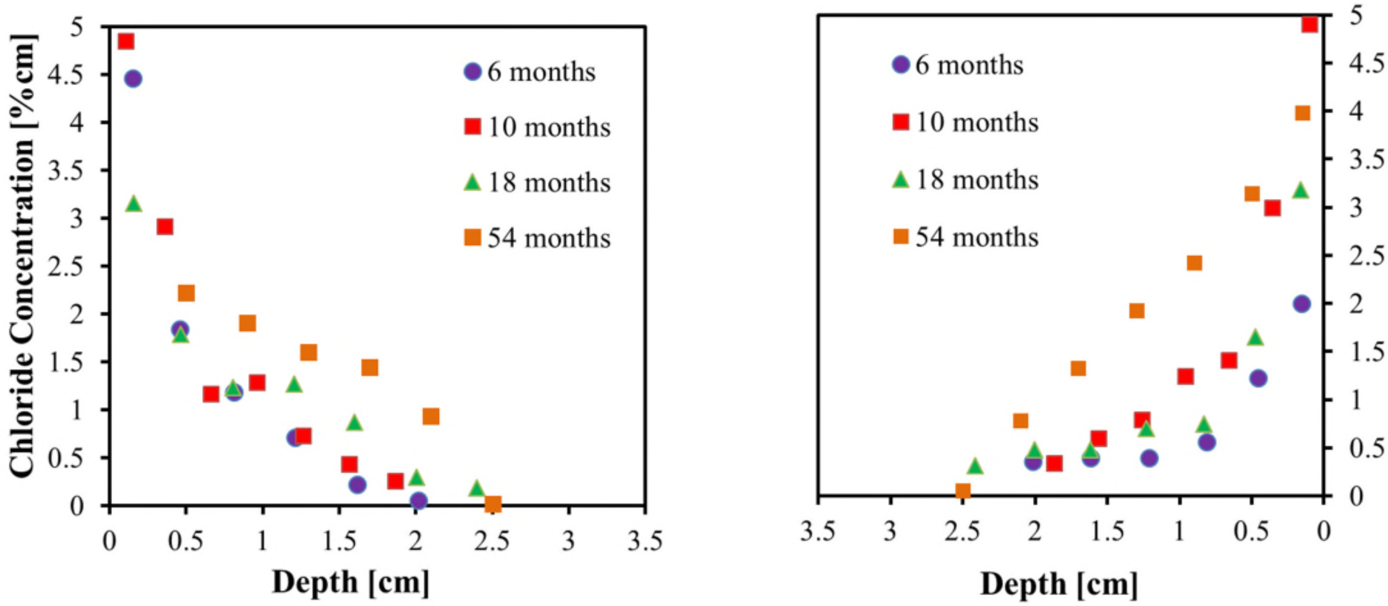


Figure 188. Chloride profile for tidal DCL7 at elevation A

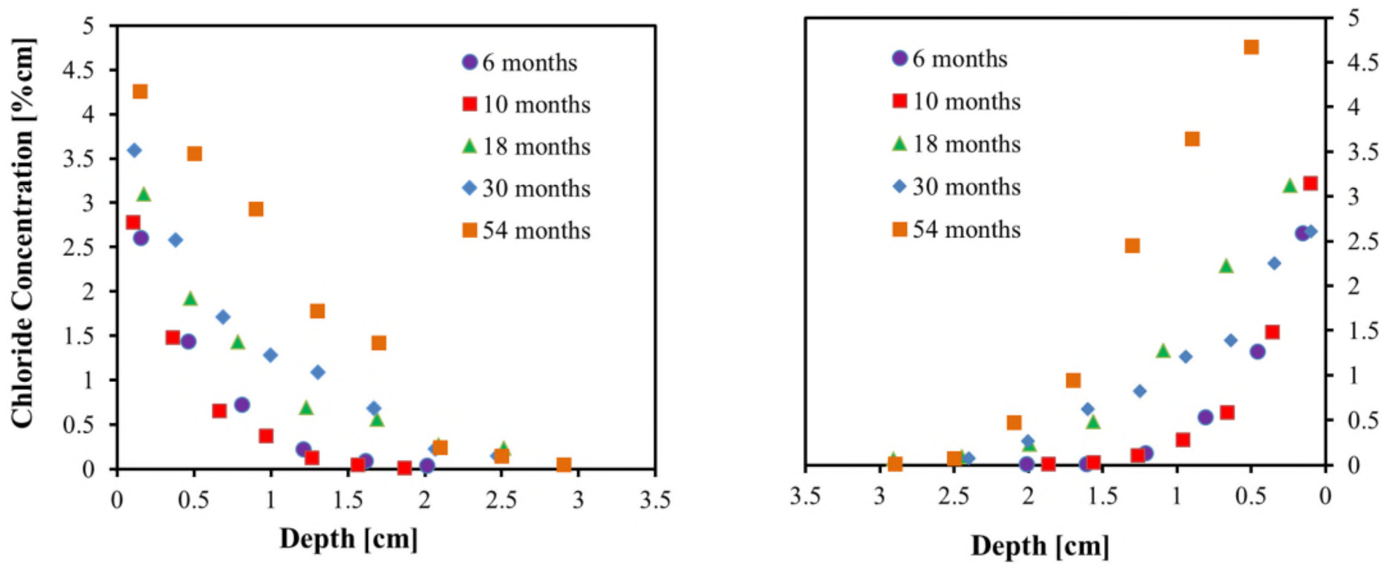


Figure 189. Chloride profile for tidal DCL8 at elevation A

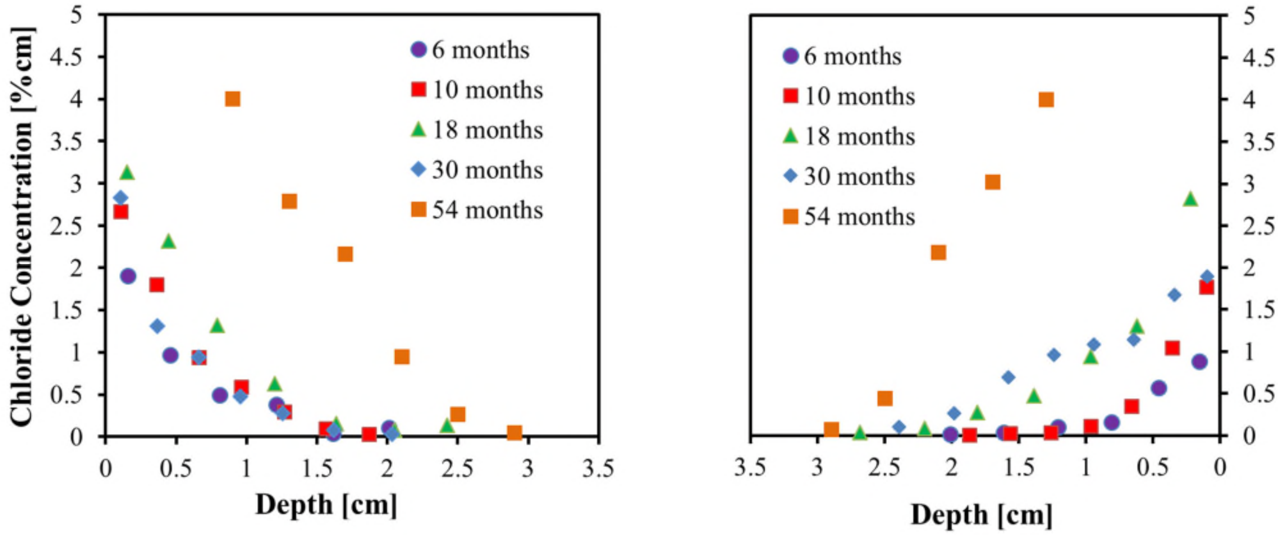


Figure 190. Chloride profile for tidal DCL9 at elevation A

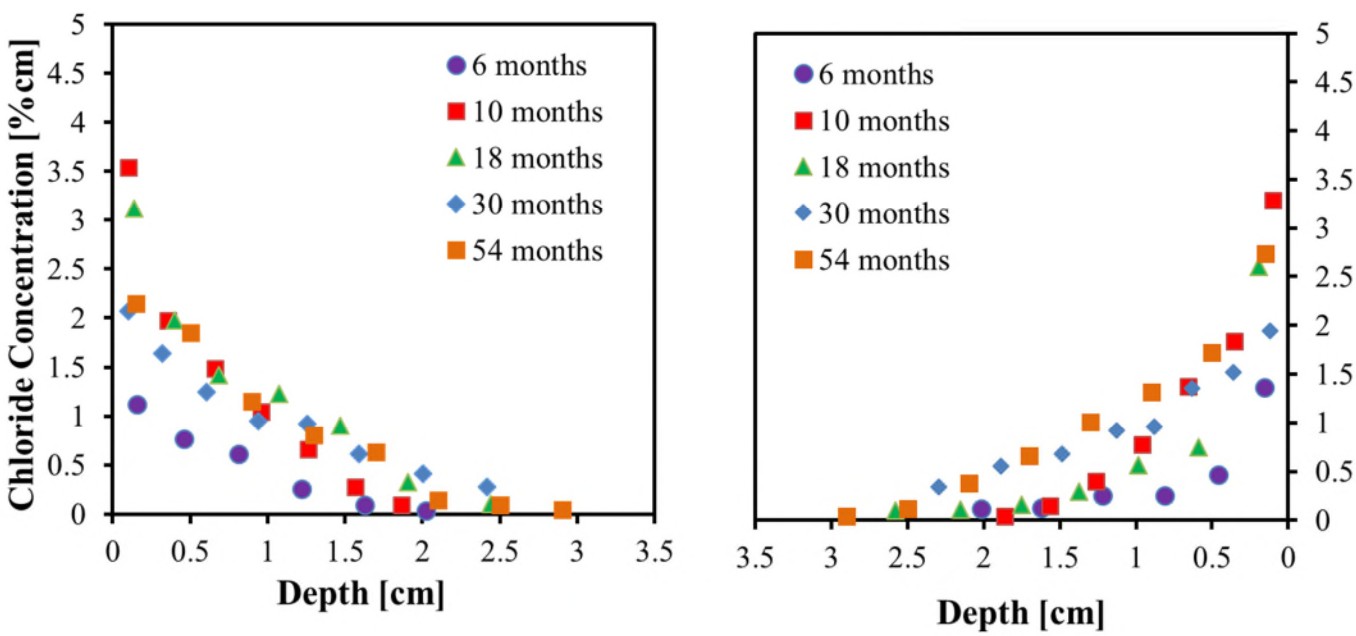


Figure 191. Chloride profile for tidal DCL10a at elevation A

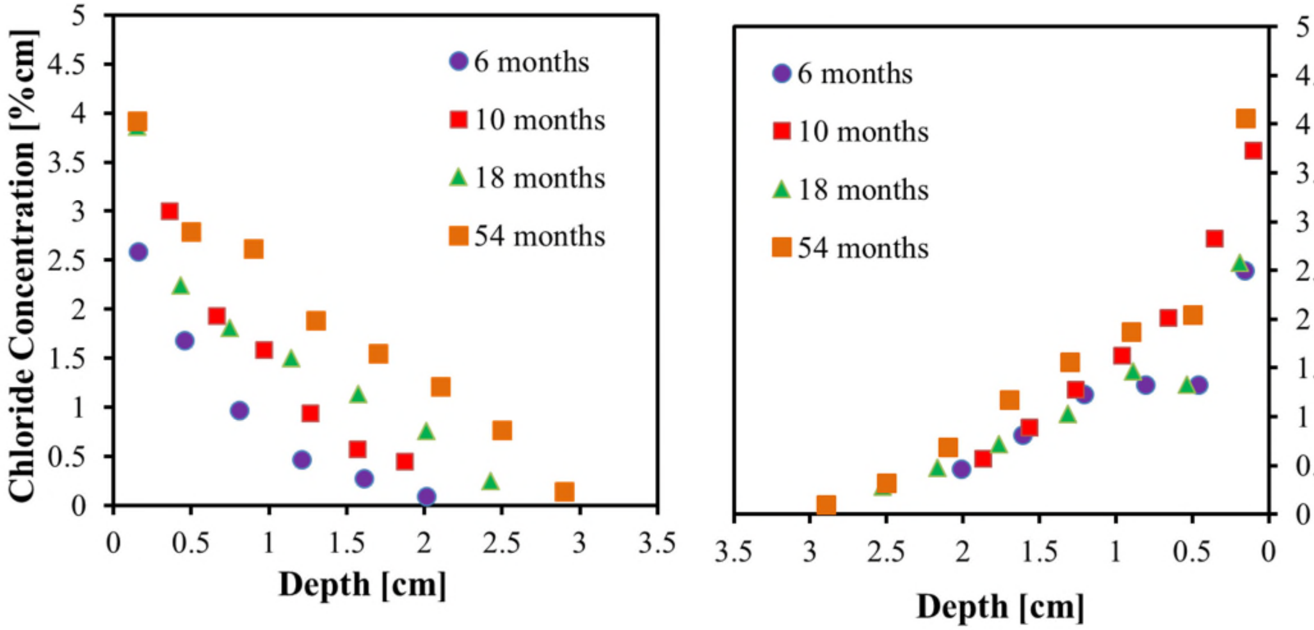


Figure 192. Chloride profile for tidal DCL10b at elevation A

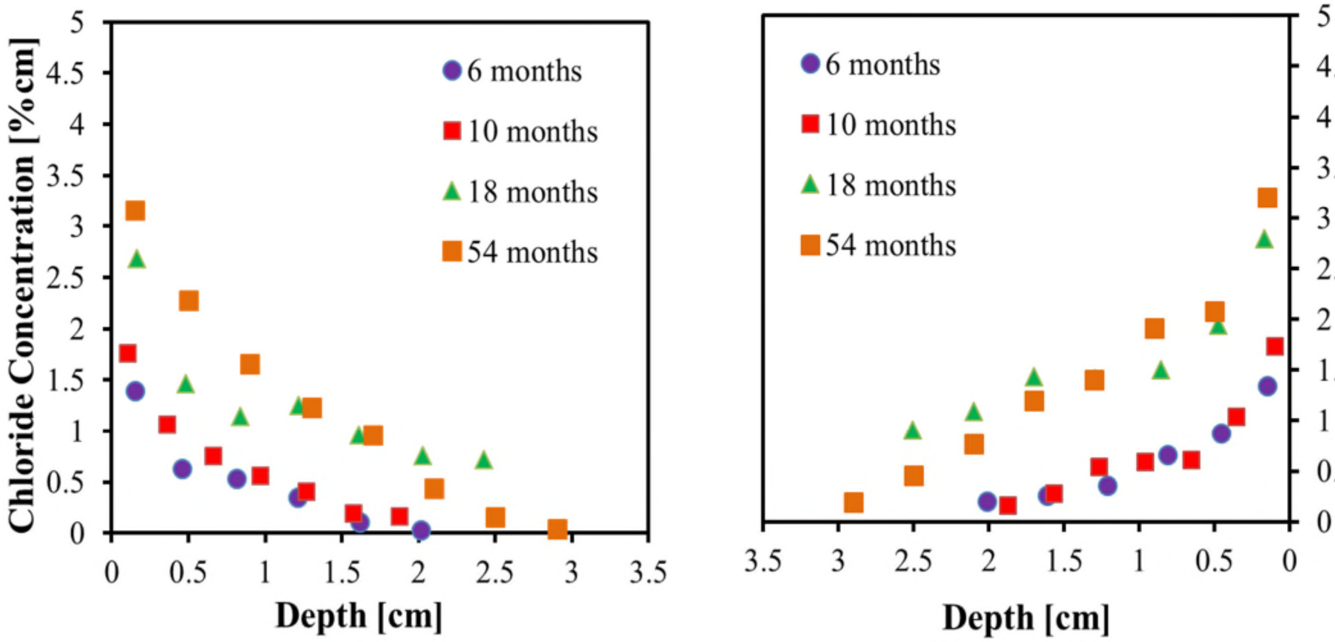
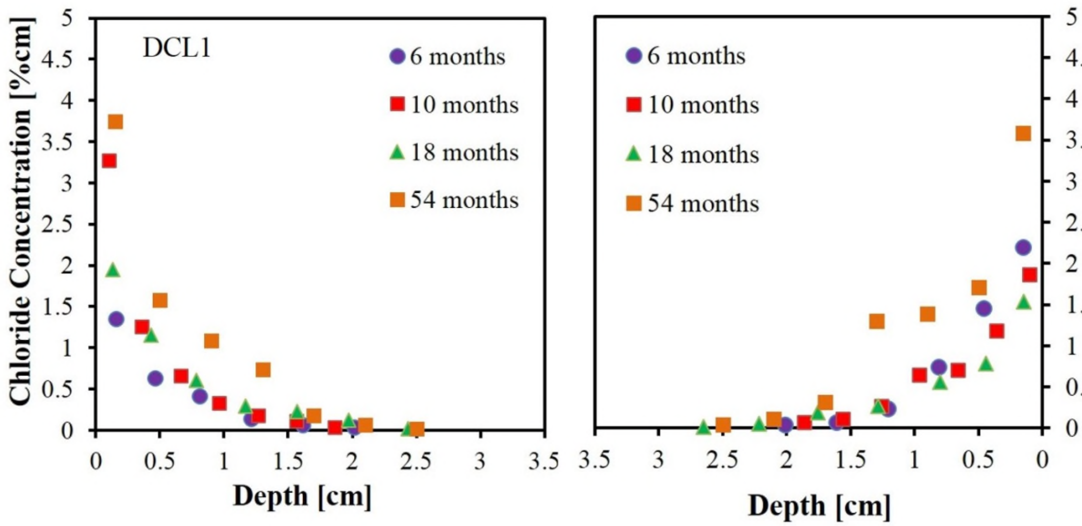
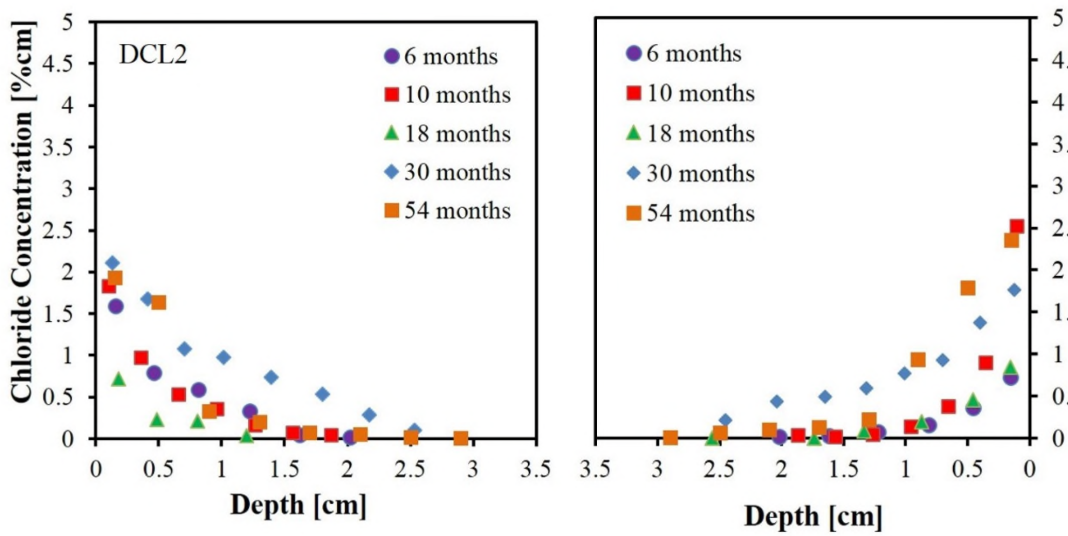
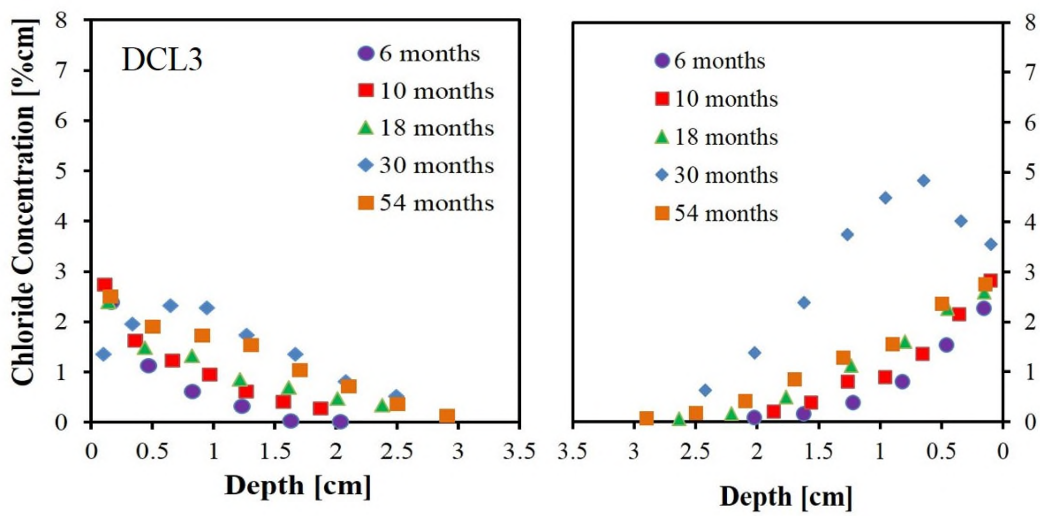


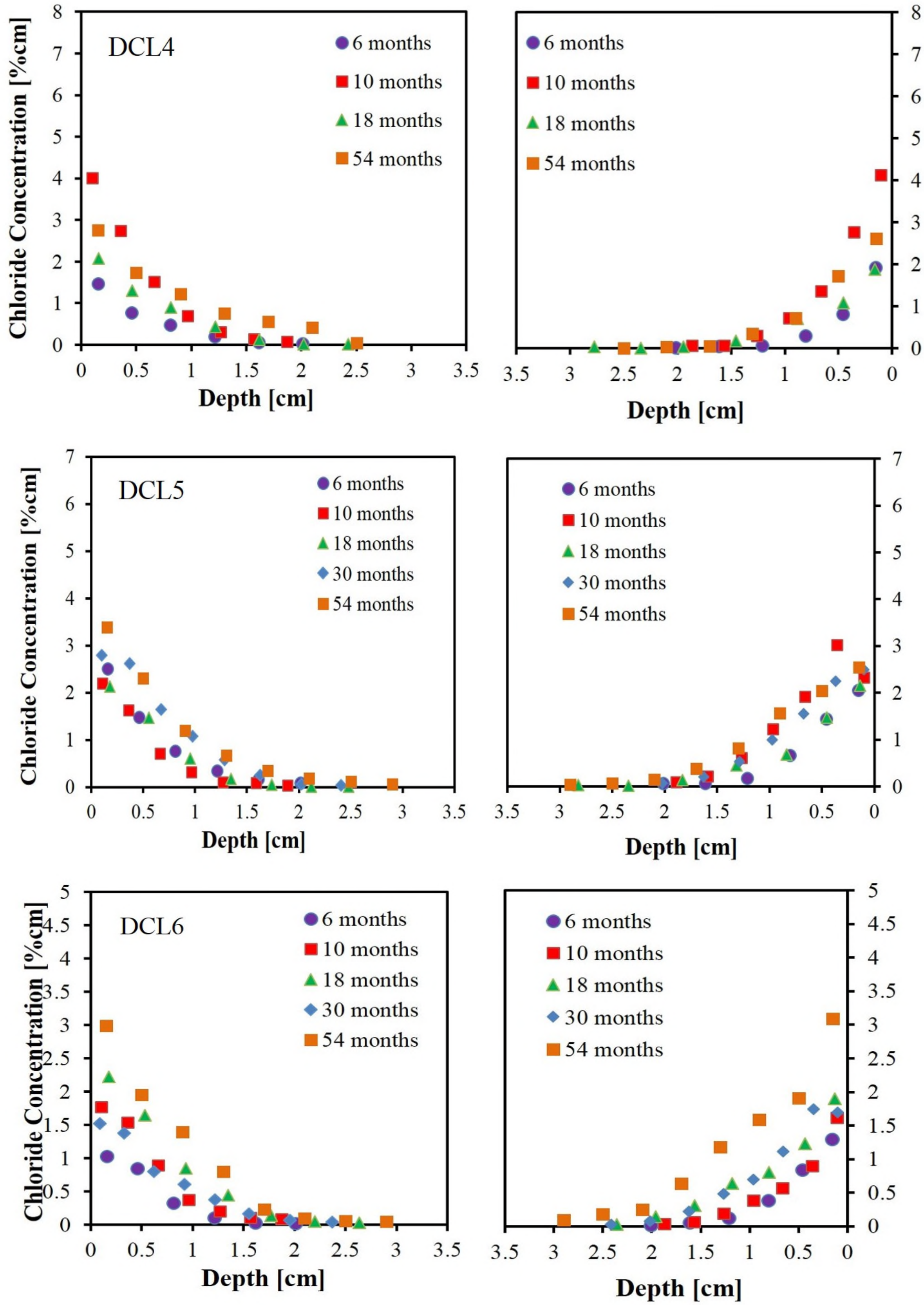
Figure 193. Chloride profile for tidal DCL11 at elevation A

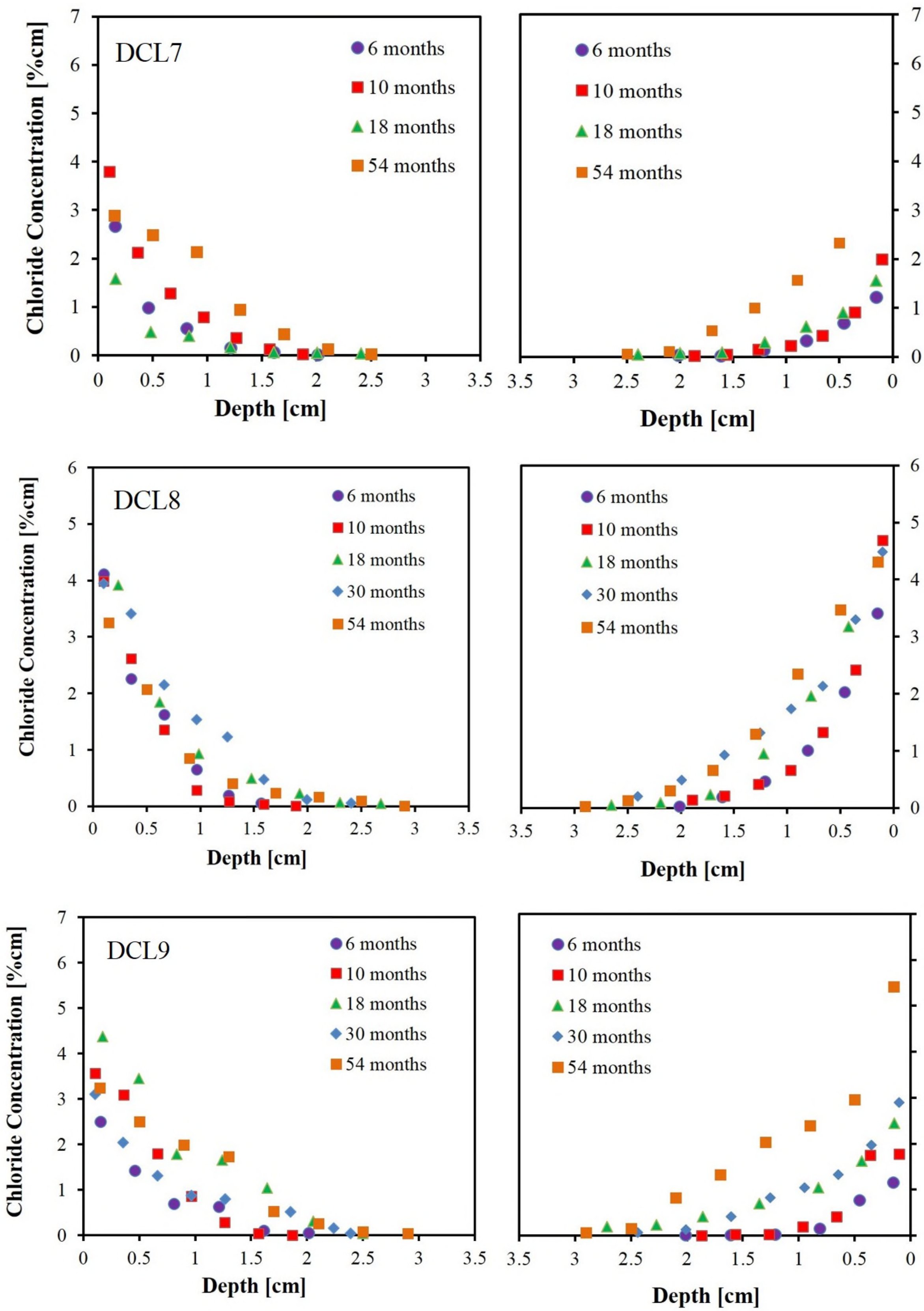
M.1.2 Tidal: Elevation B








DCL4
DCL5
DCL6
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]


DCL7
6 months
10 months
18 months
54 months
Chloride Concentration [%cm]
Depth [cm]
DCL8
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]
DCL9
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]

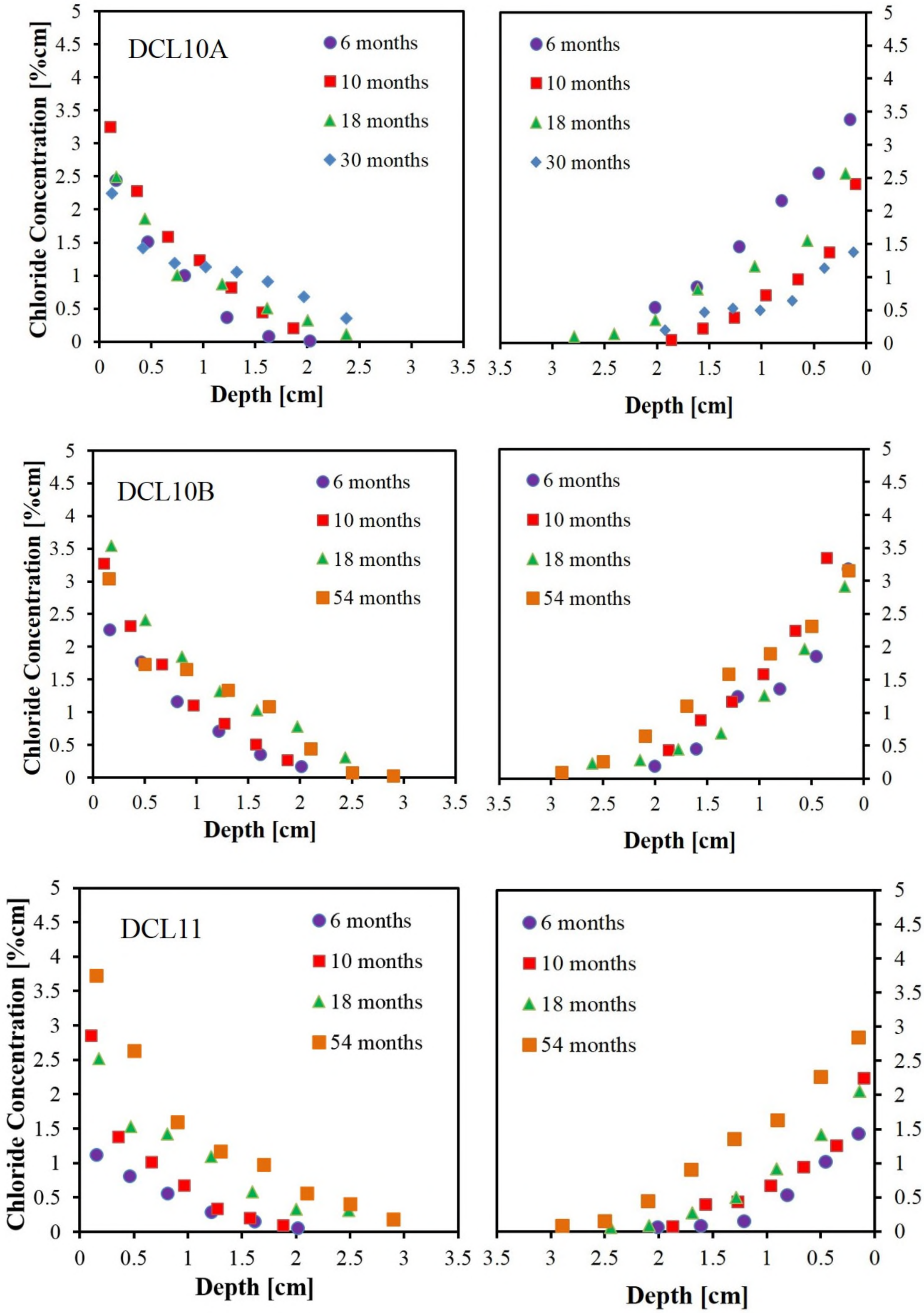
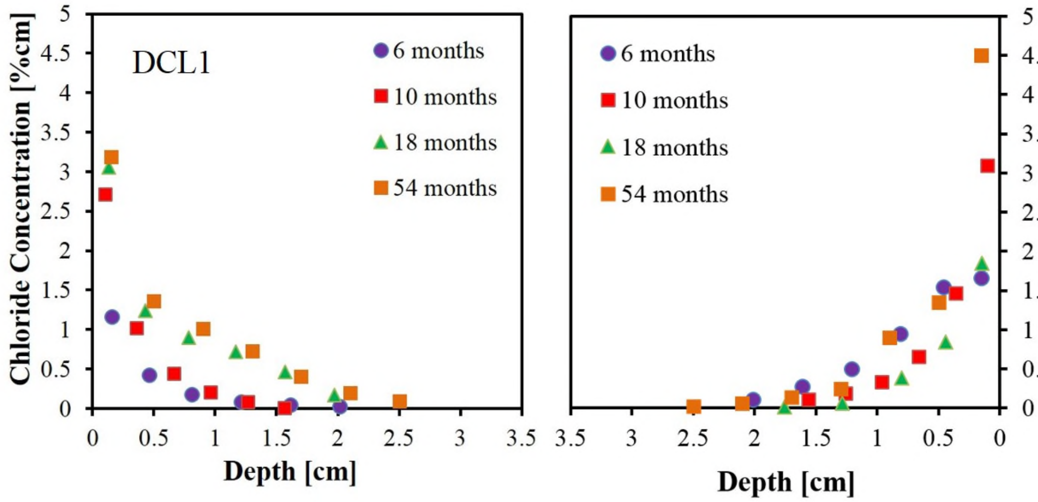
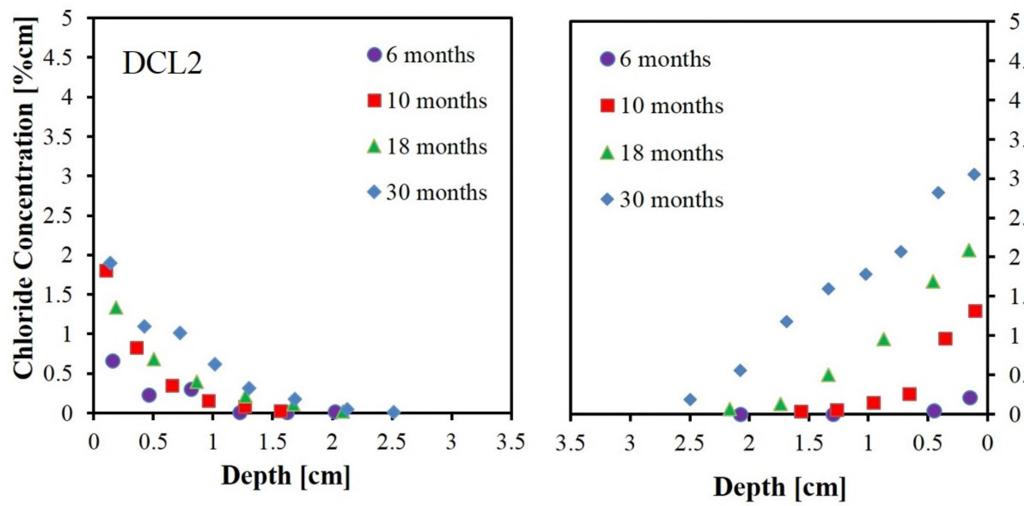
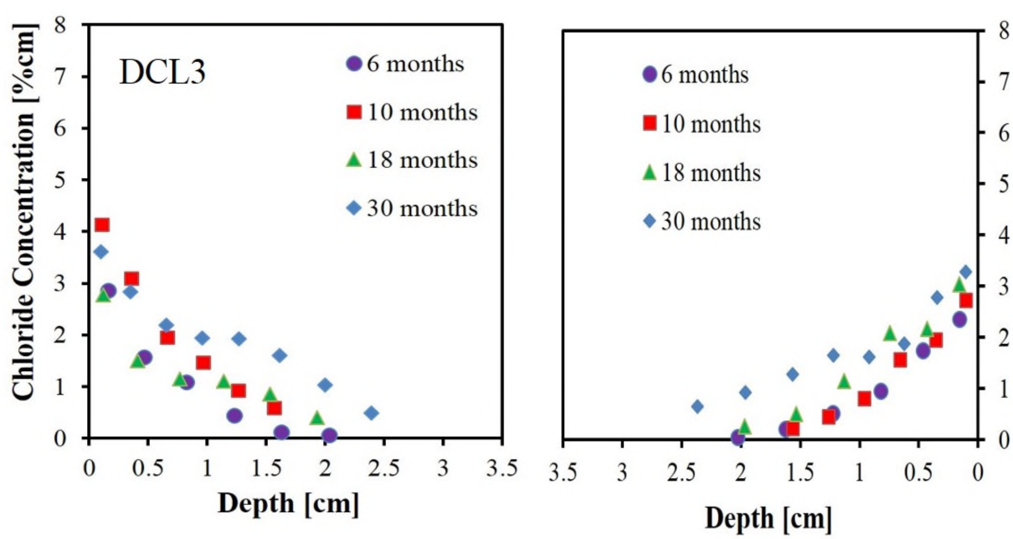


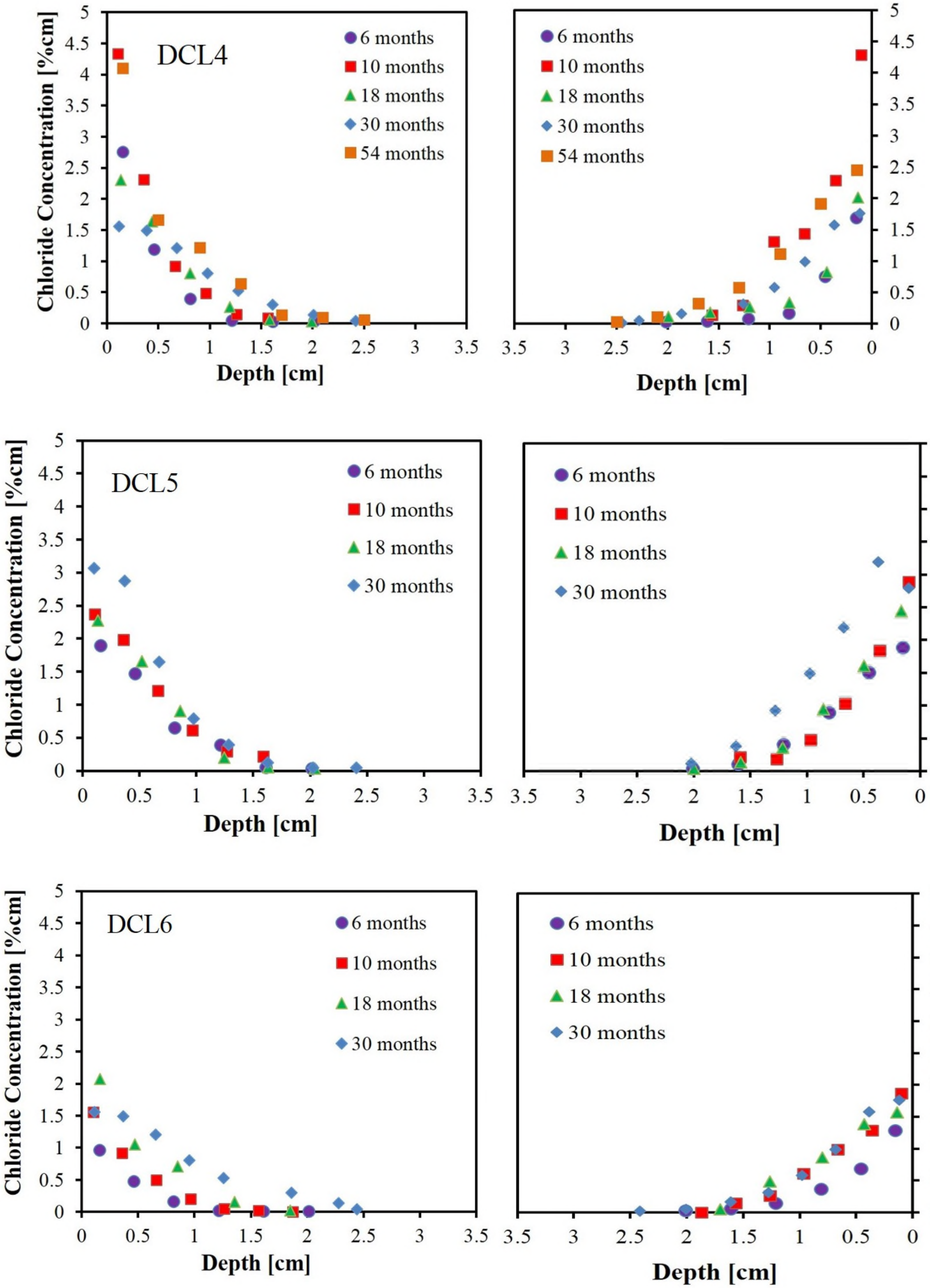
Figure 194. Chloride profile for tidal DCL1 to DCL11 at elevation B

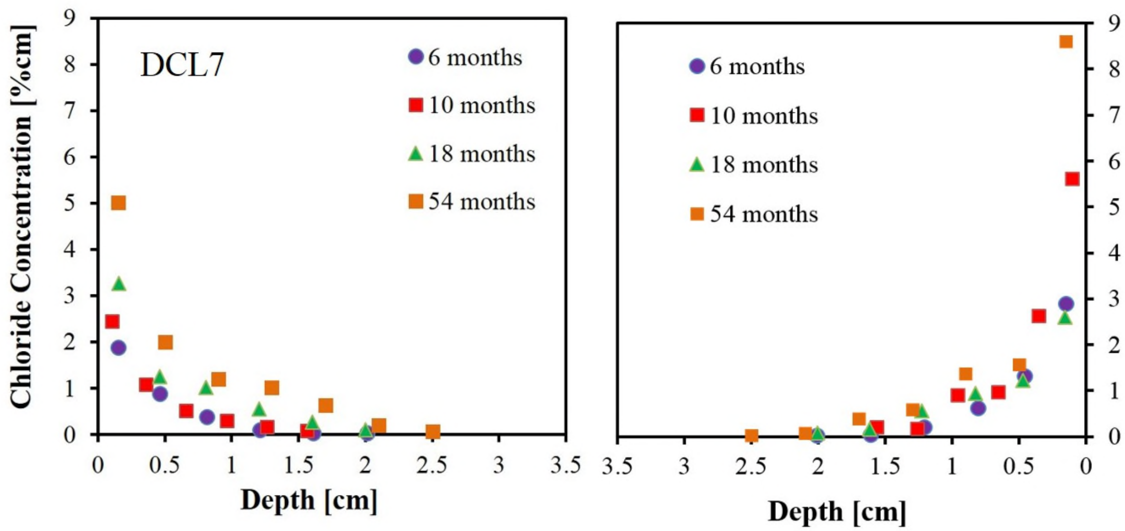
M.1.3 Tidal: Elevation C

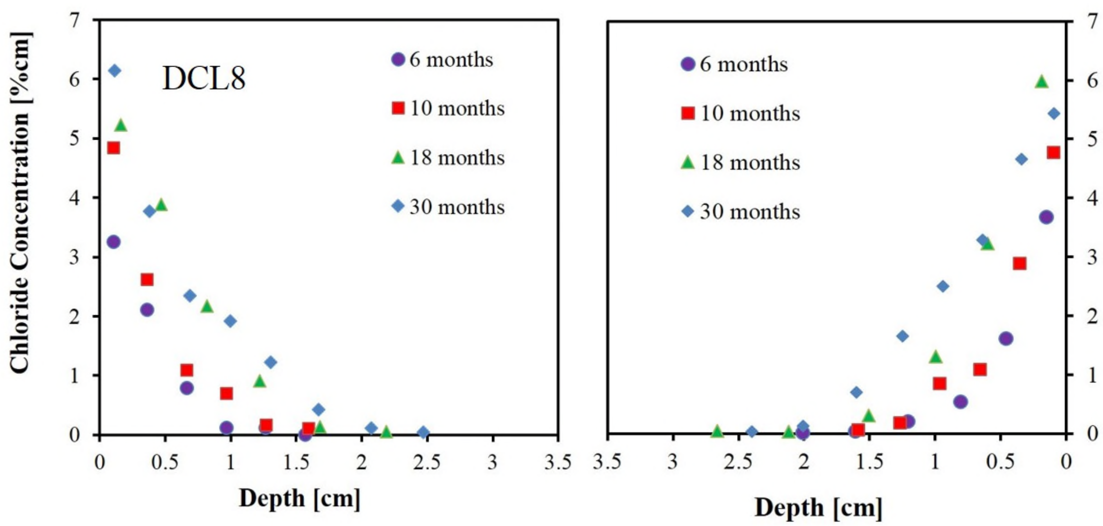


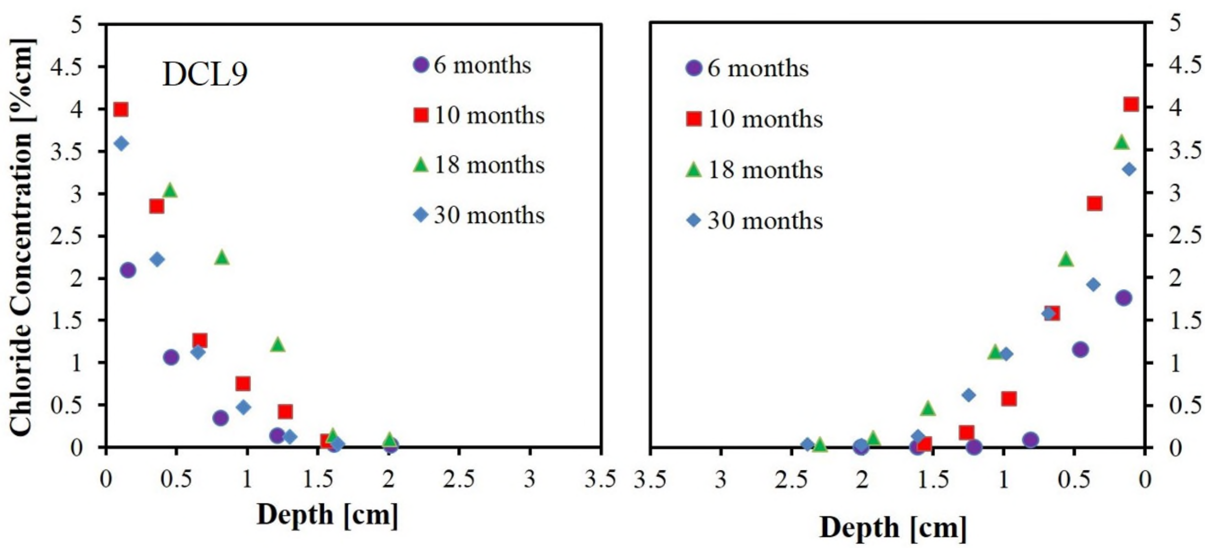





DCL4
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]
DCL5
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]
DCL6
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]


DCL7
6 months
10 months
18 months
54 months
Chloride Concentration [%cm]
Depth [cm]


DCL8
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]


DCL9
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]

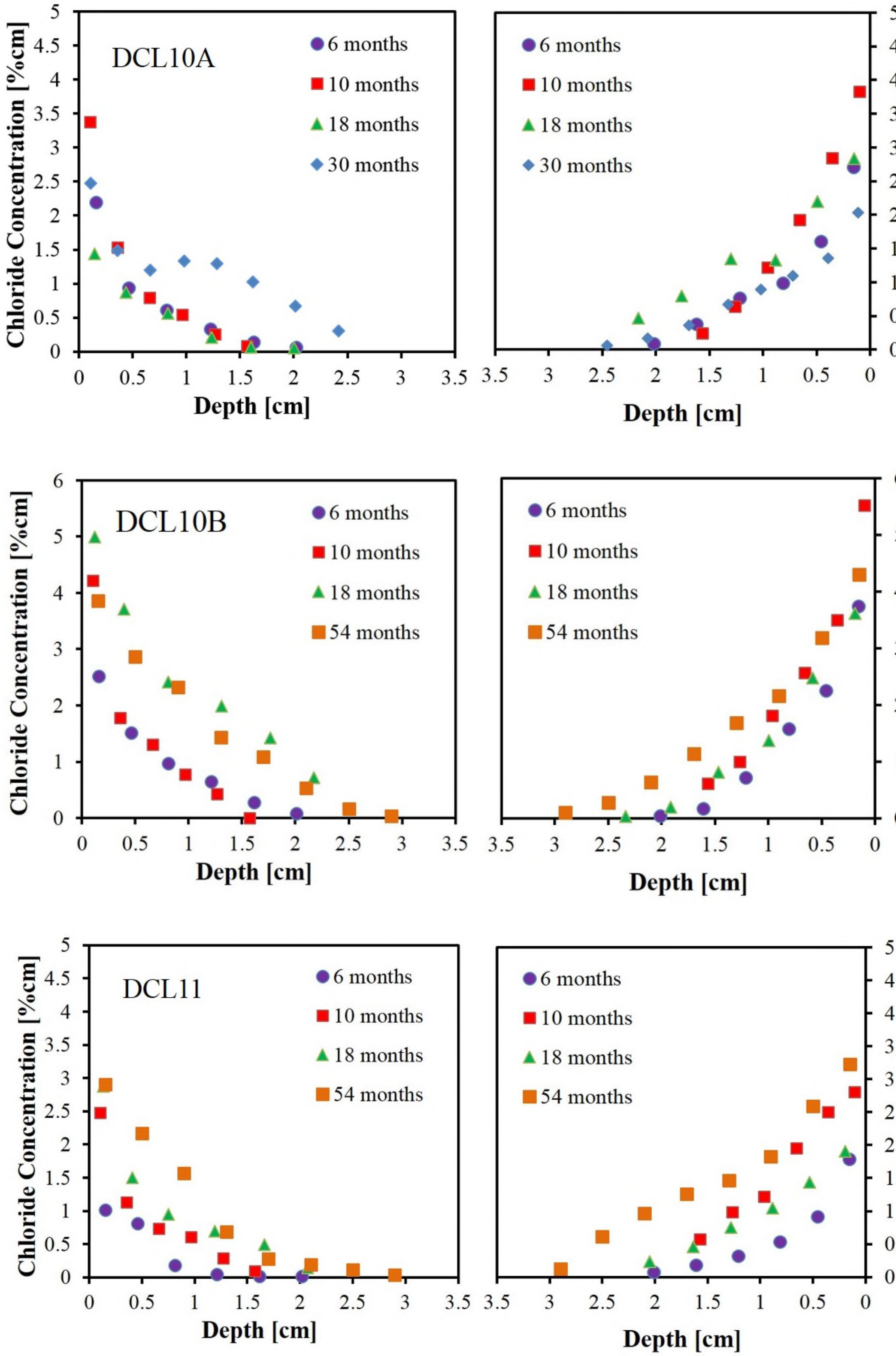
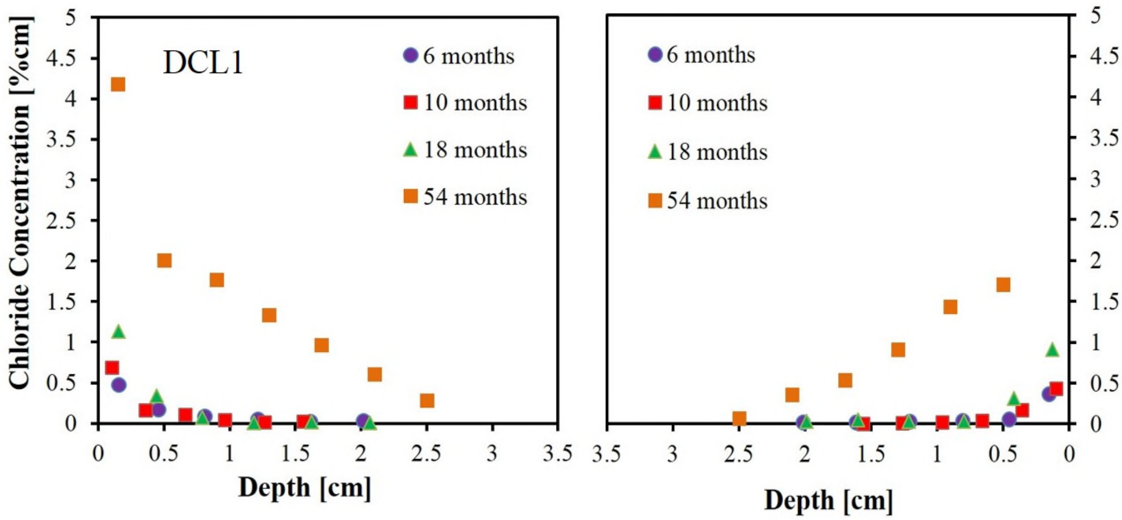
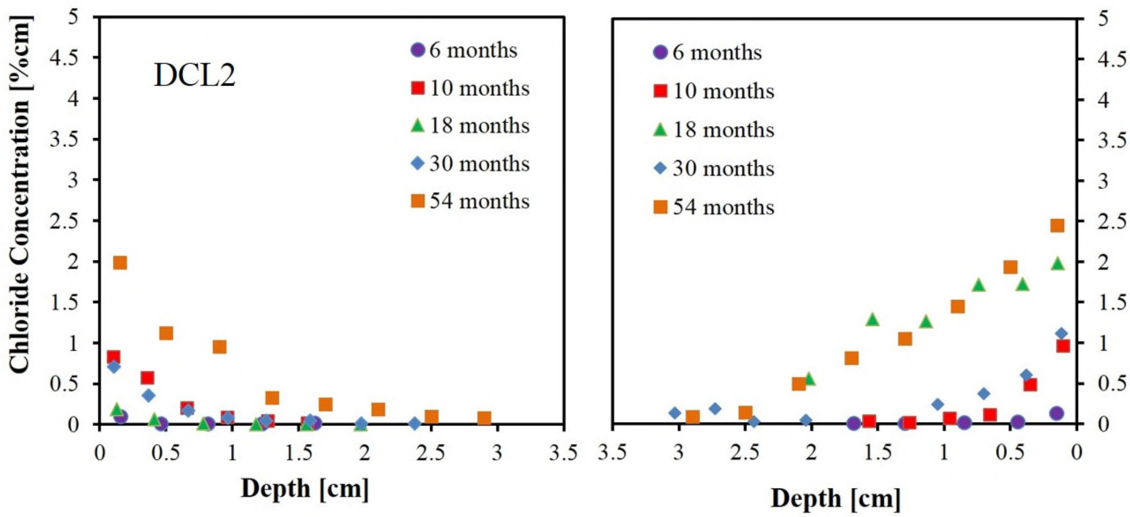
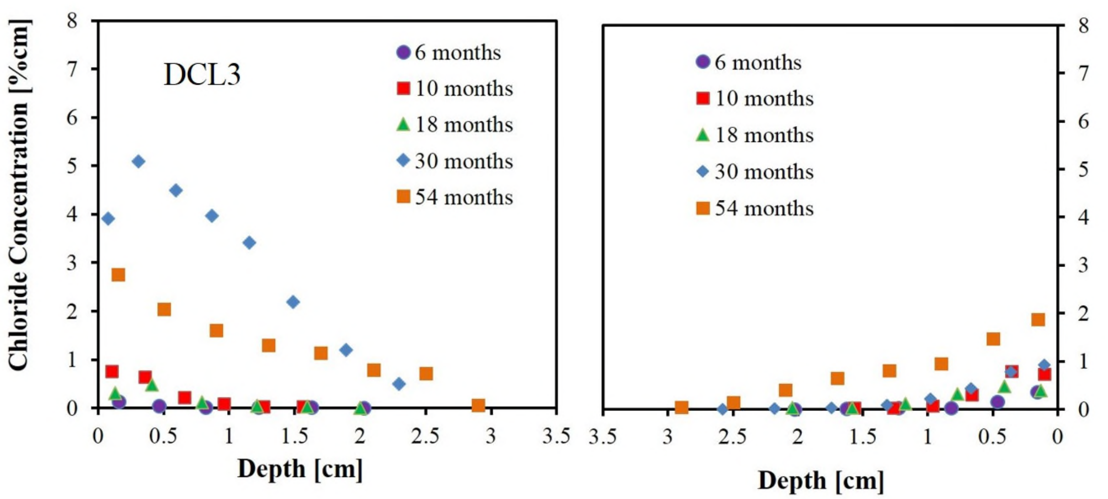


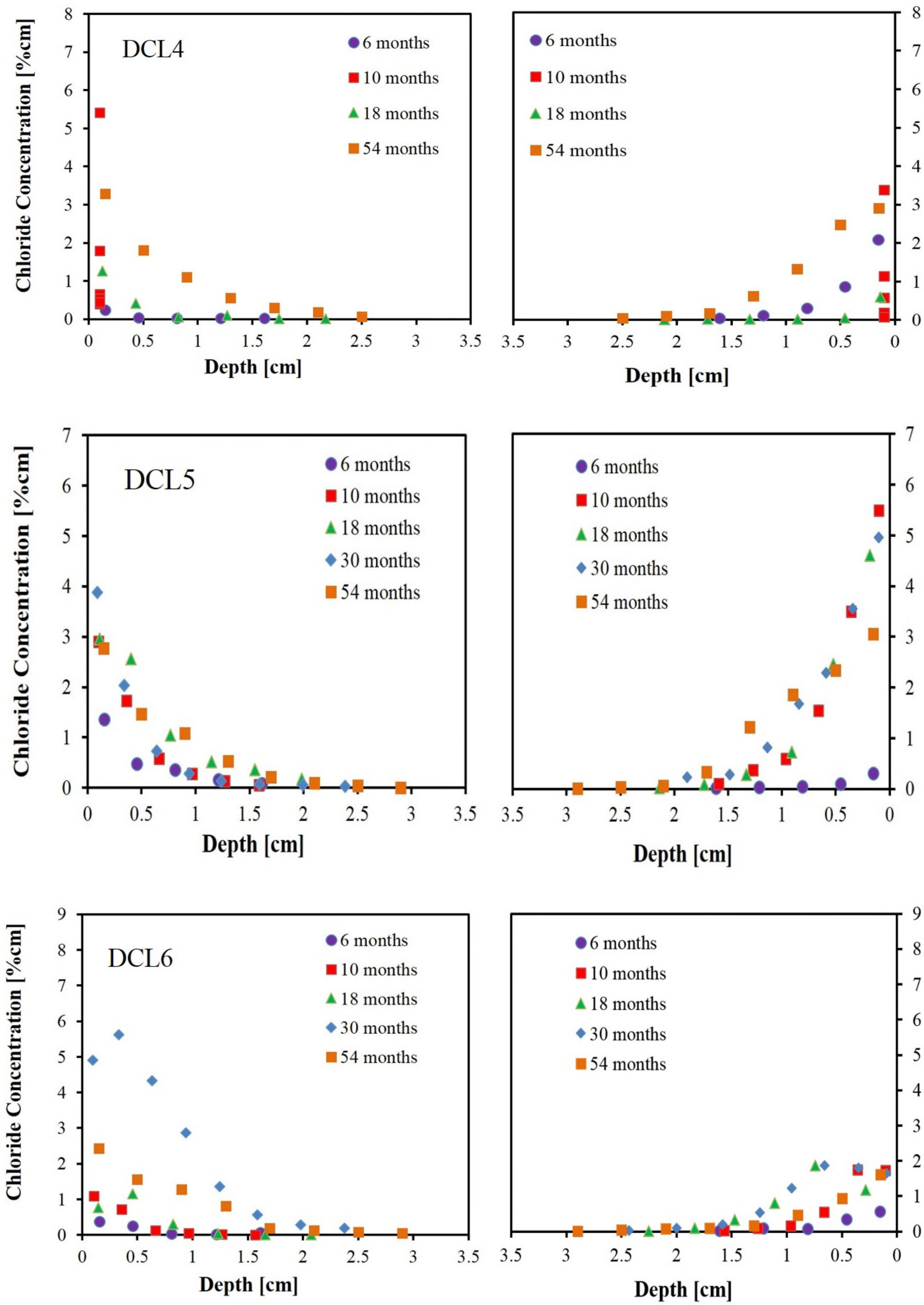
Figure 195. Chloride profile for tidal DCL1 to DCL11 at elevation C

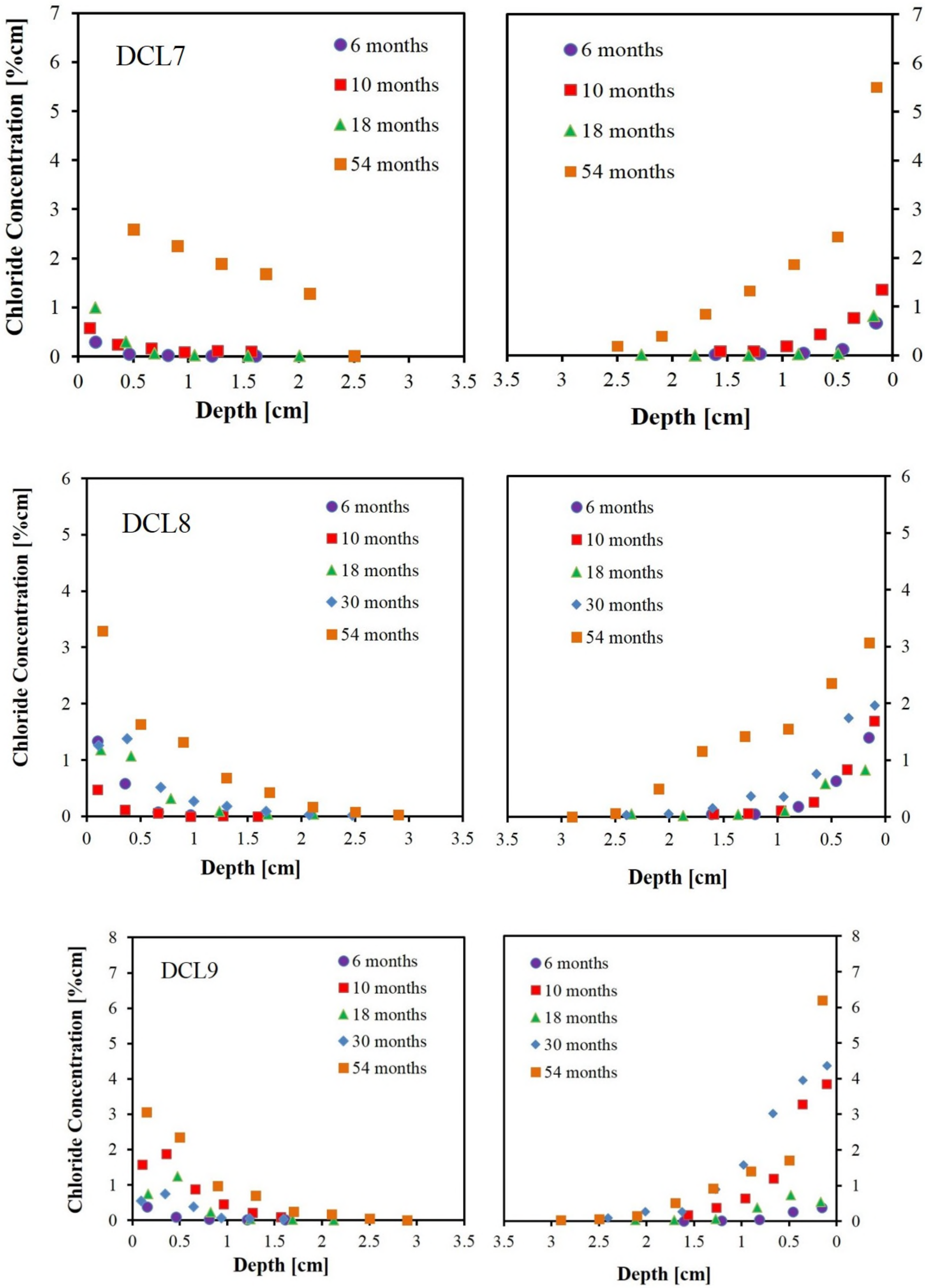
M.1.4 Tidal: Elevation D








DCL4
DCL5
DCL6
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]


DCL7
6 months
10 months
18 months
54 months
Chloride Concentration [%cm]
Depth [cm]
DCL8
30 months
DCL9

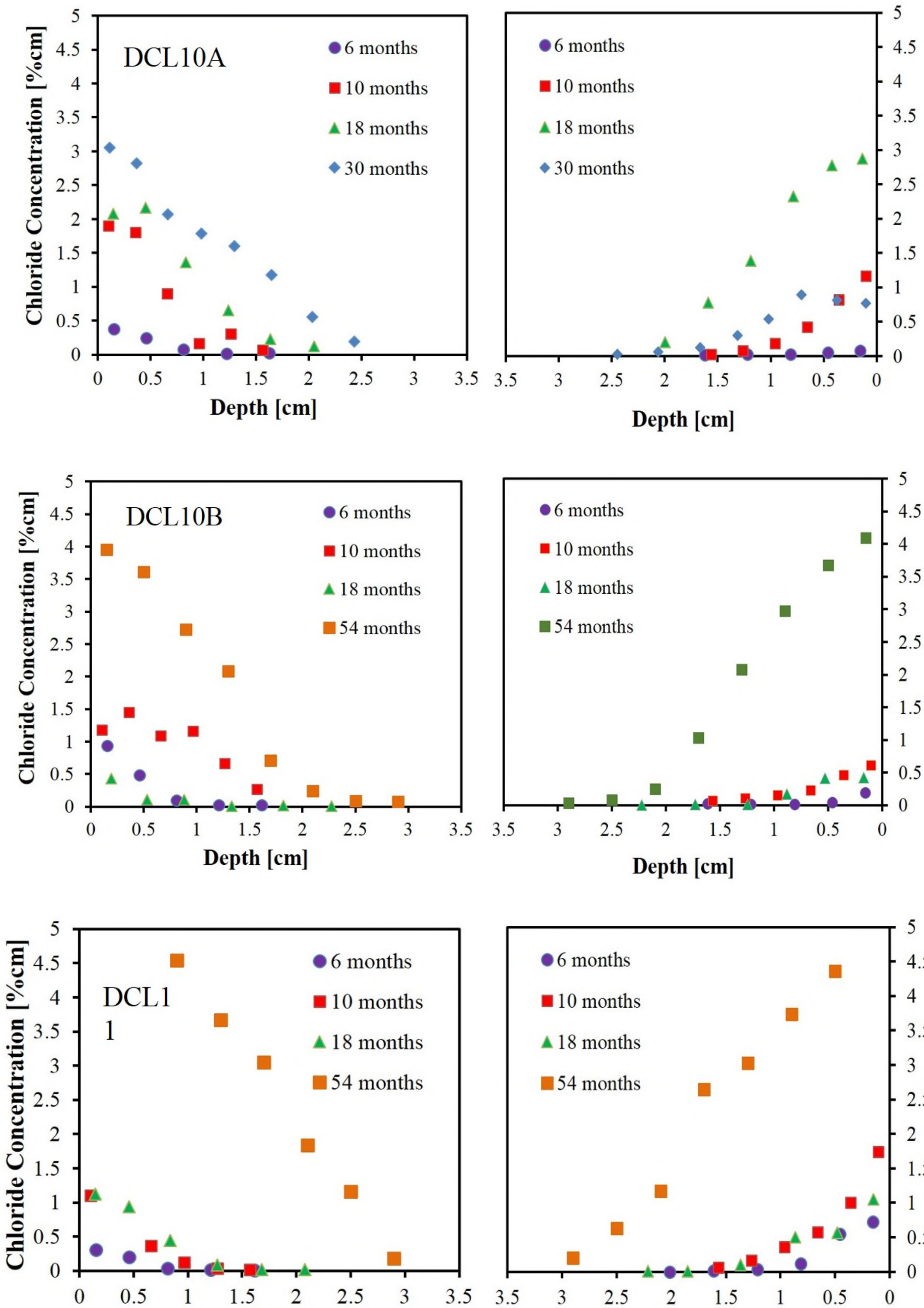
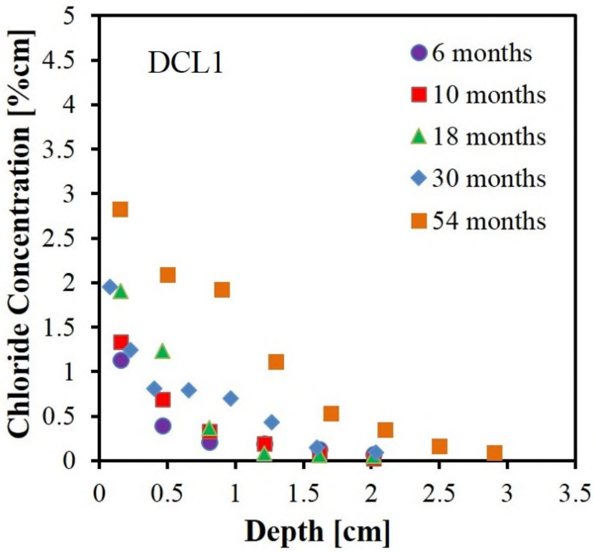
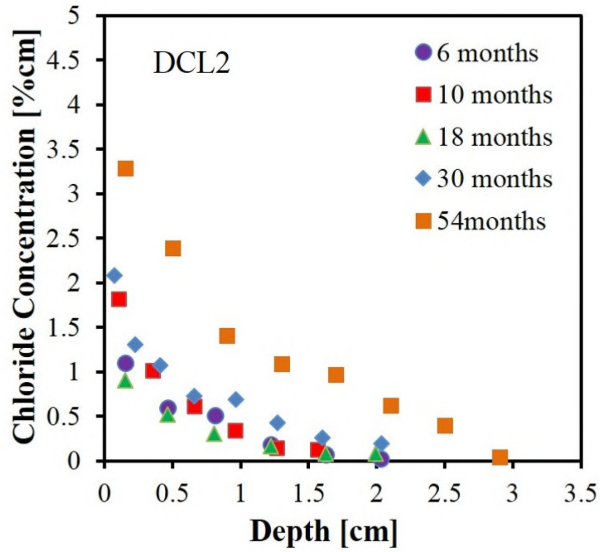


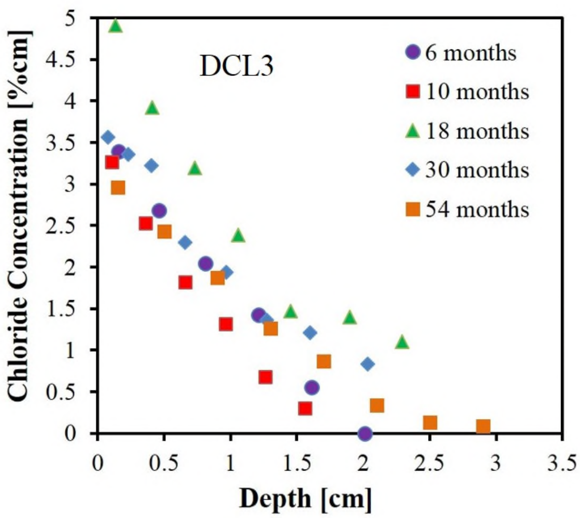
Figure 196. Chloride profile for tidal DCL1 to DCL11 at elevation D

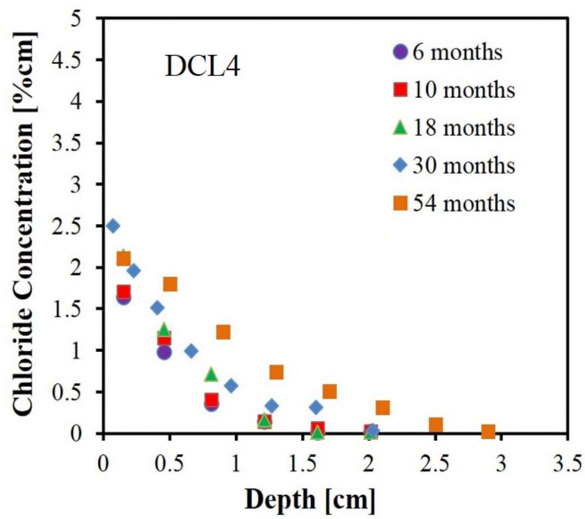
M.2 Splash simulation chloride profiles

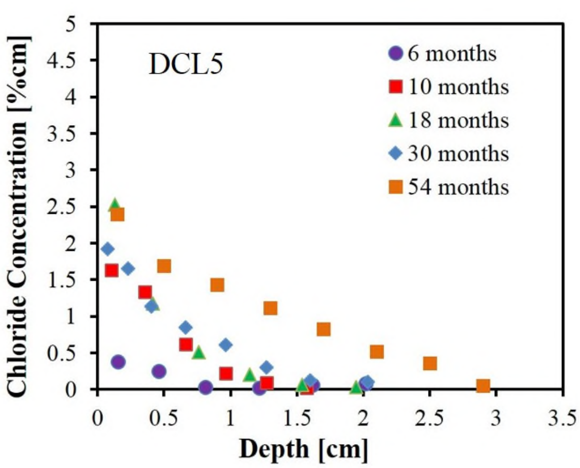
M.2.1 Splash: Elevation A

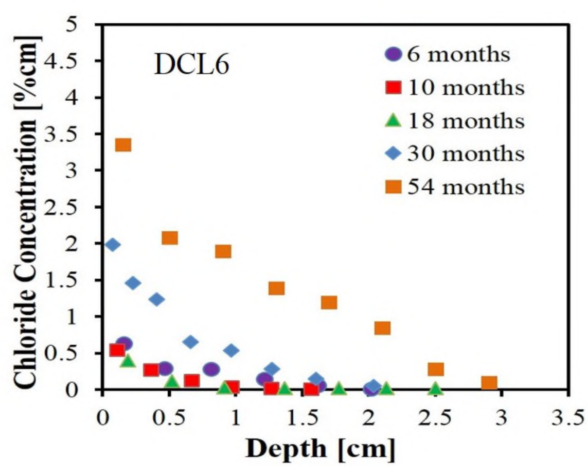












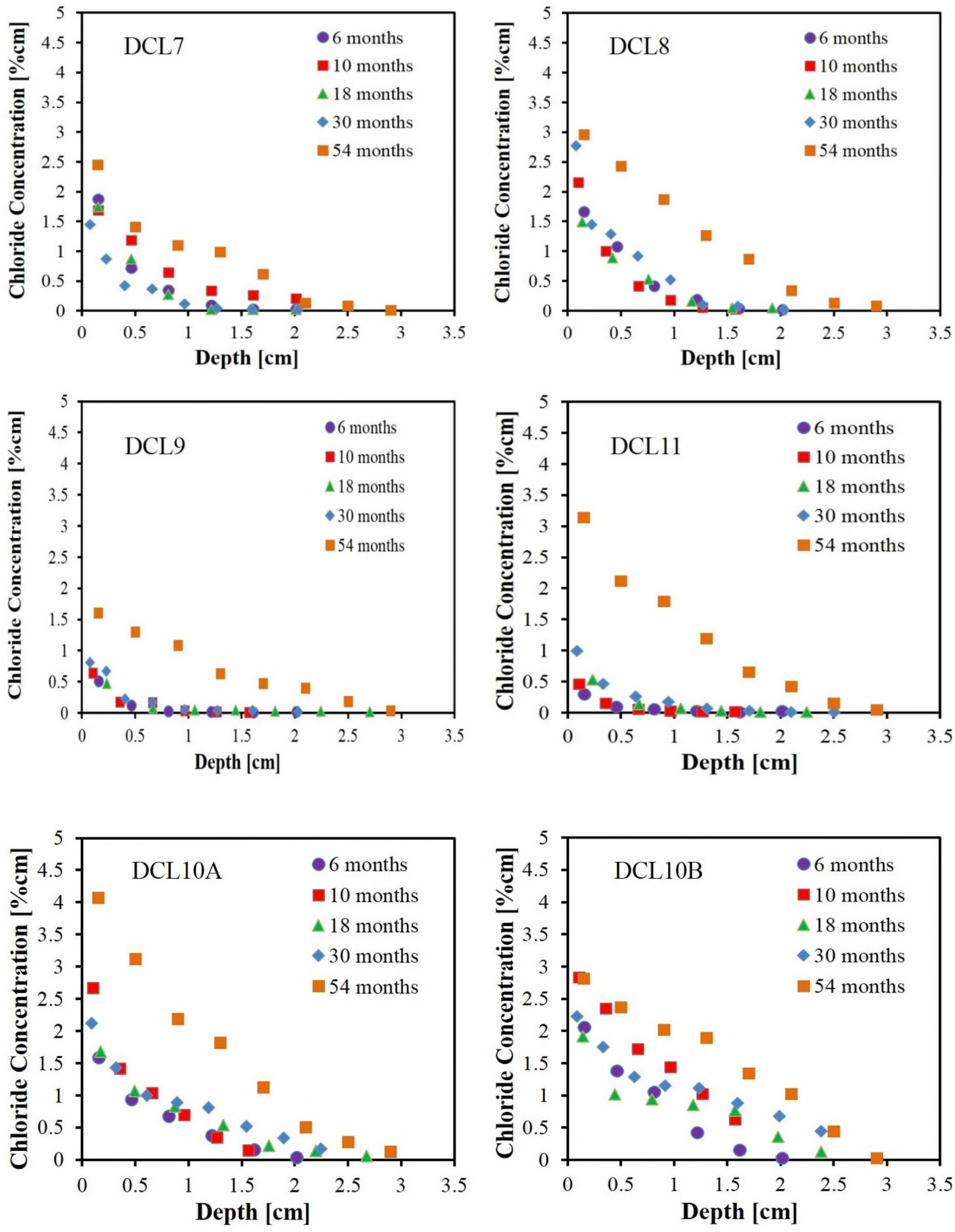


Figure 197. Chloride profile for splash DCL1 to DCL11 at elevation A

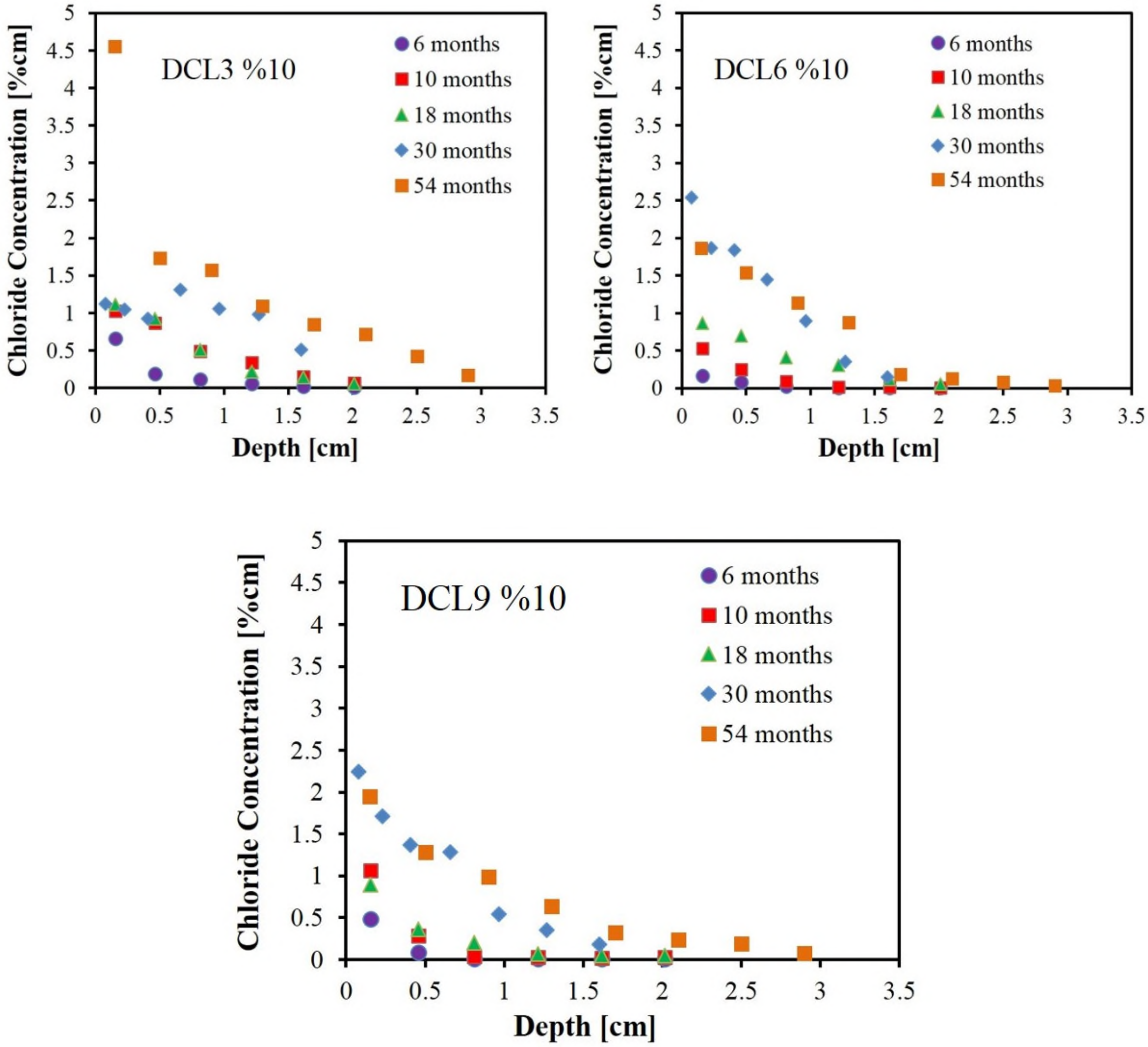
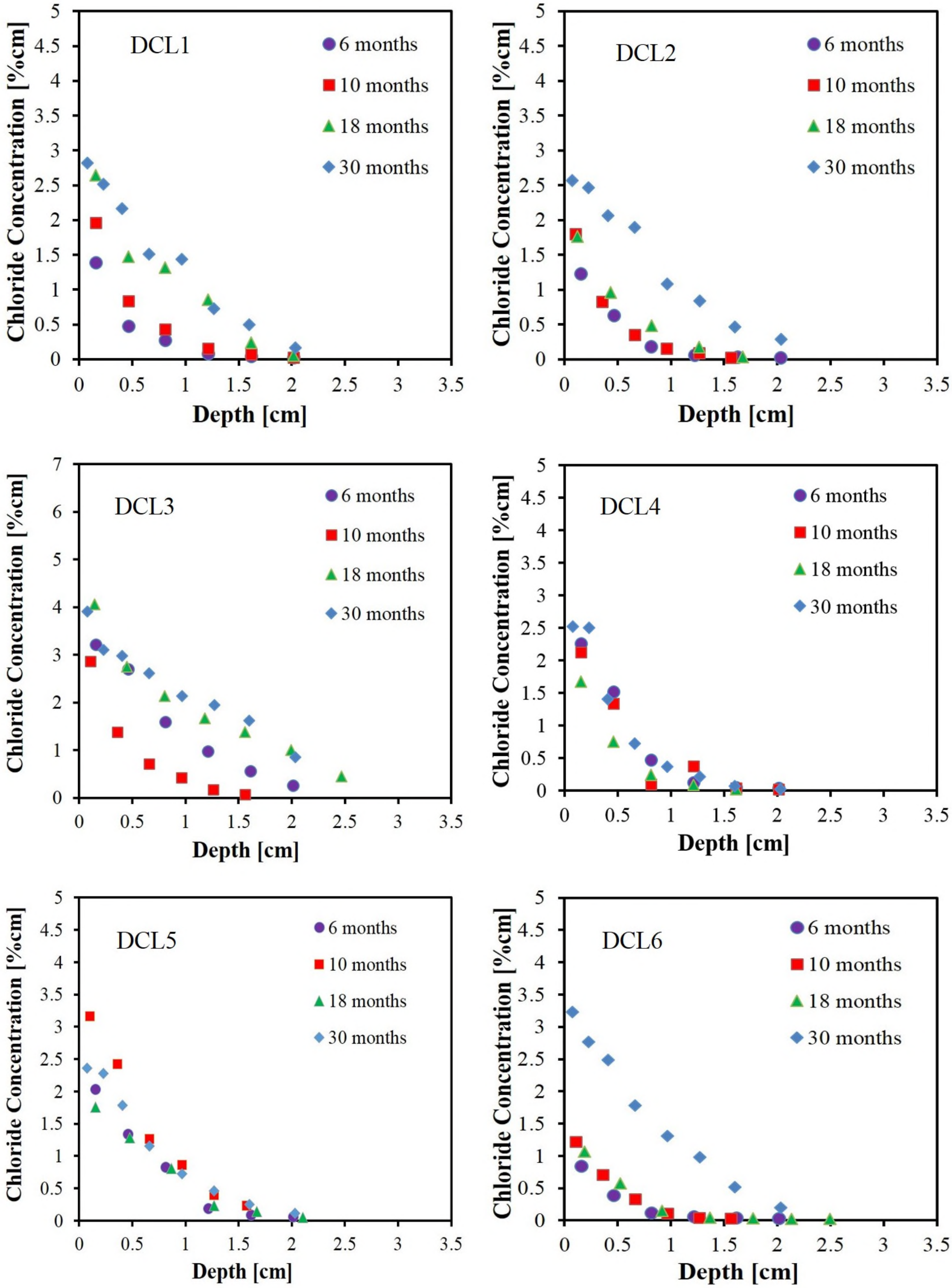


Figure 198. Chloride profile for splash 10% seawater DCL3, DCL6, and DCL9 at elevation A

M.2.2 Splash: Elevation B



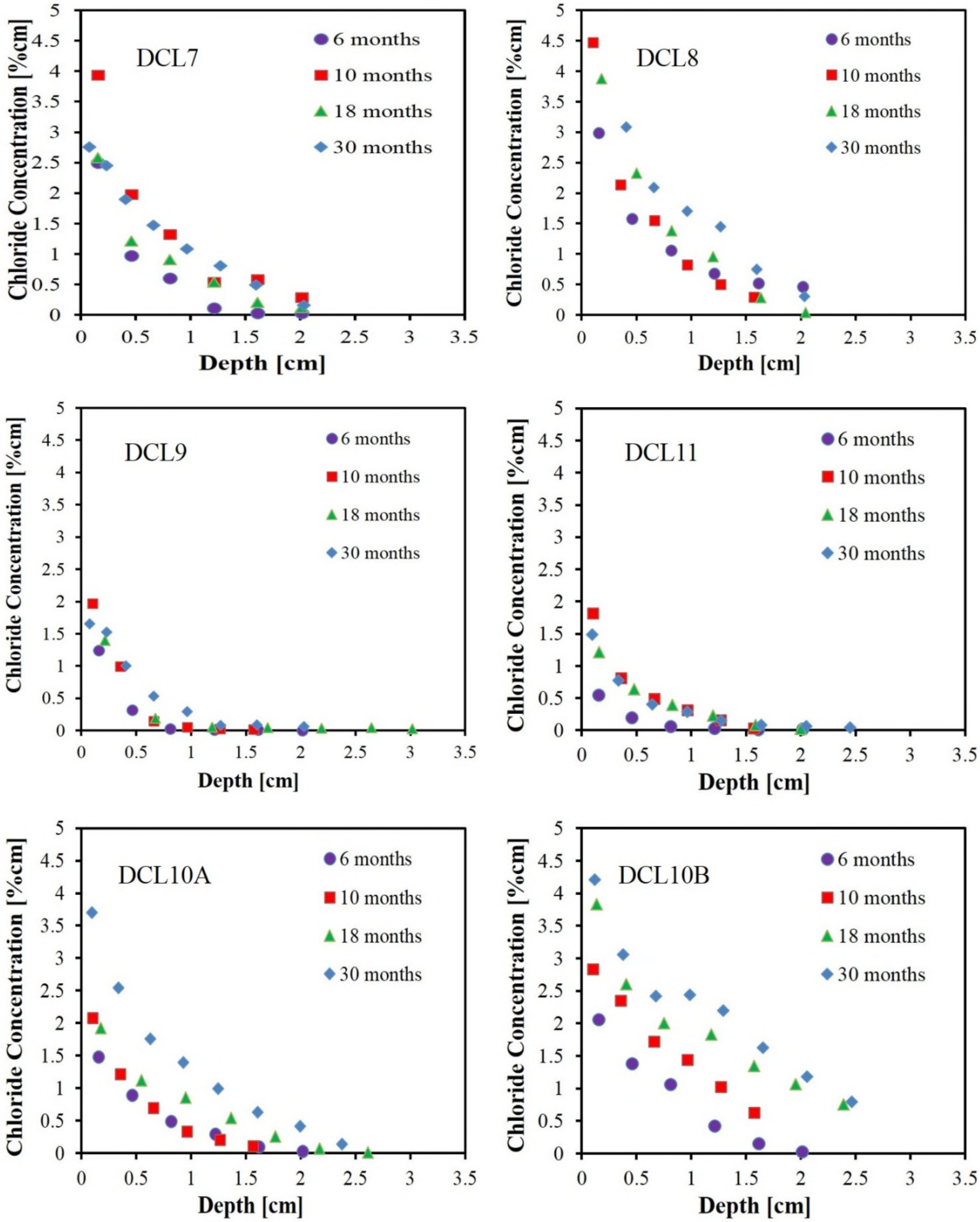


Figure 199. Chloride profile for splash DCL1 to DCL11 at elevation B

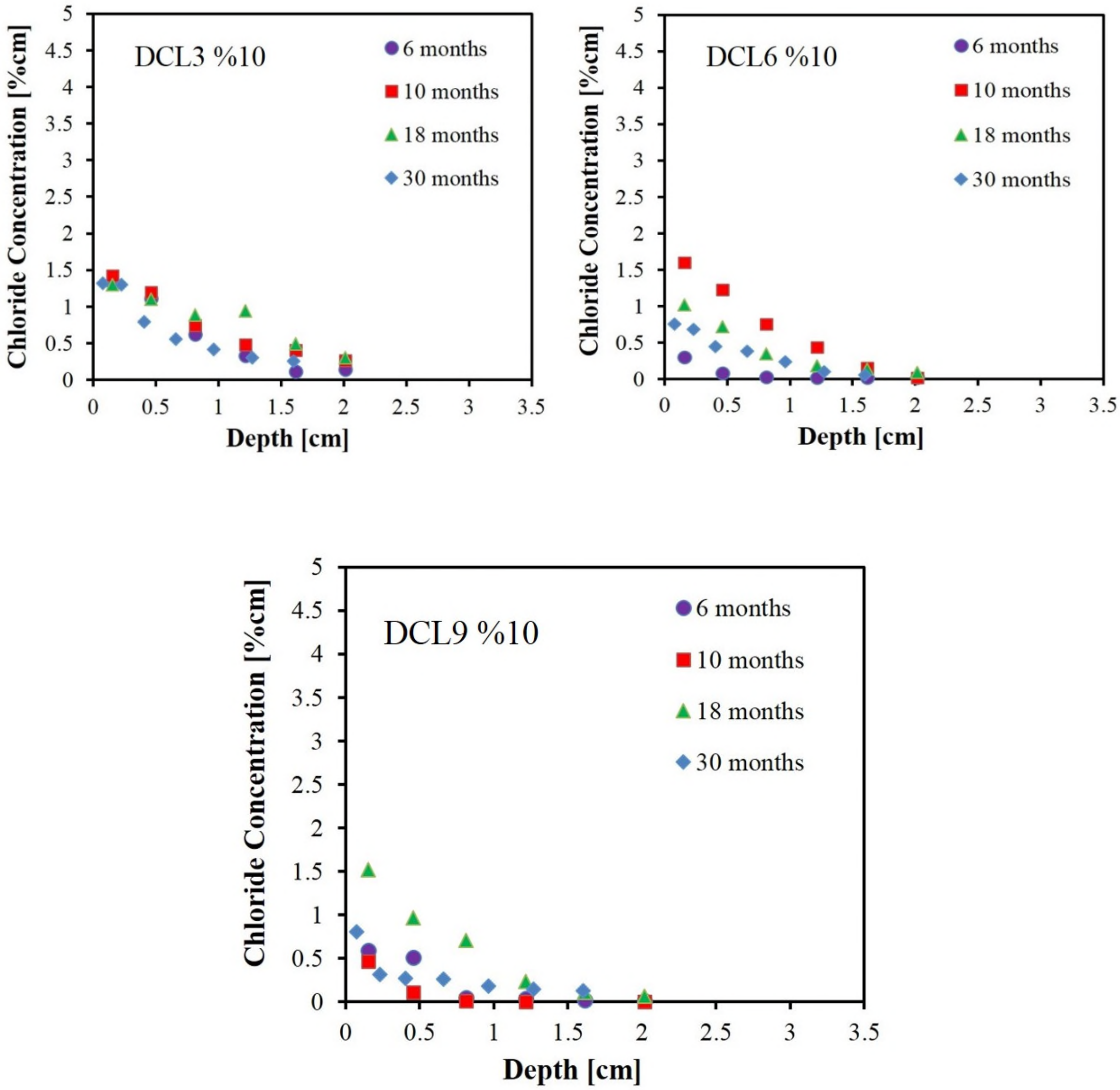
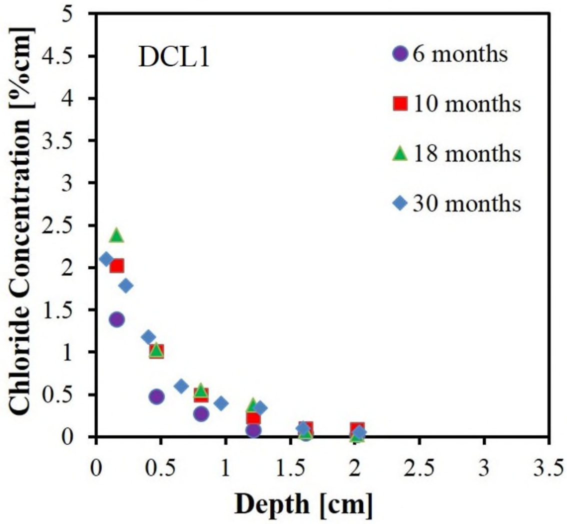
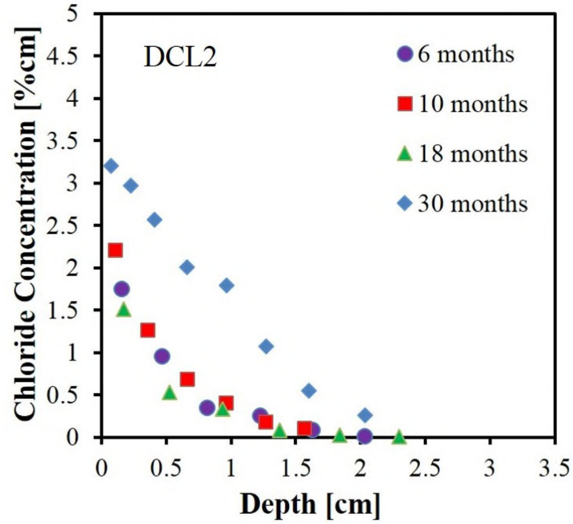
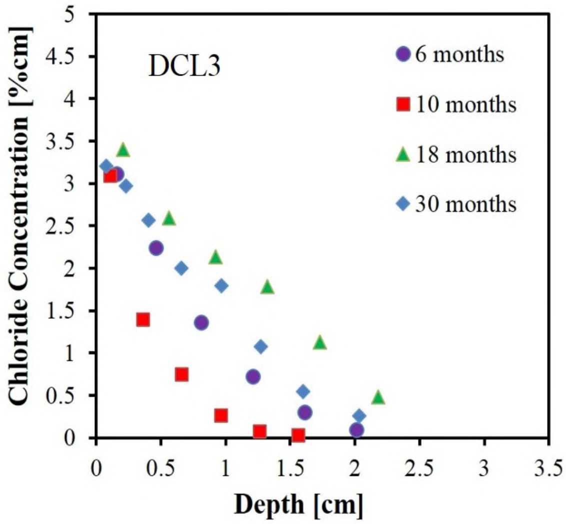


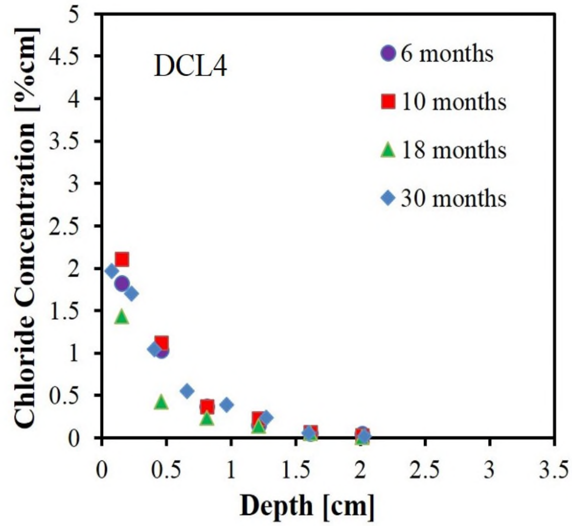
Figure 200. Chloride profile for splash 10% seawater DCL3, DCL6, and DCL9 at elevation B

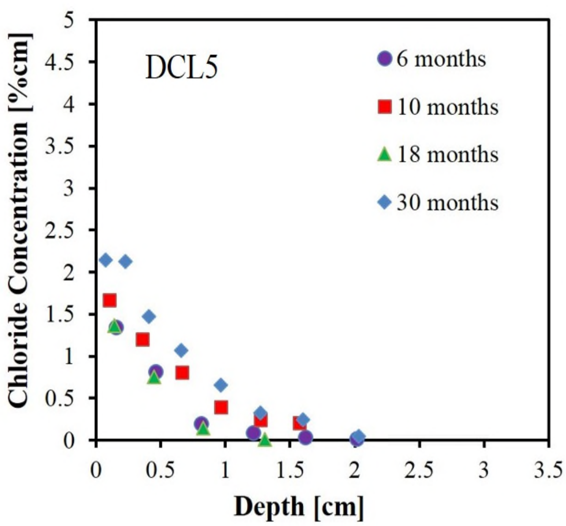
M.2.3 Splash: Elevation C

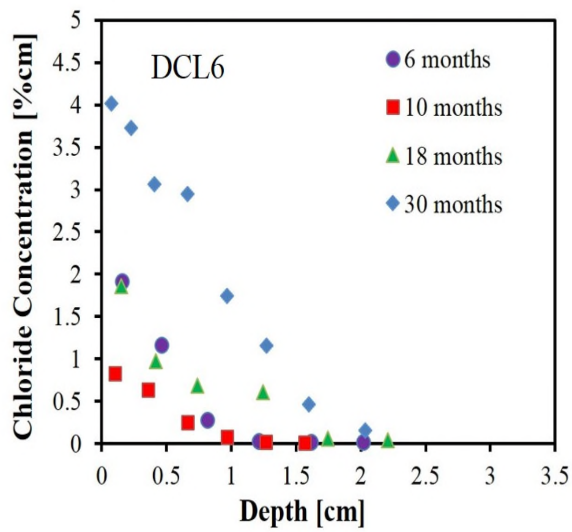












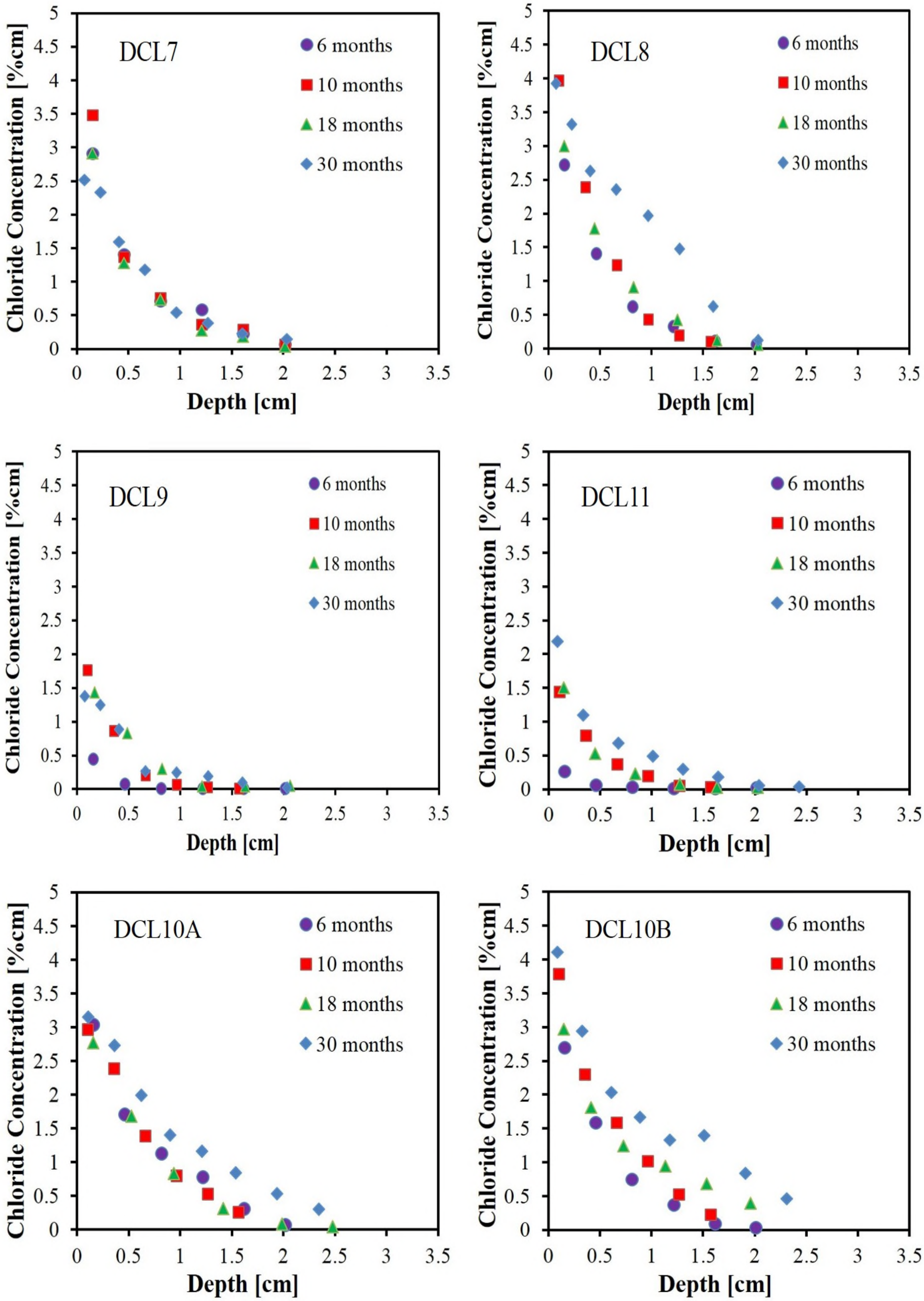


Figure 201. Chloride profile for splash DCL1 to DCL11 at elevation C

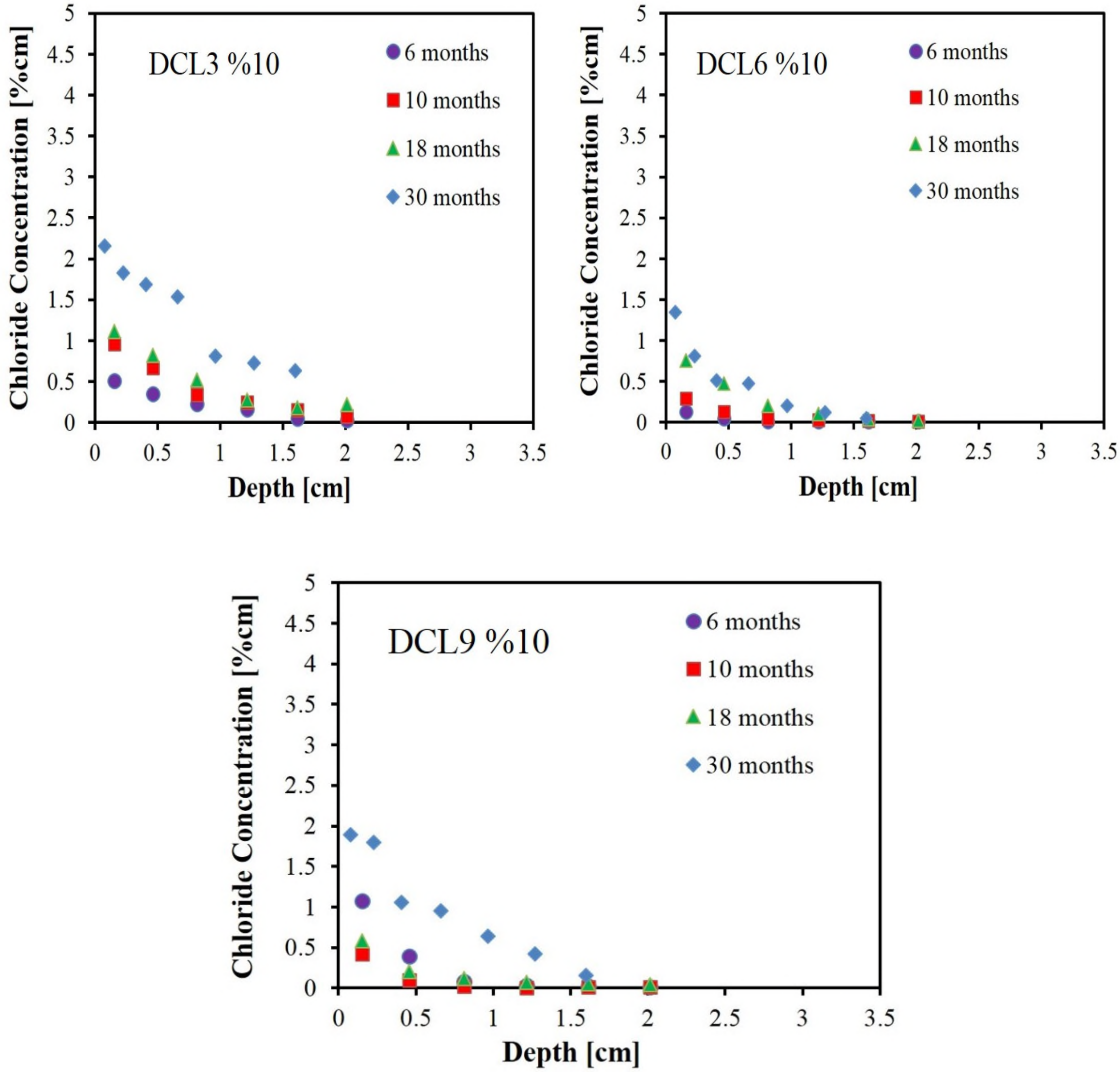
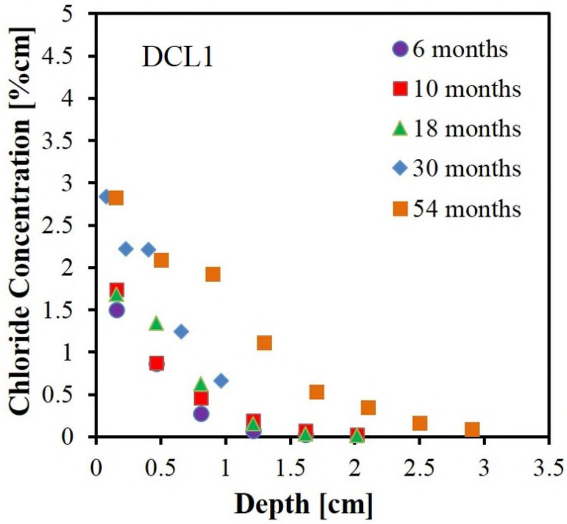
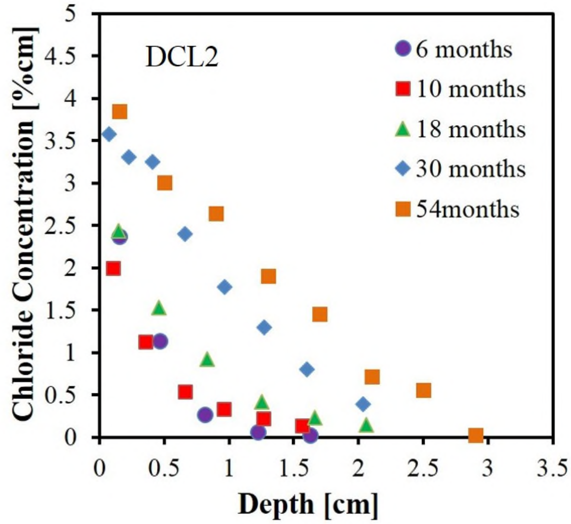
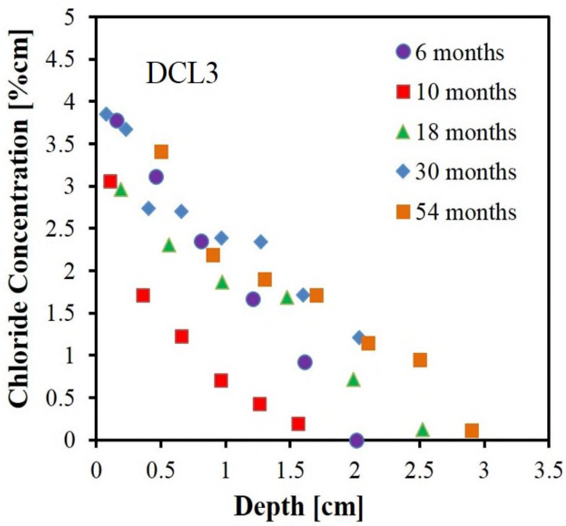


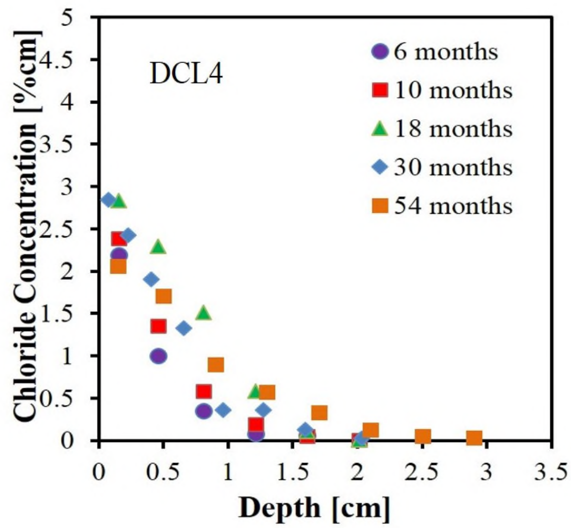
Figure 202. Chloride profile for splash 10% seawater DCL3, DCL6, and DCL9 at elevation C

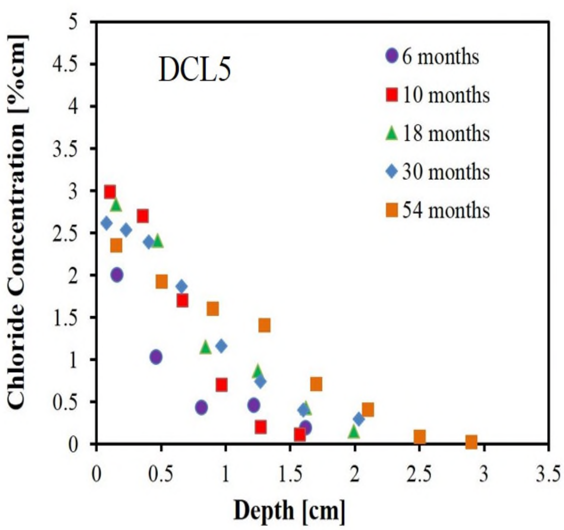
M.2.4 Splash: Elevation D

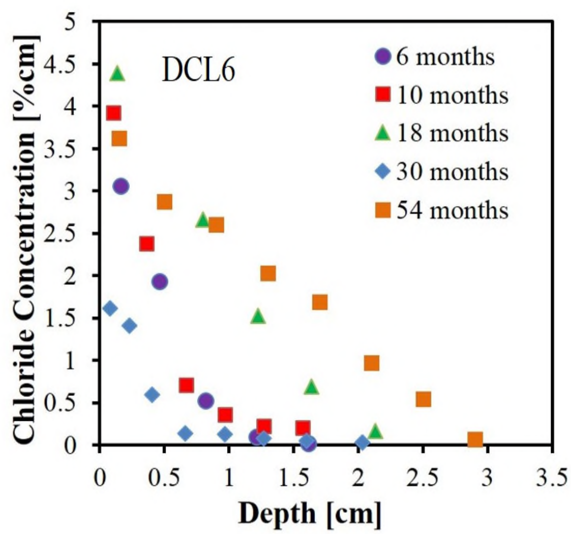












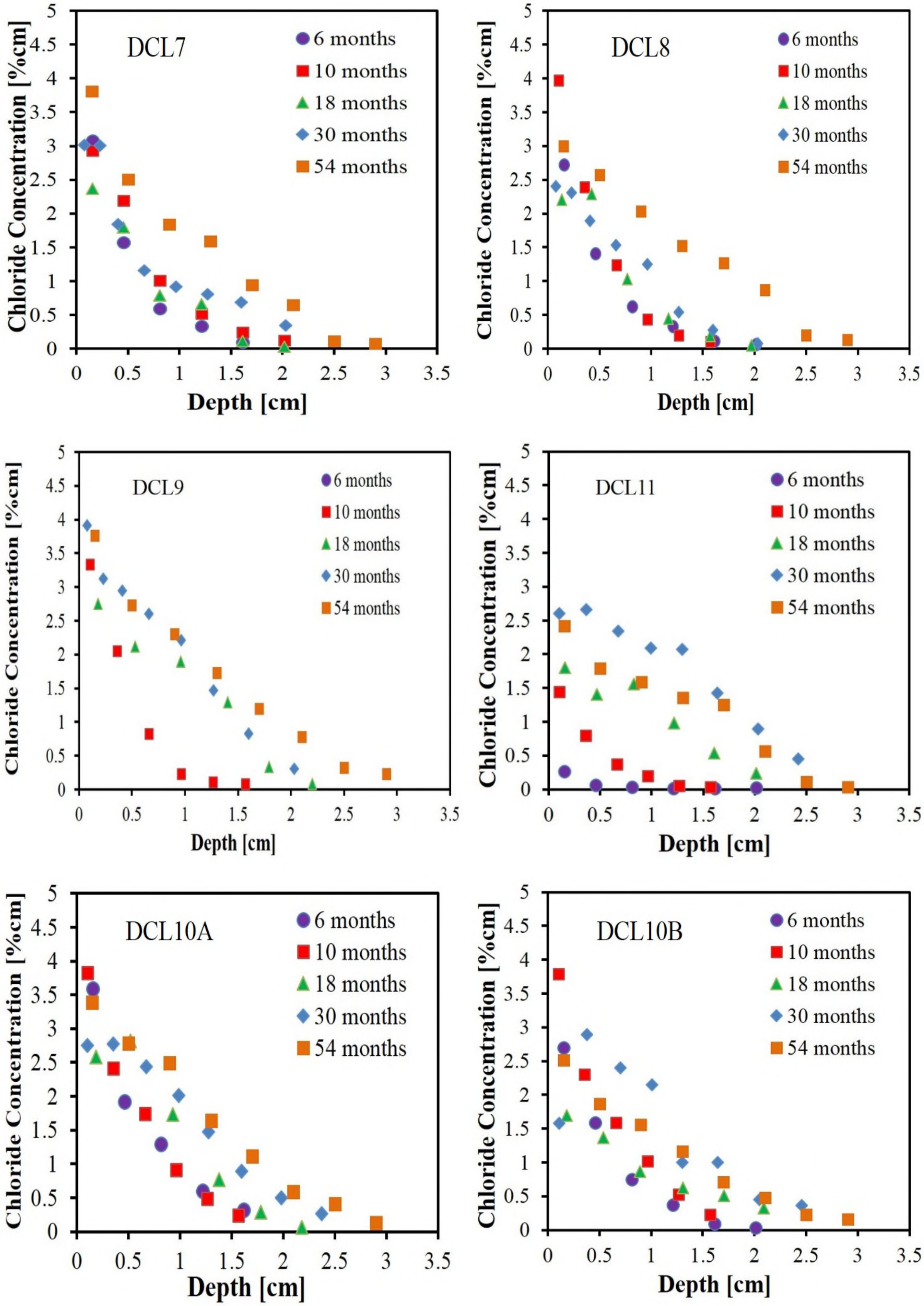


Figure 203. Chloride profile for splash DCL1 to DCL11 at elevation D

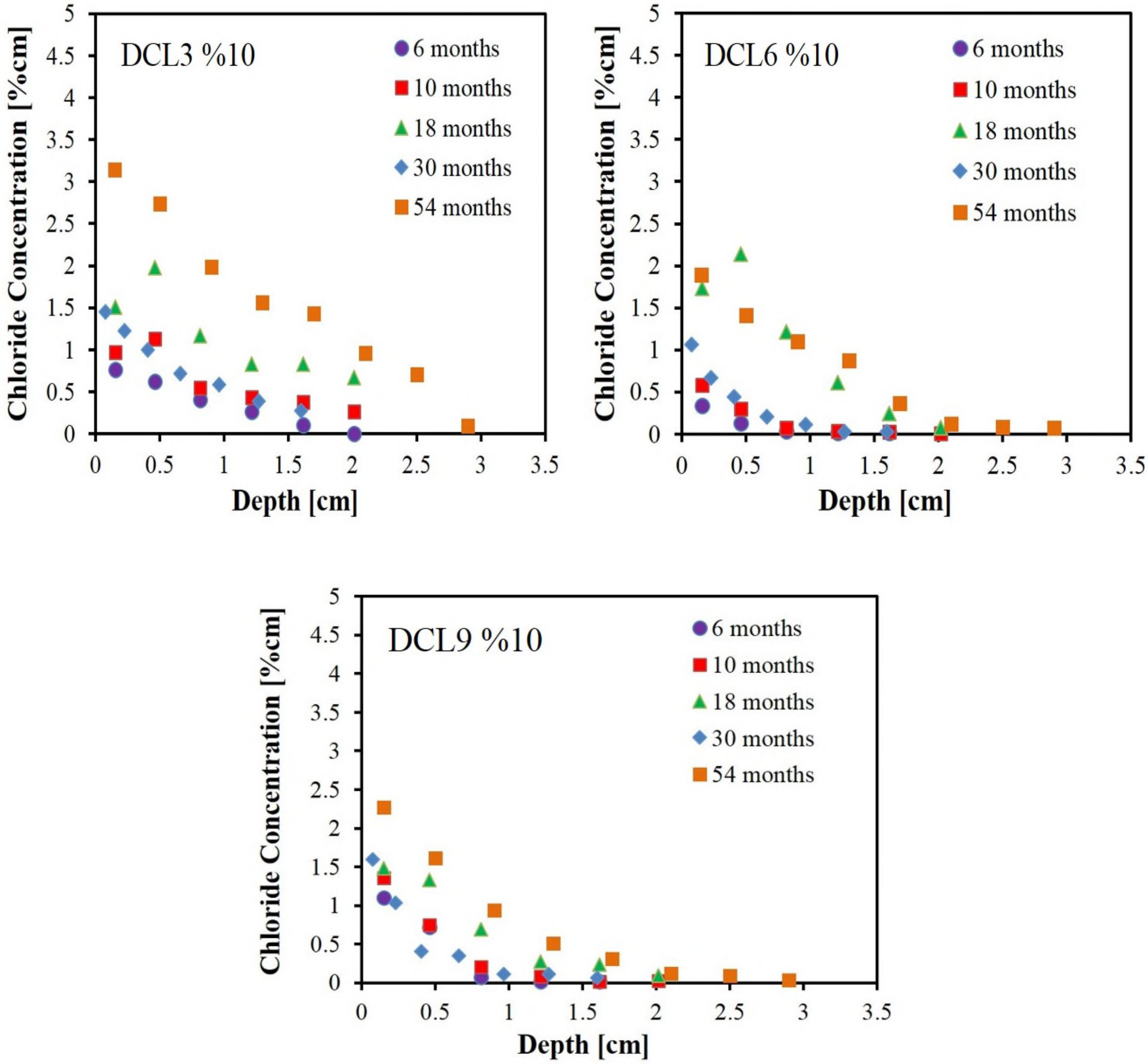
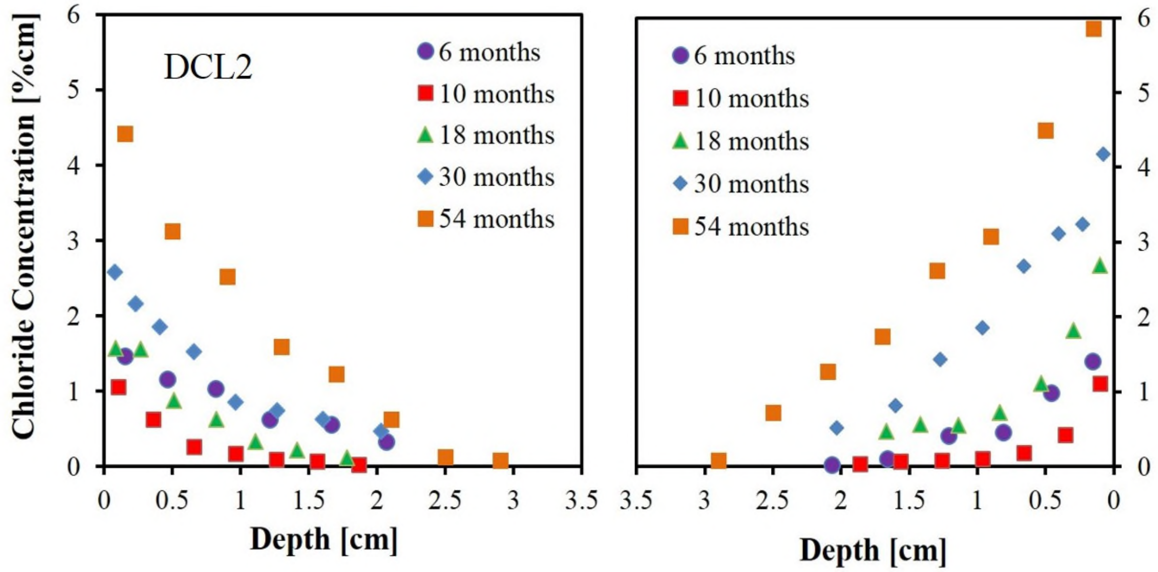
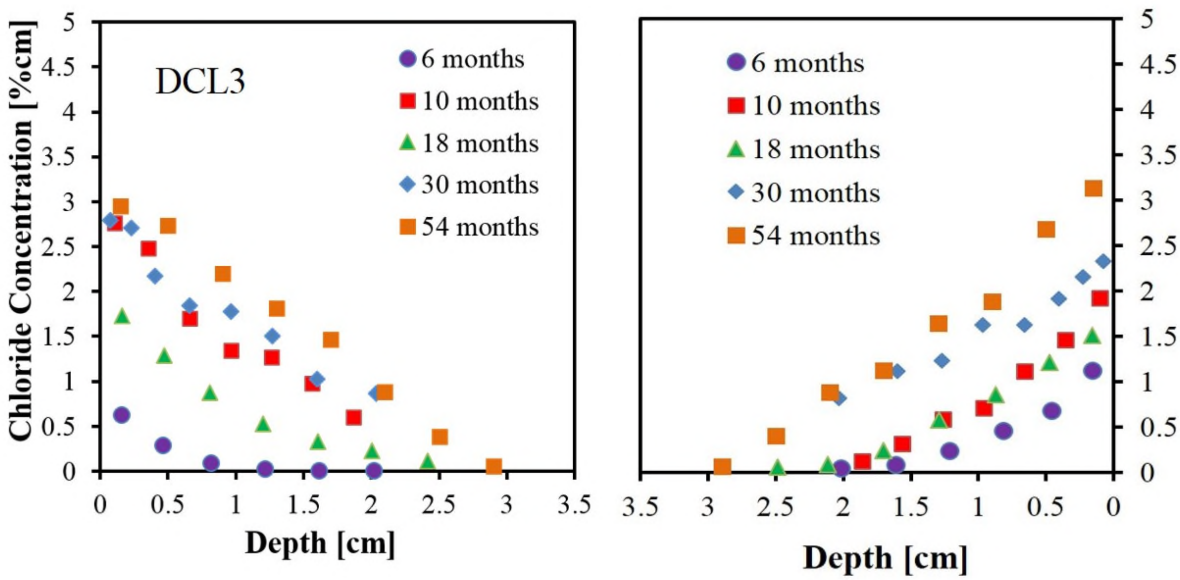


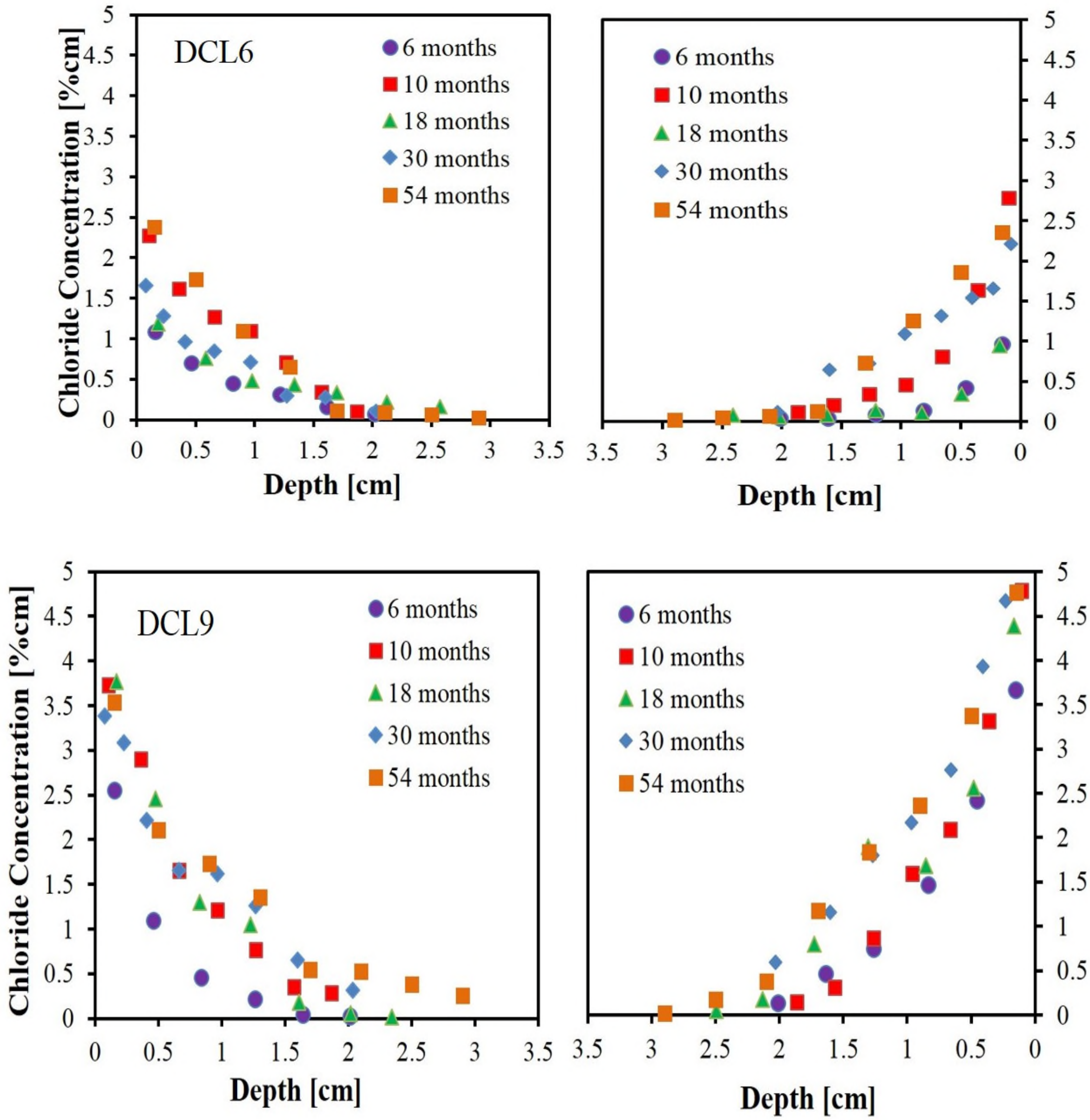
Figure 204. Chloride profile for splash 10% seawater DCL3, DCL6, and DCL9 at elev. D

M.3 Barge simulation chloride profiles

M.3.1 Barge: Elevation A






DCL6
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]
DCL9
Chloride Concentration [%cm]
Depth [cm]

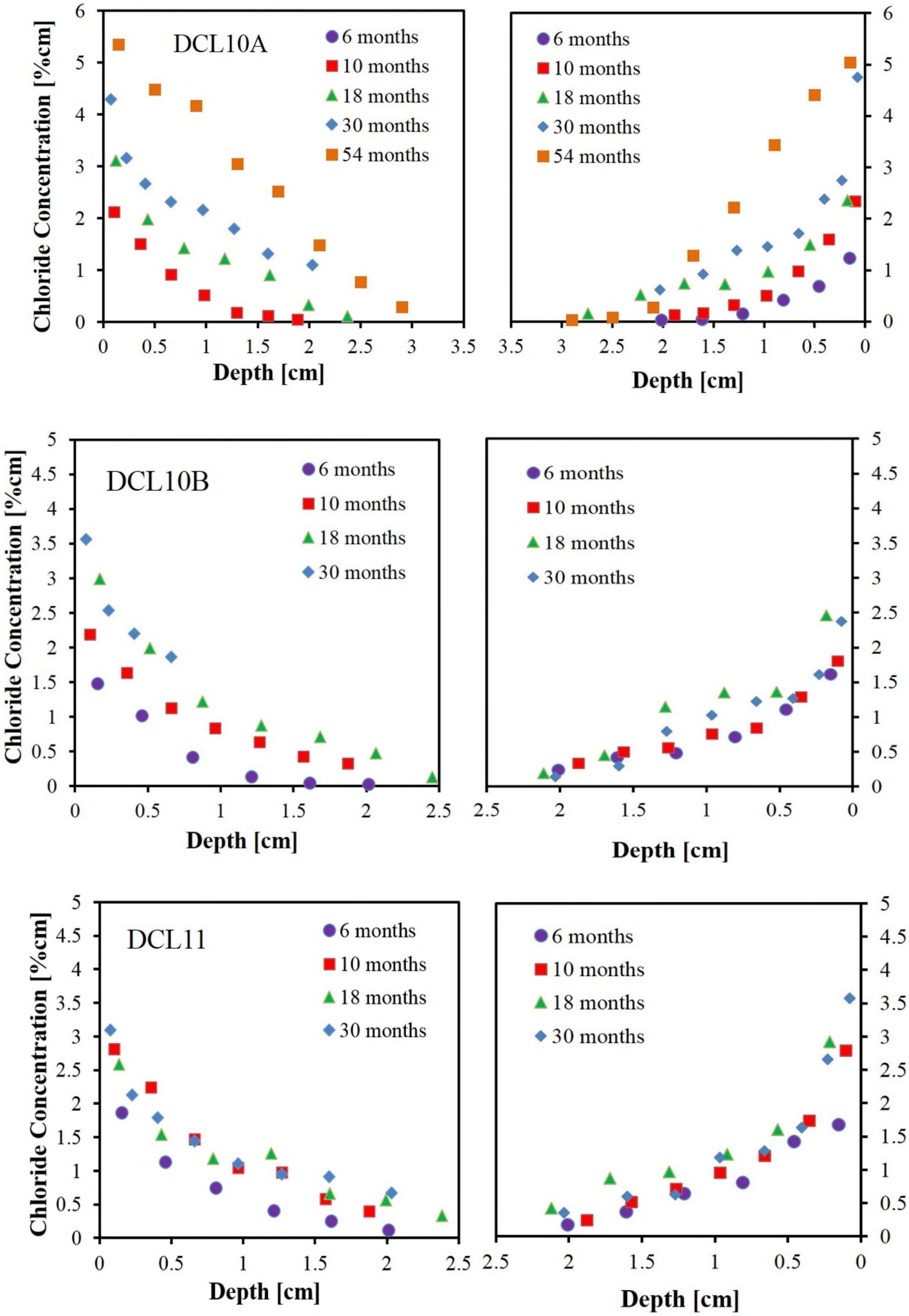
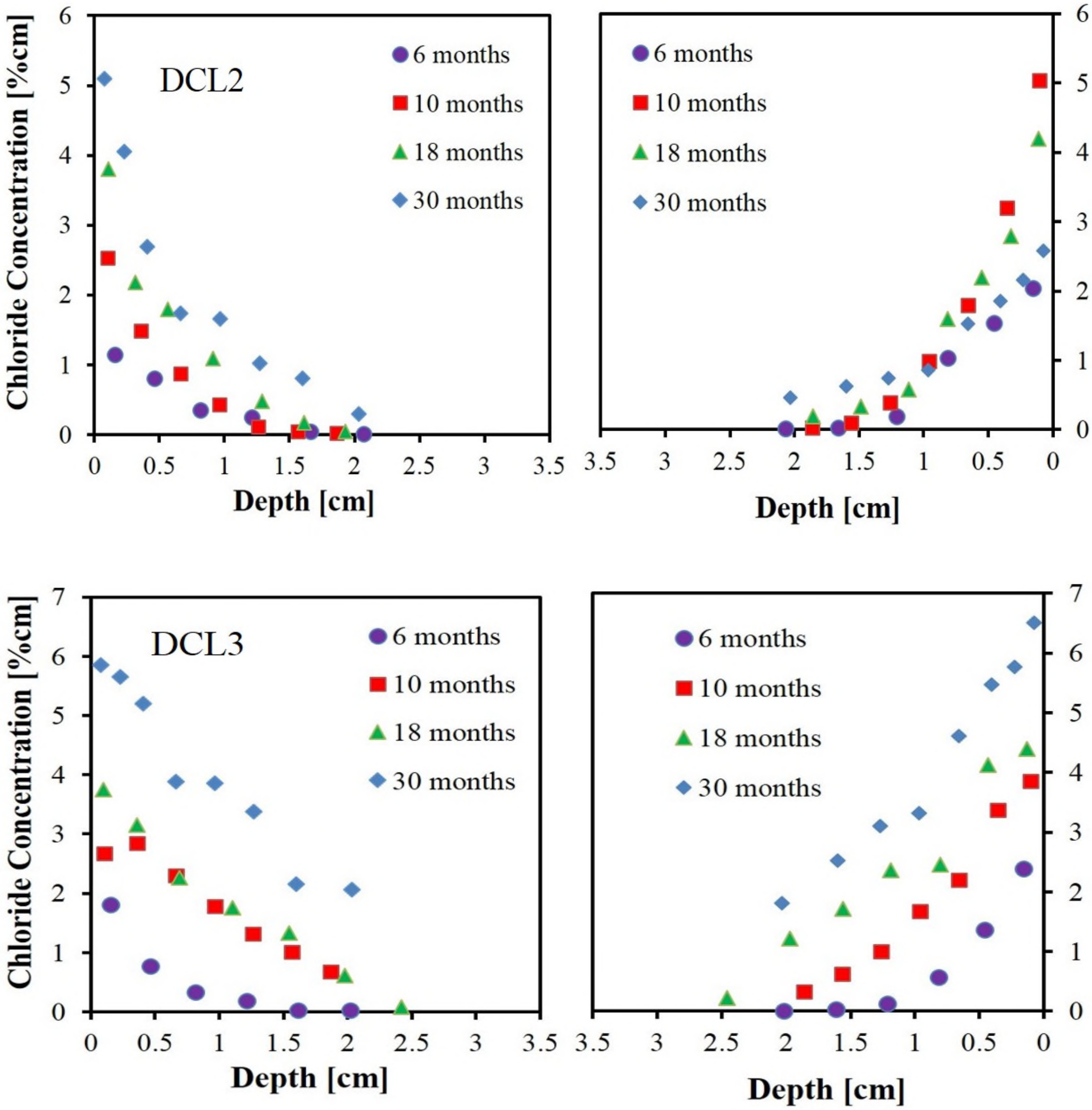
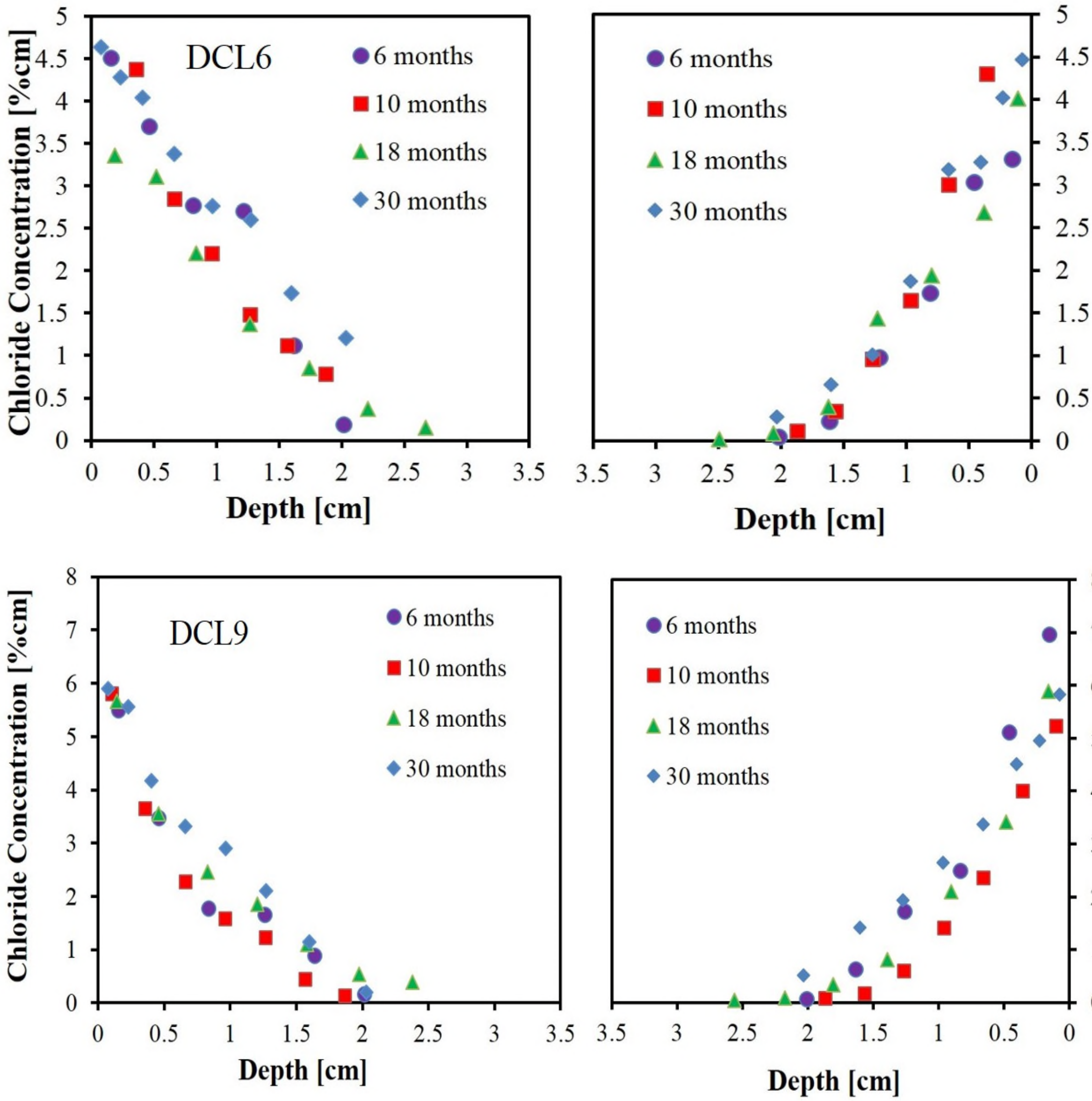


Figure 205. Chloride profile for barge DCL2 to DCL11 at elevation A

M.3.2 Barge: Elevation B





DCL6
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]
DCL9
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]

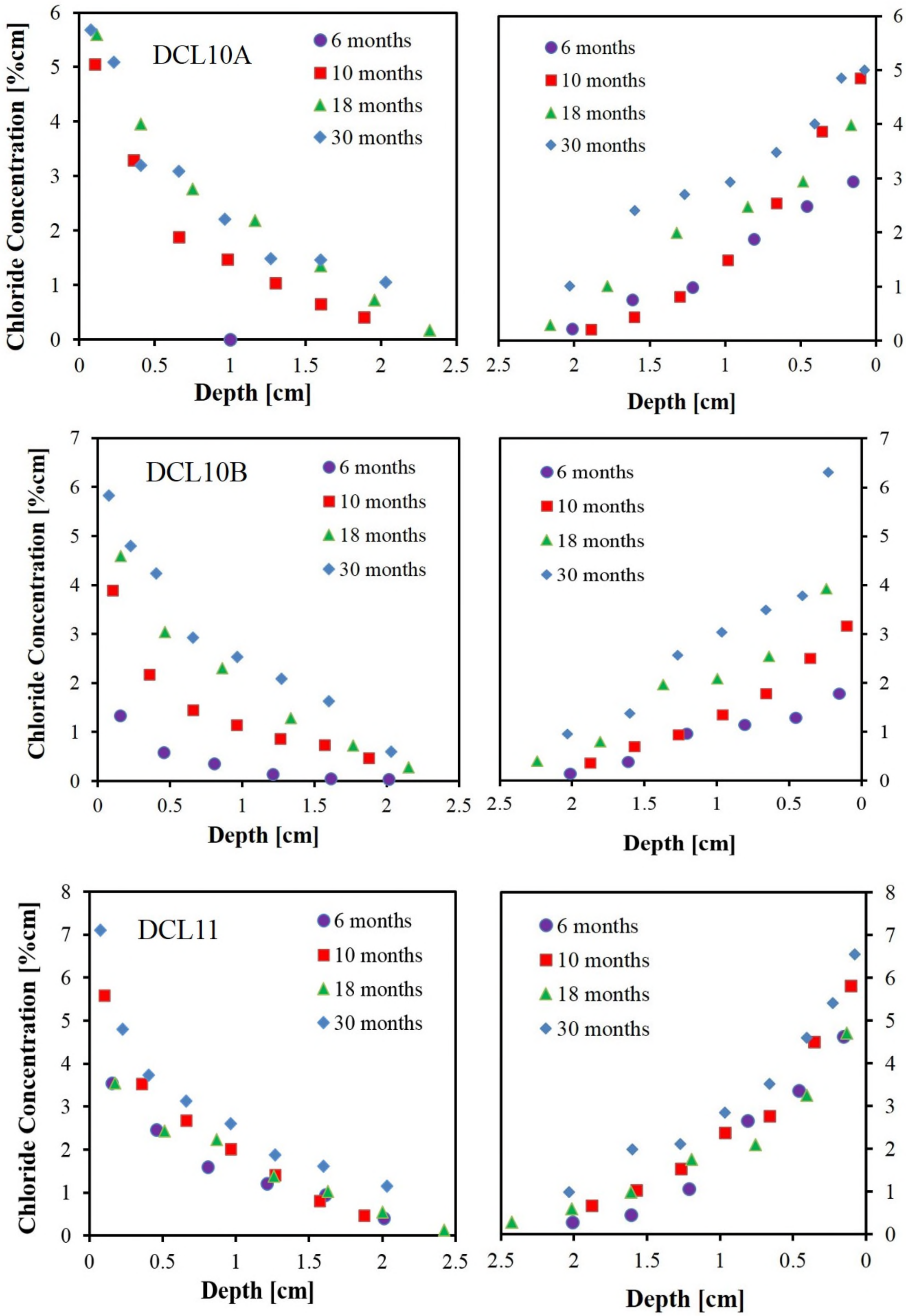
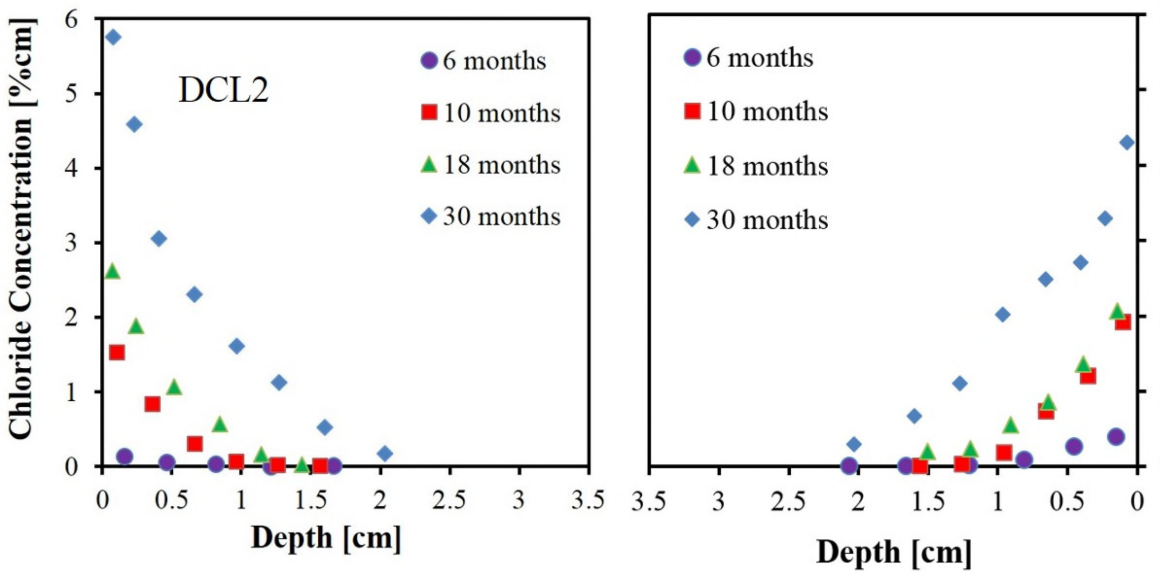
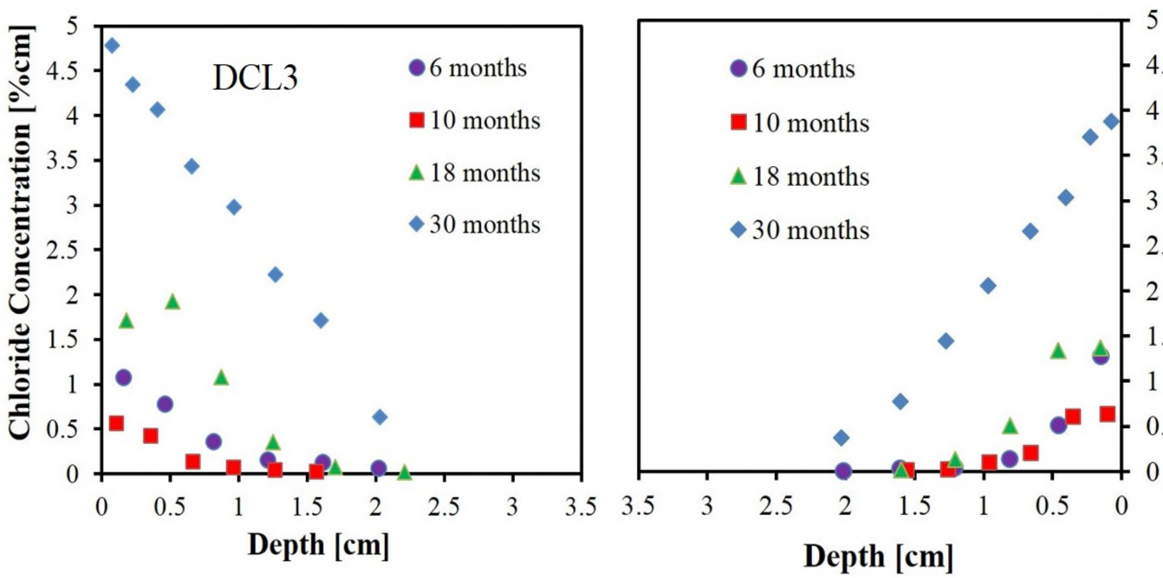
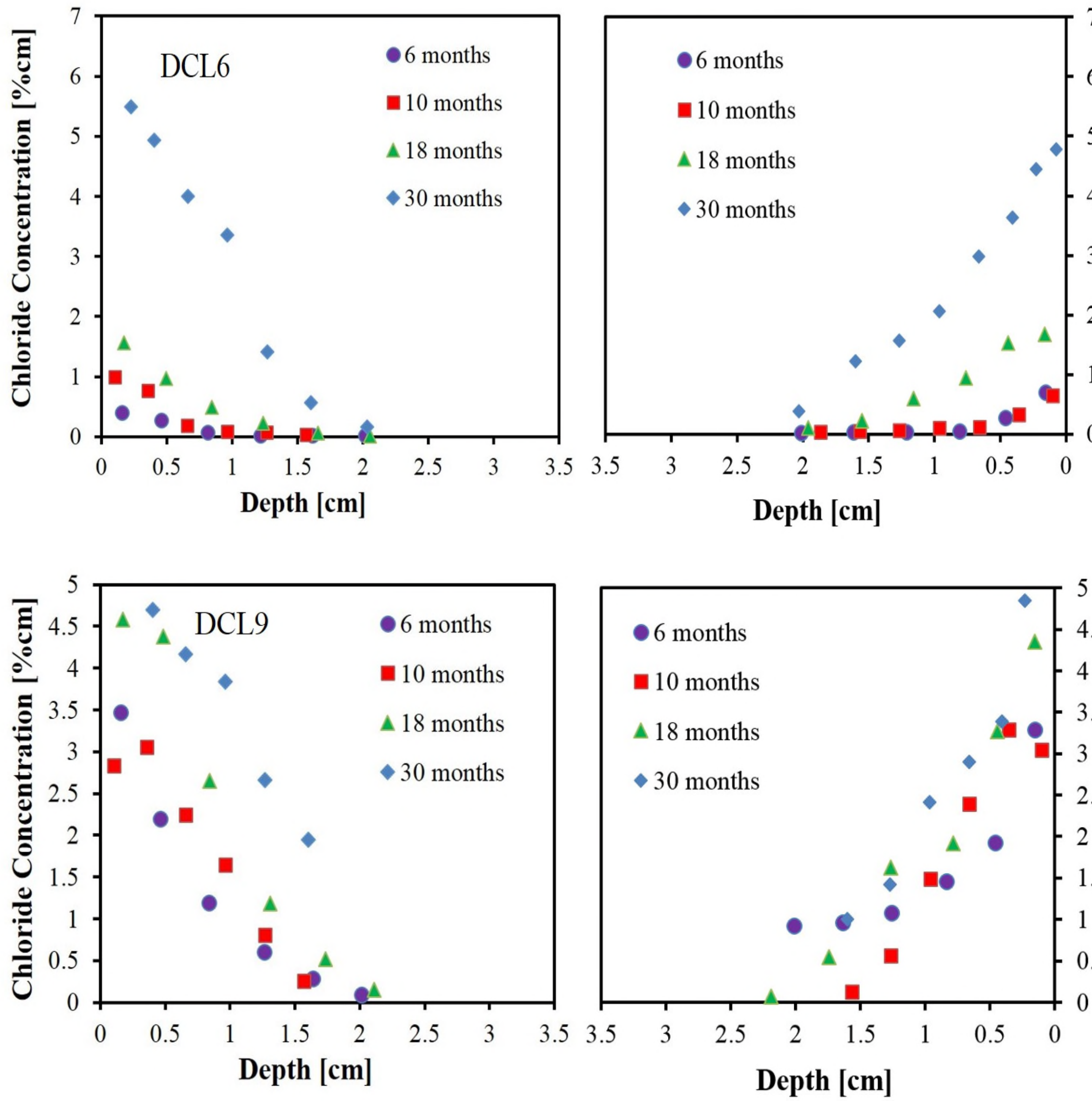


Figure 206. Chloride profile for barge DCL2 to DCL11 at elevation B

M.3.3 Barge: Elevation C






DCL6
6 months
10 months
18 months
30 months
Chloride Concentration [%cm]
Depth [cm]
DCL9
Chloride Concentration [%cm]
Depth [cm]

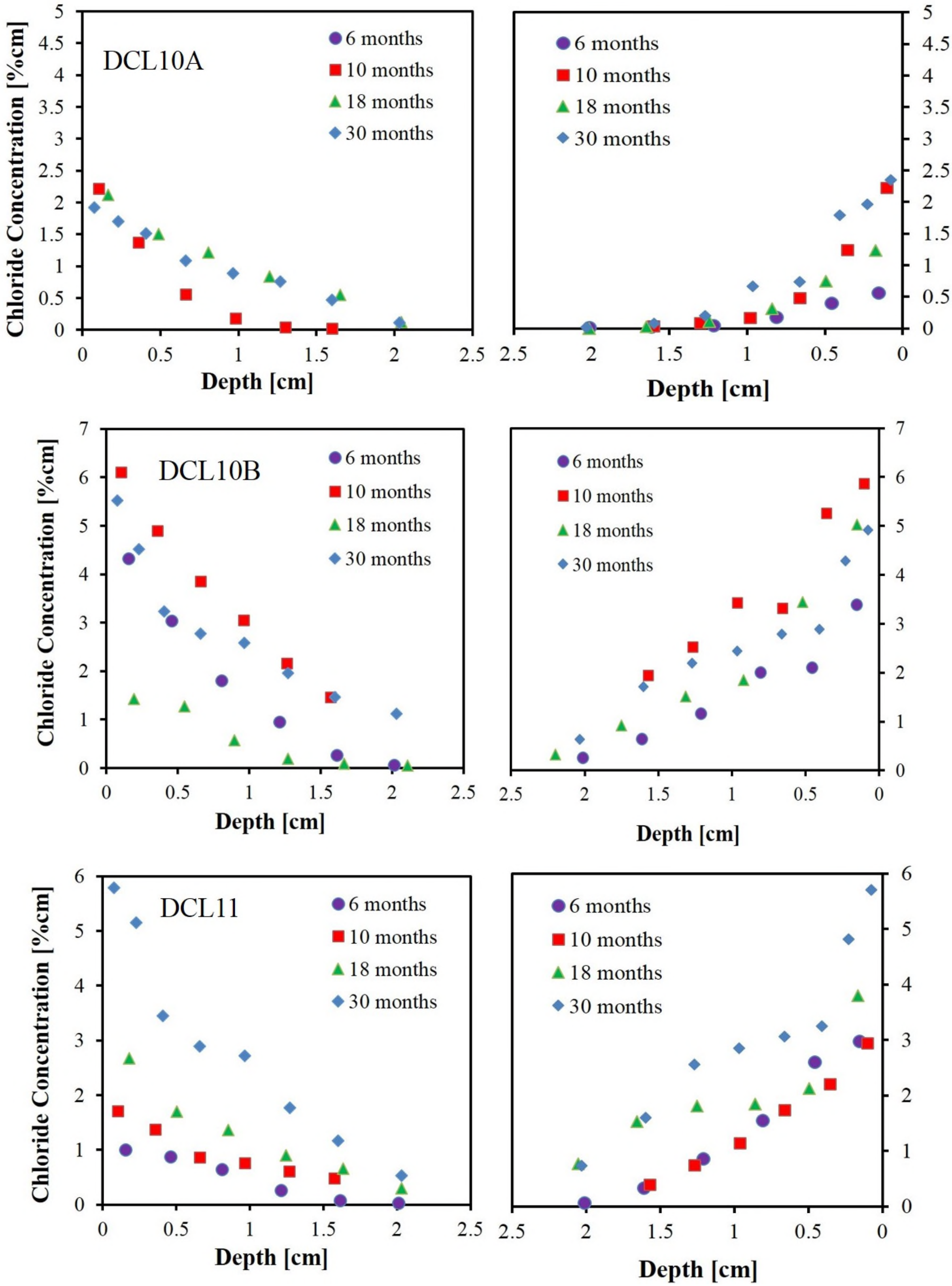
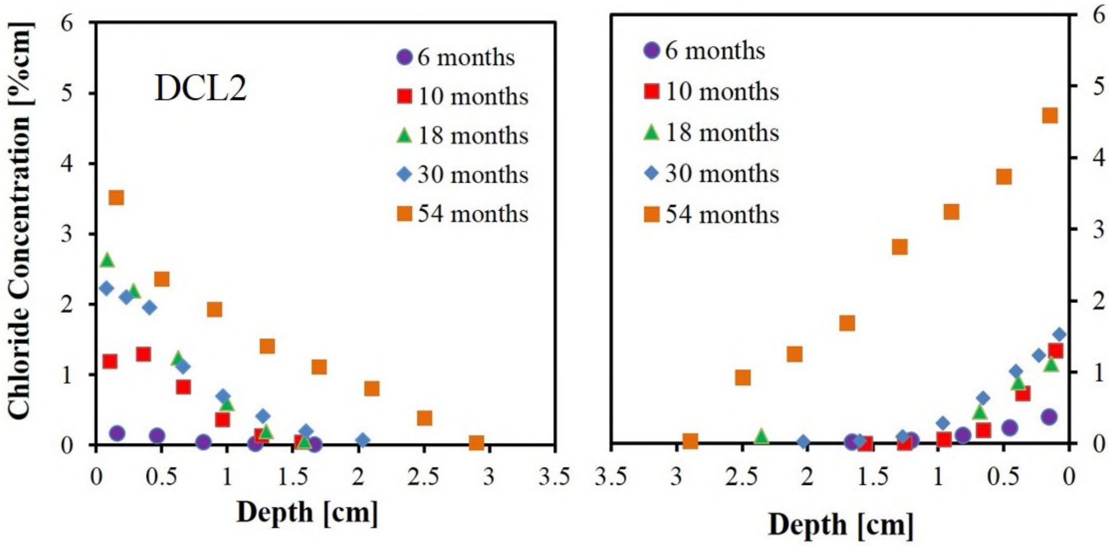
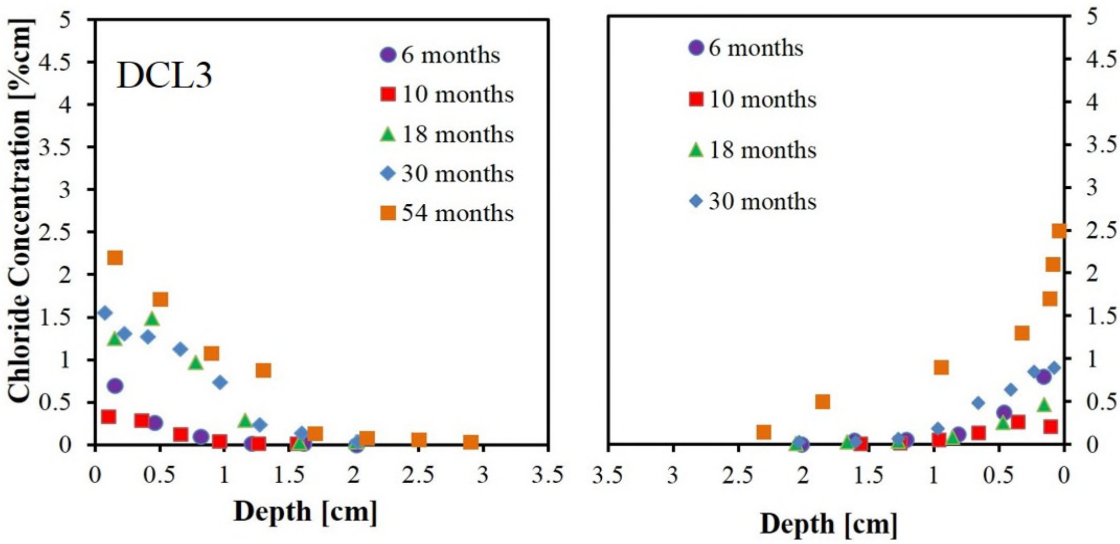
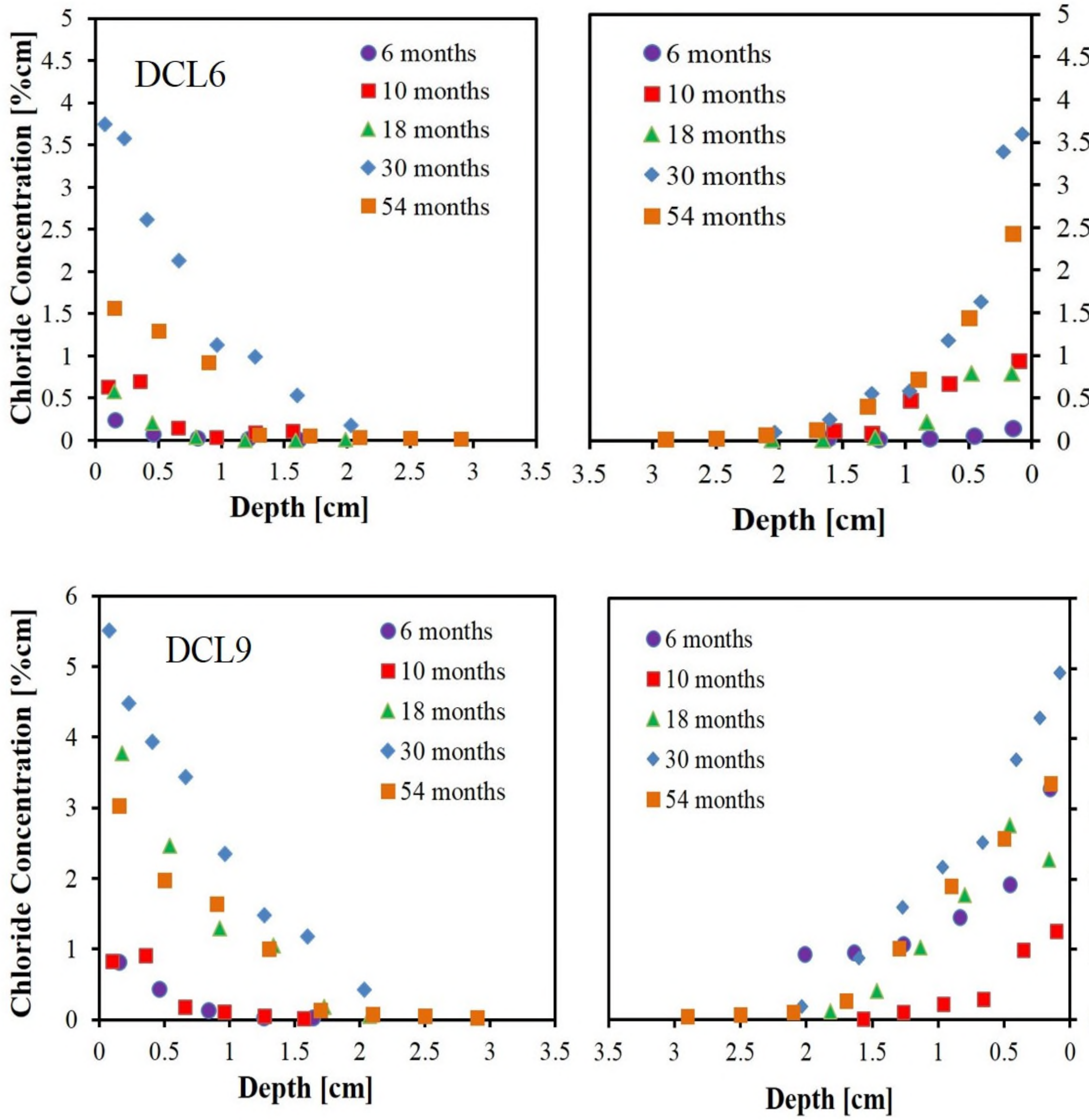


Figure 207. Chloride profile for barge DCL2 to DCL11 at elevation C

M.3.4 Barge: Elevation D






DCL6
6 months
10 months
18 months
30 months
54 months
Chloride Concentration [%cm]
Depth [cm]
DCL9

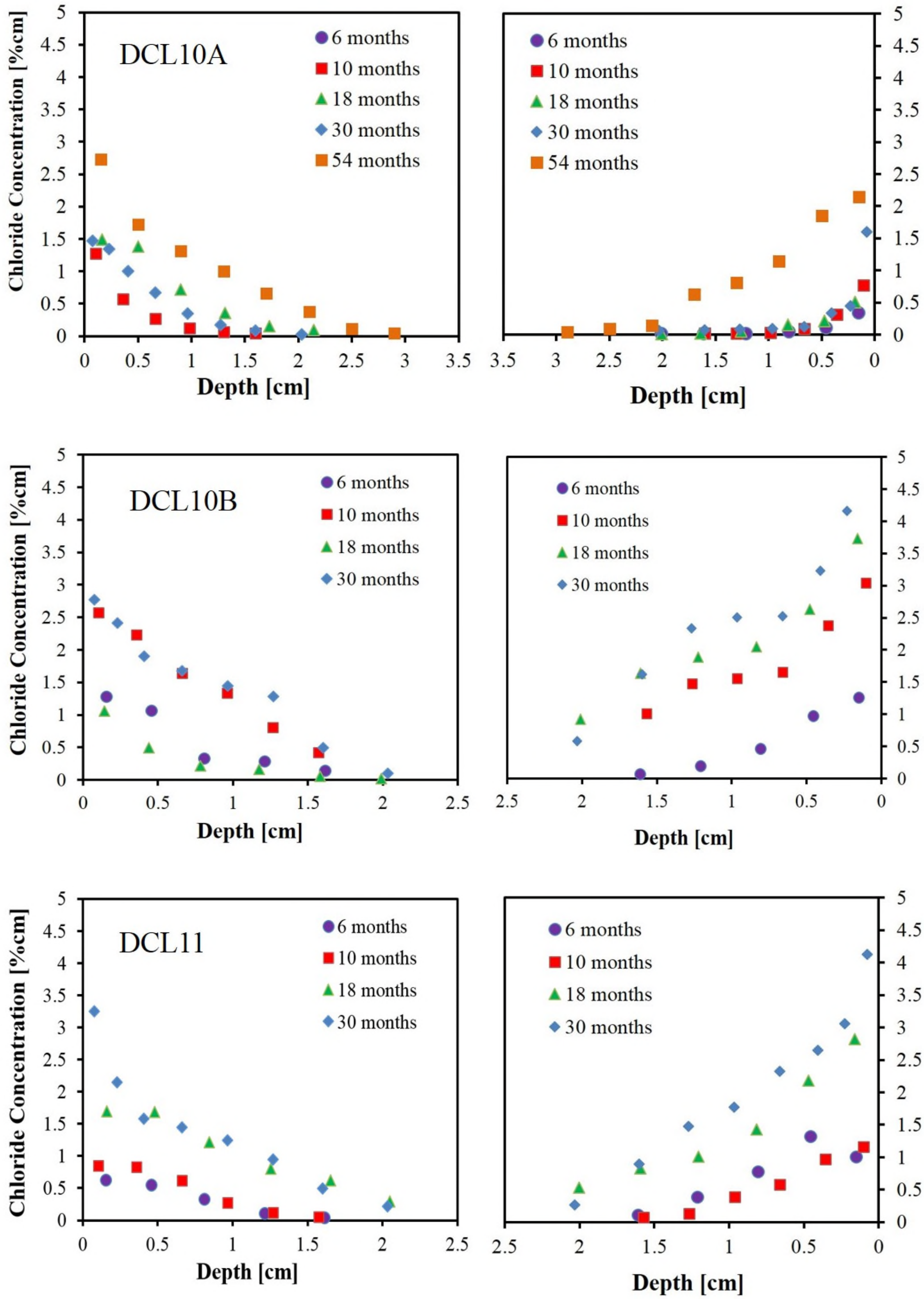


Figure 208. Chloride profile for barge DCL2 to DCL11 at elevation D

Appendix N – D_{app} Values for Field Simulated Exposures

Table 58. Tidal exposure – elevation A

Mix	Side	Apparent chloride diffusivity × 10^{-12} (m^2/s)				
		6 Months	10 Months	18 Months	30 Months	54 Months
DCL1	R	2.28	1.29	1.32		0.18
	L	2.18	1.10	1.05		0.13
DCL2	R	7.04	2.29	0.99	0.55	0.80
	L	4.32	1.25	0.72	0.32	0.42
DCL3	R	4.84	1.75	1.57	1.27	0.95
	L	4.19	0.67	1.33	1.22	0.71
DCL4	R	2.16	1.14	0.96		0.37
	L	2.01	0.89	0.90		0.23
DCL5	R	1.73	1.67	1.35	0.80	0.41
	L	1.64	0.68	0.96	0.67	0.39
DCL6	R	2.28	1.15	0.98	0.54	0.74
	L	1.35	0.91	0.74	0.23	0.70
DCL7	R	2.34	1.05	1.59		0.78
	L	1.19	0.52	0.62		0.34
DCL8	R	1.34	0.94	1.25	0.87	0.63
	L	0.97	0.39	1.08	0.77	0.54
DCL9	R	1.44	1.34	0.79	1.35	0.94
	L	1.21	0.45	0.75	0.54	0.72
DCL10a	R	2.91	1.47	2.25	0.78	
	L	0.65	1.04	2.04	0.69	
DCL10b	R	8.08	2.97	2.49		1.16
	L	2.22	1.60	1.94		0.72
DCL11	R	3.81	1.90	6.58		1.01
	L	2.14		3.78		0.66

Table 59. Tidal exposure - elevation B

Mix	Side	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)				
		6 Months	10 Months	18 Months	30 Months	54 Months
DCL1	R	1.74	1.27	0.67		0.38
	L	1.28	0.32	0.56		0.19
DCL2	R	1.89	0.69	0.39	1.40	0.27
	L	1.02	0.24	0.23	1.06	0.20
DCL3	R	2.14	1.88	2.19	5.10	1.14
	L	1.23	1.86	1.77	3.39	0.72
DCL4	R	1.55	0.89	0.78		0.49
	L	0.74	0.81	0.71		0.21
DCL5	R	1.68	1.29	0.77	0.57	0.47
	L	1.66	0.78	0.67	0.54	0.30
DCL6	R	1.84	1.21	3.20	0.65	0.57
	L	1.55	0.91	0.96	0.60	0.37
DCL7	R	1.33	0.84	0.68		0.48
	L	0.73	0.42	0.25		0.10
DCL8	R	1.98	0.66	0.87	0.78	0.46
	L	1.63	0.62	0.56	0.65	0.21
DCL9	R	1.88	1.18	1.47	0.64	0.61
	L	0.97	0.27	1.43	0.55	0.58
DCL10a	R	6.20	1.93	1.85	1.02	
	L	2.06	1.27	1.27	0.49	
DCL10b	R	3.80	1.97	2.01		0.86
	L	3.77	1.82	1.32		0.74
DCL11	R	3.08	0.92	1.92		0.74
	L	1.92		1.12		0.59

Table 60. Tidal exposure - elevation C

Mix	**Side**	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)				
		6 Months	10 Months	18 Months	30 Months	54 Months
DCL1	R	3.76	0.43	0.55		0.73
	L	0.61	0.27	0.32		0.26
DCL2	R	1.23	0.56	1.01	1.64	
	L	0.22	0.37	0.55	0.58	
DCL3	R	2.63	1.79	1.73	2.11	
	L	1.91	1.56	1.42	1.96	
DCL4	R	0.72	0.97	0.62		0.38
	L	0.68	0.48	0.26		0.17
DCL5	R	2.69	1.35	0.73	0.72	
	L	2.14	0.83	0.70	0.40	
DCL6	R	1.36	1.47	3.20	0.87	
	L	0.86	0.65	0.96	0.51	
DCL7	R	0.95	0.62	0.63		0.34
	L	0.93	0.24	0.42		0.17
DCL8	R	1.32	0.81	0.78	0.68	
	L	0.77	0.61	0.58	0.43	
DCL9	R	0.93	0.86	0.92	0.51	
	L	0.74	0.84	0.85	0.51	
DCL10a	R	2.75	1.48	2.38	0.48	
	L	1.23	0.48	0.65	0.11	
DCL10b	R	2.57	1.57	2.26		0.65
	L	2.24	0.64	1.13		0.64
DCL11	R	1.65		1.74		1.06
	L	1.20	0.75	0.72		0.41

Table 61. Tidal exposure - elevation D

Mix	**Side**	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)				
		6 Months	10 Months	18 Months	30 months	54 months
DCL1	R	0.60	0.21	0.13		0.89
	L	0.18	0.13	0.12		0.56
DCL2	R	0.04	0.58	5.85	0.36	0.78
	L	0.15	0.32	0.10	0.14	0.35
DCL3	R	0.55	0.69	0.66	0.35	0.79
	L	0.26	0.37	0.22	0.19	1.19
DCL4	R	0.71	0.24	0.40		0.33
	L	0.17	0.22	0.14		0.25
DCL5	R	0.85	0.65	0.75	0.52	0.45
	L	0.43	0.50	0.39	0.17	0.28
DCL6	R	1.03	0.42	0.86	0.86	0.44
	L	0.80	0.35	0.23	0.75	0.19
DCL7	R	0.25	0.67	0.35		0.44
	L	0.21	0.55	0.11		0.31
DCL8	R	0.74	0.36	0.54	0.37	0.71
	L	0.60	0.12	0.48	0.18	0.31
DCL9	R	0.90	0.89	0.47	0.58	0.30
	L	0.29	0.70	0.17	0.13	0.76
DCL10a	R	0.63	0.78	2.01	1.03	
	L	0.63	0.52	1.36	0.53	
DCL10b	R	0.74	3.13	0.71		0.60
	L	0.19	1.07	0.15		0.57
DCL11	R	1.09	0.98	0.74		1.11
	L	0.72		0.68		0.96

Table 62. D_{app} for samples exposed at the barge - elevation A.

Mix	**Side**	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)				
		6 Months	10 Months	18 Months	30 Months	54 Months
DCL2	R	8.58	0.6	0.76	0.98	0.81
	L	2.43	0.27	0.73	0.86	0.63
DCL3	R	4.8	4.26	3.04	2.79	1.09
	L	0.74	2.22	1.65	2.09	0.96
DCL6	R	3.04	2.06	2.01	1.04	0.38
	L	0.72	0.63	0.20	0.64	0.36
DCL9	R	2.73	1.57	1.49	0.90	0.61
	L	0.85	1.45	0.77	0.89	0.57
DCL10a	R	N/A	1.14	2.21	1.68	1.13
	L	1.57	1.1	1.67	0.72	0.56
DCL10b	R	4.34	2.96	1.59	0.82	
	L	1.51	2.38	1.38	0.47	
DCL11	R	4.48	2.57	1.98	1.11	
	L	2.55	1.97	1.52	0.47	

Table 63. D_{app} for samples exposed at the barge - elevation B

Mix	**Side**	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)			
		6 Months	10 Months	18 Months	30 moths
DCL2	R	2.31	0.85	0.65	0.68
	L	1.98	0.74	0.61	0.45
DCL3	R	1.21	3.90	2.88	2.30
	L	0.84	2.20	2.06	1.83
DCL6	R	5.62	1.80	2.00	1.98
	L	2.88	1.10	1.22	0.70
DCL9	R	3.03	1.30	1.32	0.93
	L	2.67	1.20	0.77	0.82
DCL10a	R	4.72	1.60	2.20	2.00
	L		1.50	1.59	0.86
DCL10b	R	6.07	2.60	2.10	0.99
	L	1.05	1.70	1.38	0.86
DCL11	R	4.67	2.20	1.98	
	L	3.31	2.00	1.52	0.85

Table 64. D_{app} for samples exposed at the barge - elevation C

Mix	**Side**	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)			
		6 Months	10 Months	18 Months	30 moths
DCL2	R	1.24	0.71	0.55	0.80
	L	0.44	0.41	0.38	0.41
DCL3	R	2.03	0.61	1.16	1.46
	L	0.62	0.40	0.67	0.97
DCL6	R	0.98	0.48	1.10	0.90
	L	0.54	0.36	0.76	0.60
DCL9	R	6.83	1.70	1.28	1.38
	L	2.16	1.30	1.28	0.76
DCL10a	R	1.51	0.55	1.66	0.95
	L	1.51	0.47	0.45	0.33
DCL10b	R	4.54	4.40	1.32	1.40
	L	2.49	3.30	0.86	1.19
DCL11	R	3.10	3.00	3.16	1.28
	L	3.08	2.10	1.56	1.06

Table 65. D_{app} for samples exposed at the barge - elevation D

Mix	**Side**	Apparent chloride diffusivity × 10^{-12} (m^2/s)				
		6 Months	10 Months	18 Months	30 Months	54 Months
DCL2	R	1.31	1.50	0.60	0.48	1.08
	L	1.25	0.37	0.56	0.30	0.83
DCL3	R	0.79	1.80	0.60	0.59	0.49
	L	0.56	0.92	0.33	0.35	0.42
DCL6	R	0.45	3.10	0.60	0.58	0.28
	L	0.36	0.67	0.14	0.23	0.22
DCL9	R	0.97	0.71	0.85	0.76	0.40
	L	0.93	0.22	0.27		0.39
DCL10a	R	0.39	0.38	0.30	0.35	0.59
	L	0.39	0.24	1.18	0.25	0.58
DCL10b	R	2.12	4.70	3.35	1.08	
	L	2.06	2.70	0.30	0.97	
DCL11	R	4.14	1.40	2.50	0.94	
	L	2.47	1.10	1.82	0.71	

Table 66. D_{app} for samples exposed to splash environment - elevation A

Mix	Apparent chloride diffusivity× 10^{-12} (m^2/s)				
	6 Months	10 Months	18 Months	30 months	54 months
	100% Seawater				
DCL1	0.67	0.52	0.41	0.50	
DCL2	2.23	0.78	0.58	0.49	0.63
DCL3	12.35	1.86	2.63	1.35	1.37
DCL4	1.20	0.56	0.57	0.35	0.60
DCL5	0.80	0.85	0.27	0.42	0.92
DCL6	2.17	0.39	0.14	0.34	0.87
DCL7	0.72	1.06	0.28	0.09	0.55
DCL8	1.44	0.38	0.49	0.21	0.65
DCL9	0.30	0.21	0.16	0.10	0.80
DCL10a	2.55	1.05	1.38	0.91	0.85
DCL10b	2.73	3.08	2.41	2.16	0.82
DCL11	0.38	0.17	0.13	0.16	0.10
	90% Tap water/10% Seawater				
DCL3	0.44	1.36	0.864	0.37	0.37
DCL6	0.58	0.31	1.24	0.28	0.50
DCL9	0.22	0.11	0.29	0.25	0.51

Table 67. D_{app} for samples exposed to splash environment - elevation B.

Mix	Apparent chloride diffusivity × 10^{-12} (m^2/s)			
	6 Months	10 Months	18 Months	30 months
	100% Seawater			
DCL1	0.64	0.37	1.06	0.76
DCL2	0.86	0.37	0.45	0.86
DCL3	3.82	0.51	0.25	2.00
DCL4	1.28	0.40	0.33	0.21
DCL5	1.90	1.19	0.86	0.48
DCL6	0.74	0.54	0.26	0.07
DCL7	0.85	0.75	0.71	0.70
DCL8	2.79	0.81	0.74	0.43
DCL9	0.33	0.30	0.15	0.24
DCL10a	1.95	0.76	1.24	0.71
DCL10b	4.19	1.53	3.14	2.31
DCL11	0.47	0.53	0.56	0.20
	90% Tap water/10% Seawater			
DCL3	3.06	2.03	4.32	2.67
DCL6	0.33	1.15	0.73	0.23
DCL9	1.09	0.11	0.77	0.15

Table 68. D_{app} for samples exposed to splash environment - elevation C.

Mix	Apparent chloride diffusivity × 10^{-12} (m^2/s)			
	6 Months	10 Months	18 Months	30 months
	100% Seawater			
DCL1	0.96	0.49	0.38	0.25
DCL2	1.21	0.74	0.3	0.89
DCL3	2.75	0.43	2.8	1.81
DCL4	1.15	0.42	0.17	0.23
DCL5	1.04	1.31	0.28	0.44
DCL6	1	0.66	0.82	0.70
DCL7	1.43	0.36	0.34	0.37
DCL8	1.2	0.66	0.56	0.85
DCL9	0.23	0.32	0.37	0.22
DCL10a	2.46	1.38	0.71	1.04
DCL10b	1.51	1.18	1.22	1.05
DCL11	0.26	0.54	0.19	0.31
	90% Tap water/10% Seawater			
DCL3	2.9	1.05	1.25	0.57
DCL6	0.37	0.25	0.5	0.11
DCL9	0.51	0.11	0.2	0.27

Table 69. D_{app} for samples exposed to splash environment - elevation D

Mix	Apparent chloride diffusivity $\times 10^{-12}$ (m^2/s)				
	6 Months	10 Months	18 Months	30 months	54 months
	100% Seawater				
DCL1	3.82	0.5	0.25	0.38	0.61
DCL2	0.49	0.66	0.77	0.97	0.85
DCL3	0.77	1.06	3.04	2.67	0.63
DCL4	3.82	0.5	0.86	0.32	0.41
DCL5	0.49	1.27	1.15	0.79	0.77
DCL6	0.77	0.49	1.4	1.02	1.05
DCL7	3.82	0.87	0.71	0.54	0.65
DCL8	0.49	0.17	0.87	0.65	0.94
DCL9	0.77	0.54	2.05	1.05	0.84
DCL10a	3.82	1.17	1.57	1.45	0.69
DCL10b	0.49	1.03	2.07	2.13	1.23
DCL11	0.77	4.63	2.57	2.73	0.61
	90% Tap water/10% Seawater				
DCL3	3.82	1.79	4.49	3.88	1.12
DCL6	0.49	0.32	0.81	0.64	0.57
DCL9	0.77	0.38	0.95	0.46	0.34

Appendix O – D_{nssd} for DCL1 to DCL10

Table 70. D_{nssd} for DC1 to DC10B

Mix	Sample ID	D_{nssd} all Layers × 10^{-12} (m^2/s)	D_{nssd} 1 Layer Removed × 10^{-12} (m^2/s)
DC1	**1**	0.50	0.67
	7	1.02	1.31
	24	0.61	0.91
DC2	**2**	1.32	1.72
	7	0.38	1.40
	23	0.85	1.51
DC3	**1**	1.41	1.60
	7	1.19	1.65
	23	0.58	0.88
DC4	**1**	0.37	0.46
	7	0.55	0.47
	27	0.42	0.56
DC5	**1**	0.58	0.94
	7	0.52	0.97
	26	0.48	1.13
	27	0.63	0.61
DC6	**1**	0.71	1.01
	7	0.87	1.26
	26	0.24	0.51
	27	0.36	0.98
DC7	**1**	0.66	0.56
	7	0.80	1.22
	26	0.46	0.64
	27	0.87	1.40
DC8	**1**	0.53	1.47
	7	0.40	0.54
	26	0.76	0.93
	27	1.05	1.17
DC9	**1**	0.73	0.82
	7	1.63	1.83
	26	1.19	1.44
	27	0.76	1.22
DC10	**1**	1.07	1.72

Table 70 continues

DC10A	**1**	1.10	1.96
	7	0.83	1.50
	24	0.87	0.99
	27	1.08	1.04
DC10B	**1**	1.49	1.81
	7	1.29	1.17
	24	0.66	1.39

Table 71. D_{nssd} for different immersion time. (DC1 to DC11).

Mix	D_{nssd} Chloride Diffusivity ($\times 10^{-12}$ m^2/s) / All layers					
		700 Days	1950 Days (1-6)	1950 Days (7-15)	1950 Days (22-36)	
	NC	RT	14RT/14ET/RT	14RT/28ET/RT	RT	
DCL 1	1.98	0.95	0.50	1.02	0.61	
DCL 2	2.11	0.92	1.32	0.38	0.85	
DCL 3	2.90	1.87	1.41	1.19	0.58	
DCL 4	1.95	0.60	0.37	0.55	0.42	
DCL 5	2.01	0.42	0.58	0.52	0.48	0.63
DCL 6	2.80	0.99	0.71	0.87	0.24	0.36
DCL 7	2.01	1.36	0.66	0.80	0.46	0.87
DCL 8	2.03	1.05	0.53	0.40	0.76	1.05
DCL 9	2.28	1.31	0.73	1.63	1.19	0.76
DCL 10	3.91	2.20	1.07			
DCL 10a	3.45	1.75	1.10	0.83	0.87	1.08
DCL 10b	3.40		1.49	1.29	0.66	
DCL 11	4.06					

Table 72. D_{nssd} for different immersion time. (DC1 to DC11). One layer removed

Mix	Chloride Diffusivity (× 10^{-12} m^2/s) / Layer one removed					
		700 Days	1950 Days (1-6)	1950 Days (7-15)	1950 Days (22-36)	
	NC	RT	14RT/14ET/RT	14RT/28ET/RT	RT	
DCL 1	1.98	0.95	0.67	1.31	0.91	
DCL 2	2.11	0.92	1.72	1.40	1.51	
DCL 3	2.90	1.87	1.60	1.65	0.88	
DCL 4	1.95	0.60	0.46	0.47	0.56	
DCL 5	2.01	0.42	0.94	0.97	1.13	0.61
DCL 6	2.80	0.99	1.01	1.26	0.51	0.98
DCL 7	2.01	1.36	0.56	1.22	0.64	1.40
DCL 8	2.03	1.05	1.47	0.54	0.93	1.17
DCL 9	2.28	1.31	0.81	1.83	1.44	1.22
DCL 10	3.91	2.20	1.72			
DCL 10a	3.45	1.75	1.96	1.50	0.99	1.04
DCL 10b	3.40		1.81	1.17	1.39	
DCL 11	4.06					

Appendix P – D_{nssm} vs. Resistivity for Other Groupings

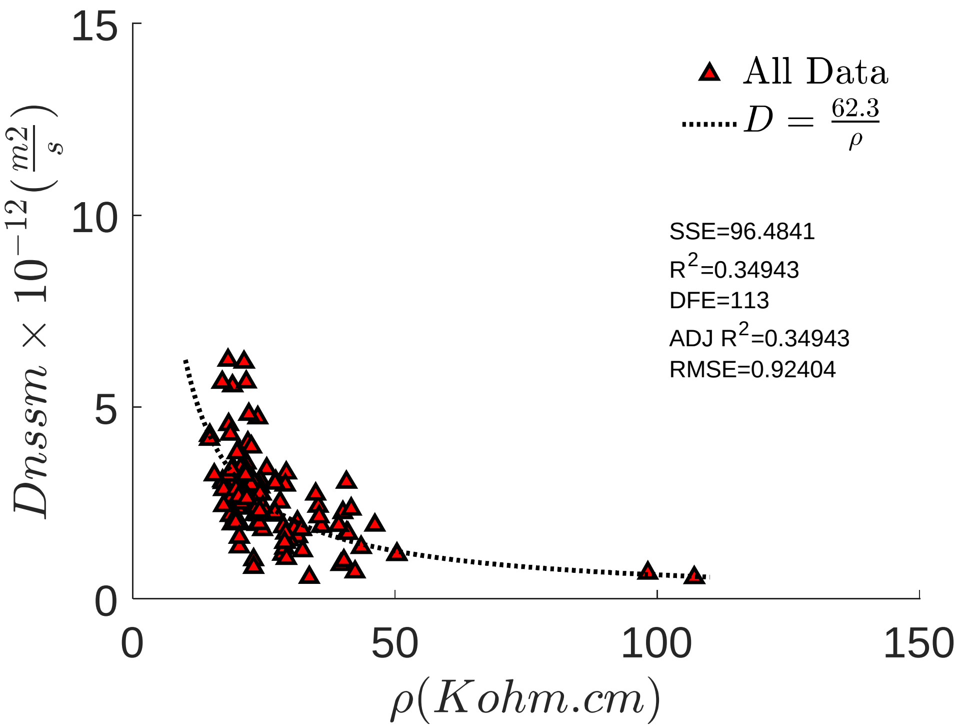


Figure 209. D_{nssm} vs. resistivity for samples prepared with slag (as cementitious replacement)

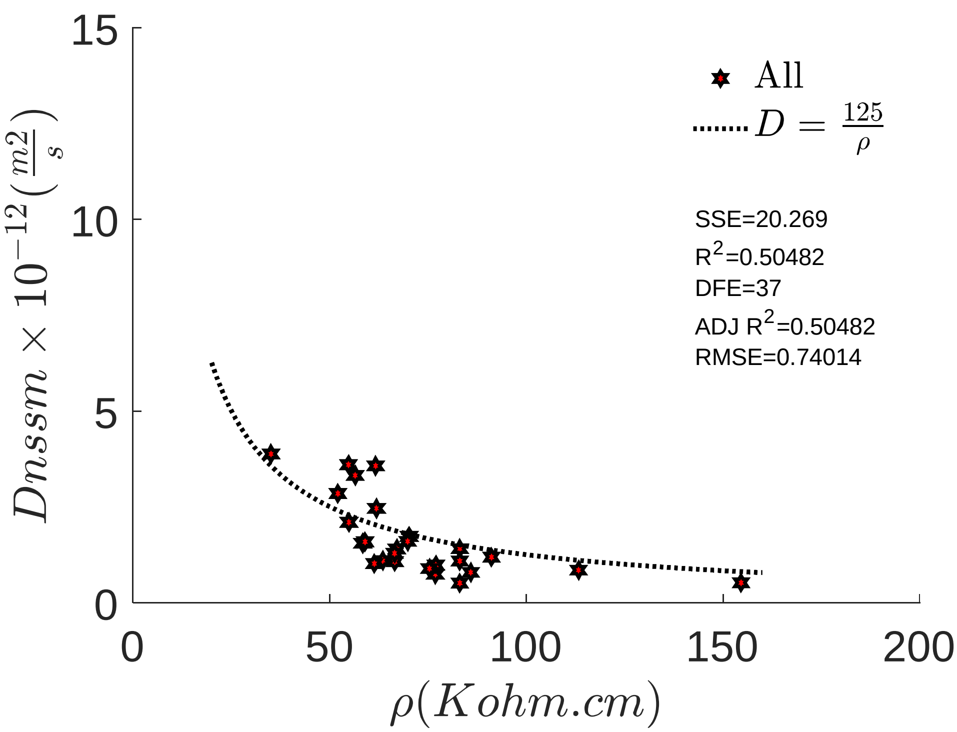


Figure 210. D_{nssm} vs. resistivity for samples prepared with fly ash and slag

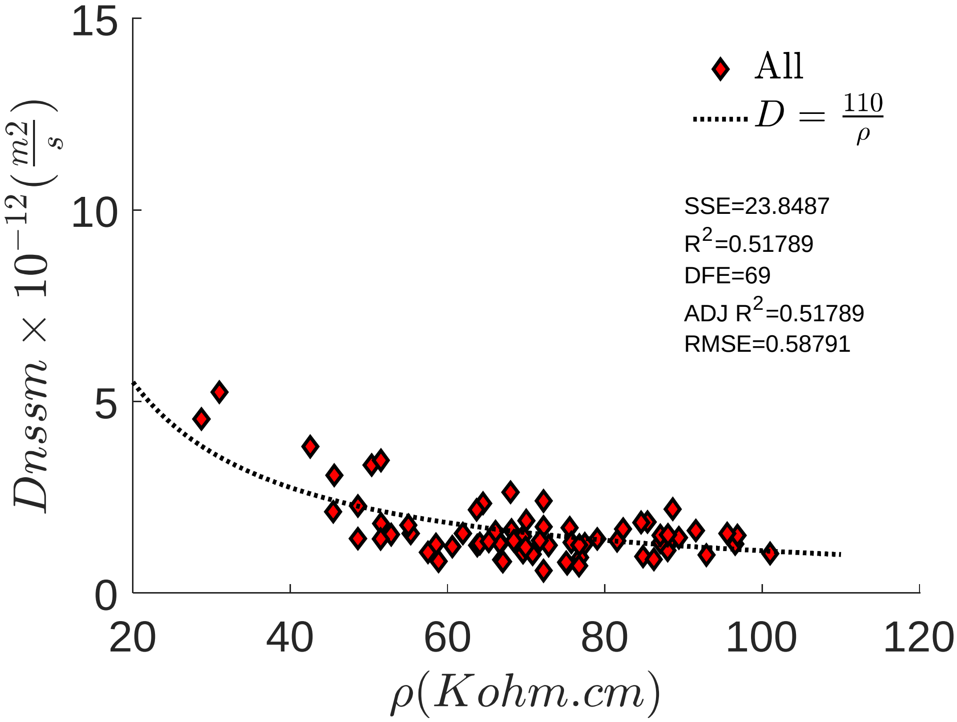


Figure 211. D_{nssm} vs. resistivity for samples prepared with fly ash and silica fume

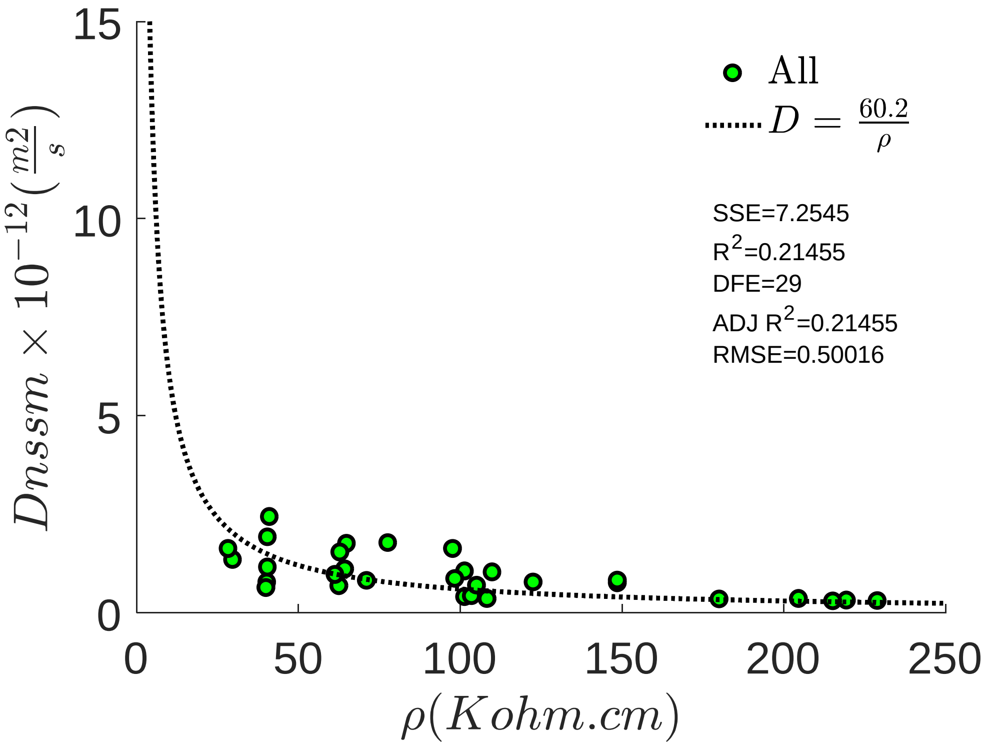


Figure 212. D_{nssm} vs. resistivity for samples with various amounts of fly ash (A, B, D, J samples)

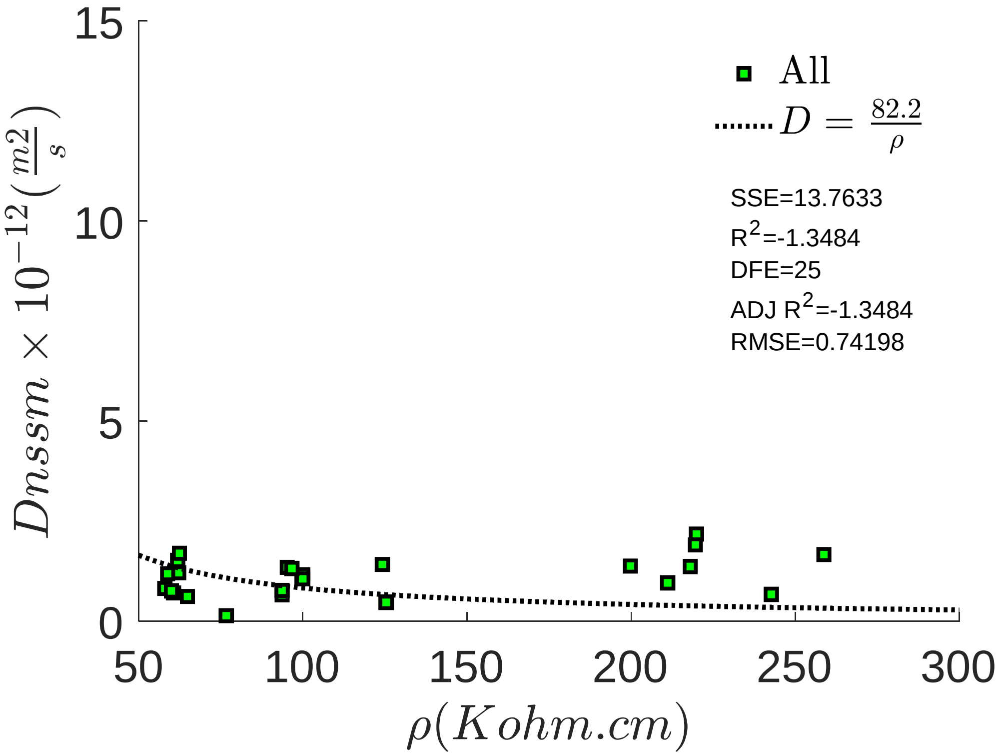


Figure 213. D_{nssm} vs. resistivity for samples with various amounts of fly ash (C, K, and L samples)

Appendix Q – D_{app} vs. Exposure Time

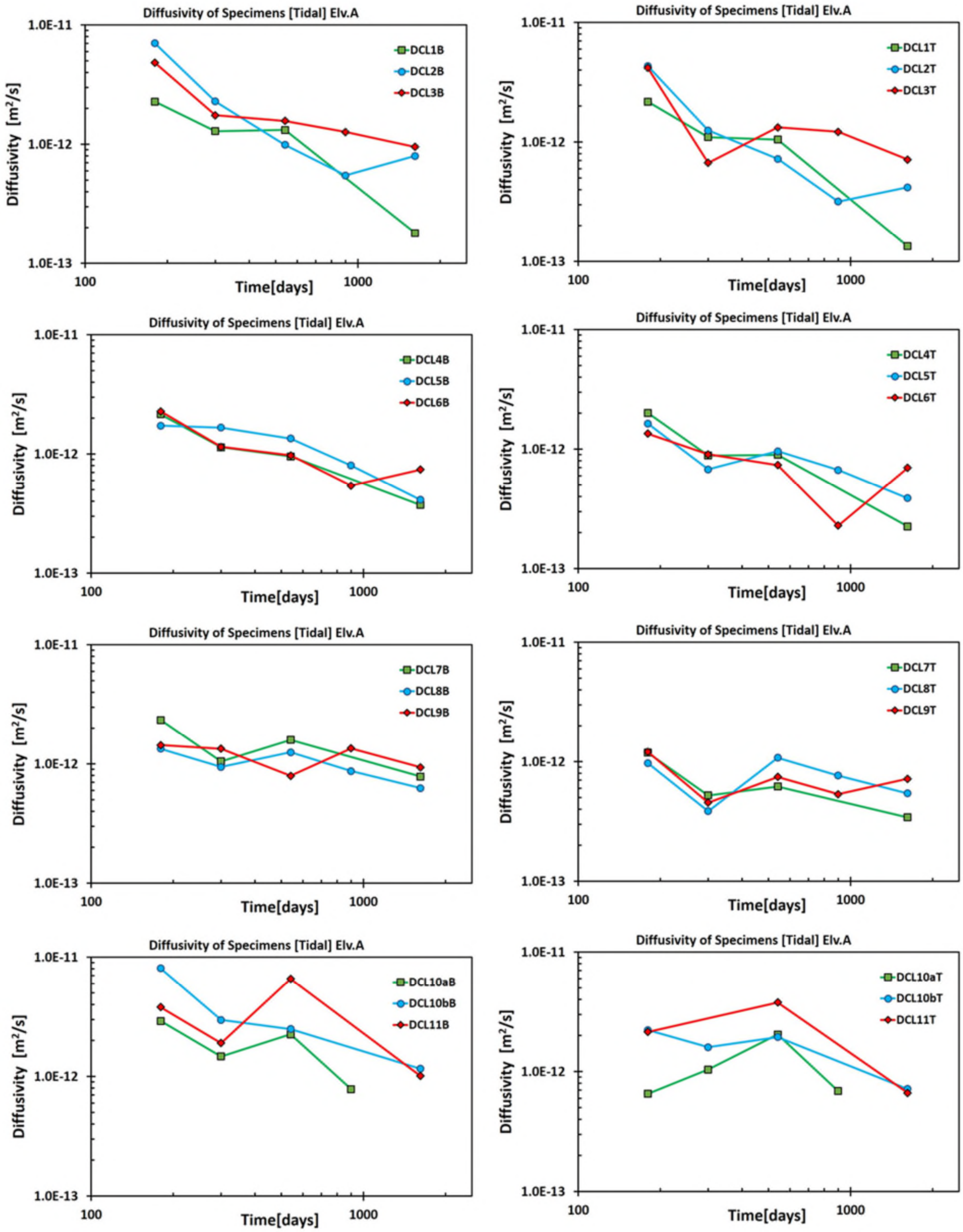


Figure 214. D_{app} vs. exposure time: tidal elevation A

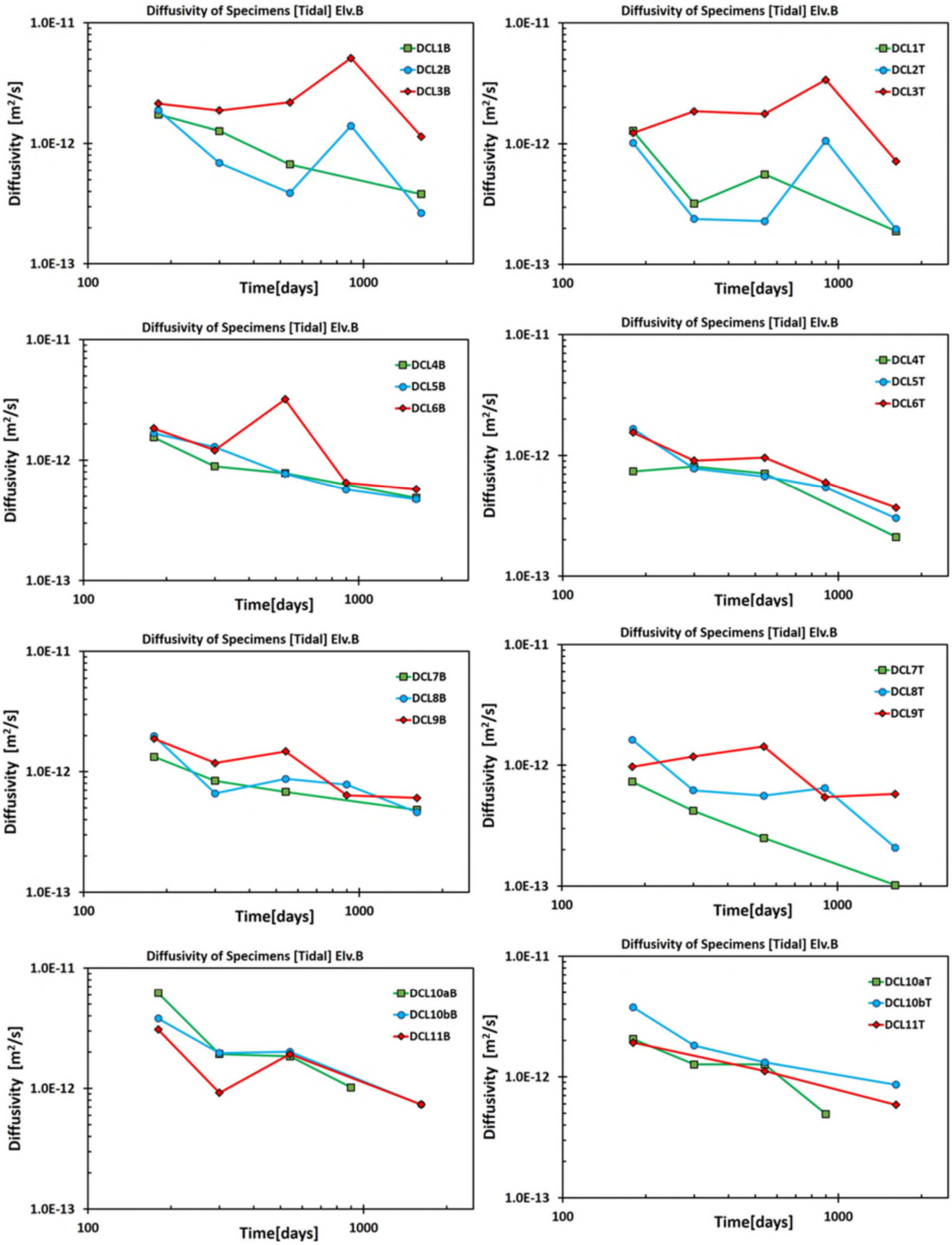


Figure 215. D_{app} vs. exposure time: tidal elevation B

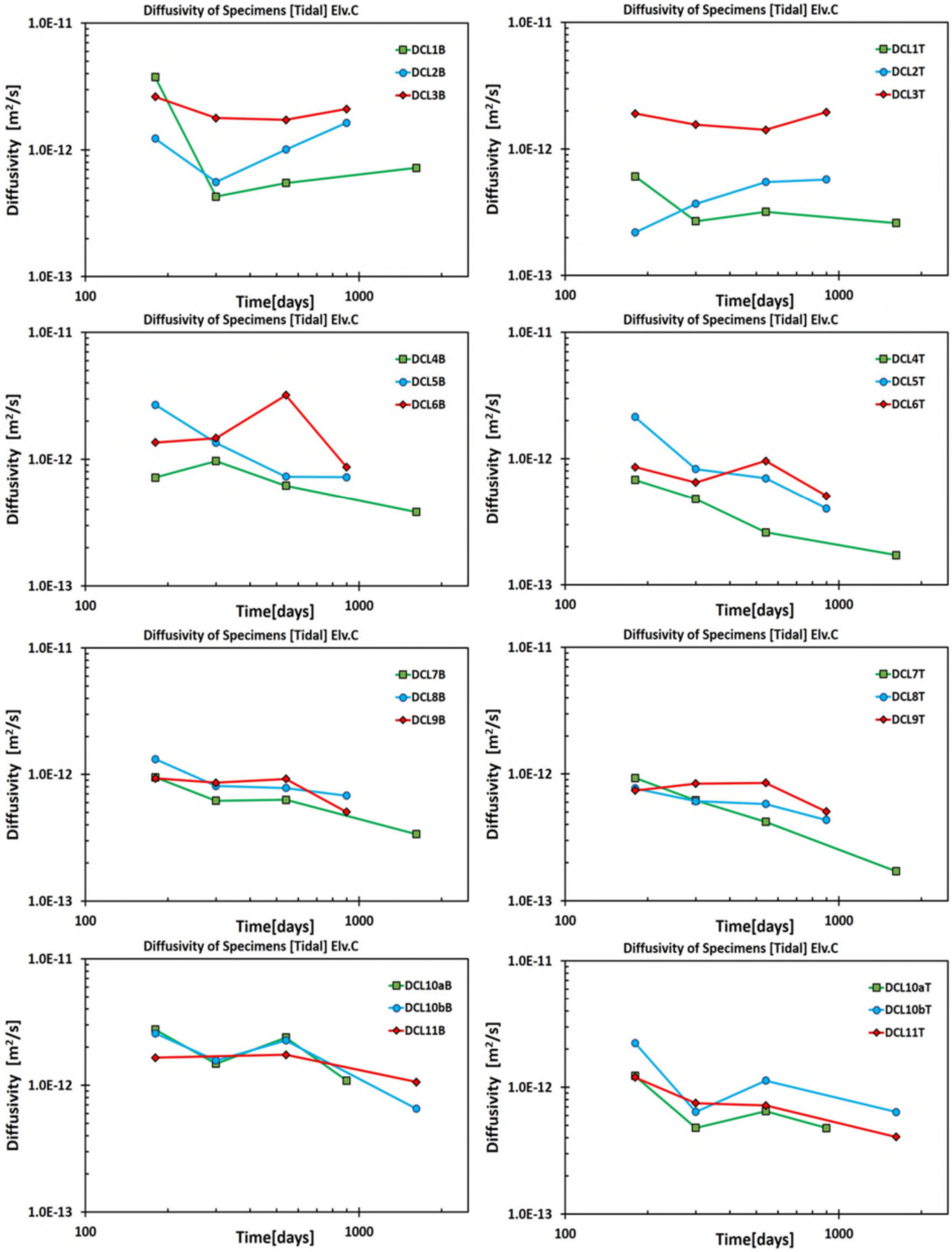


Figure 216. D_{app} vs. time: tidal elevation C

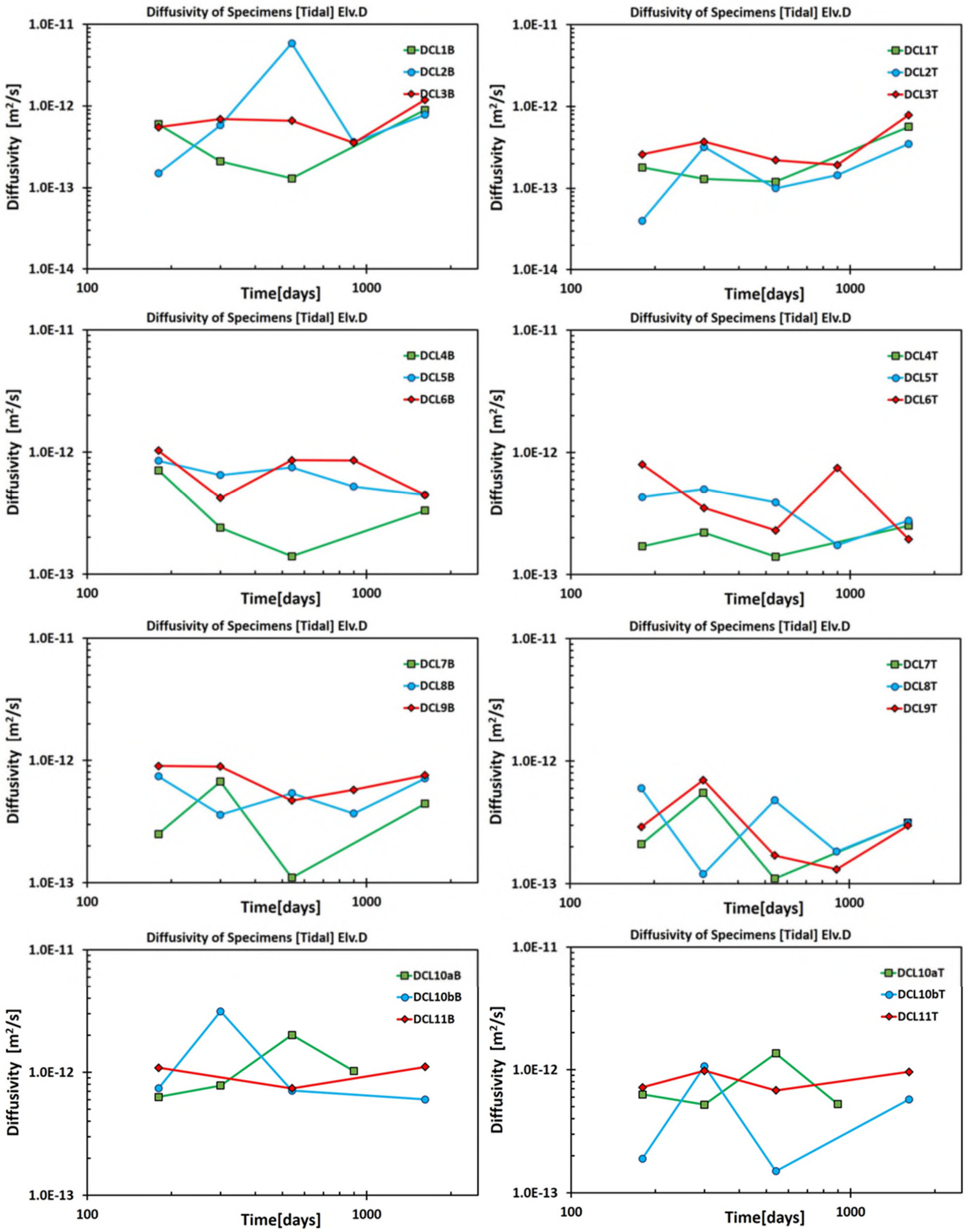


Figure 217. D_{app} vs. time: tidal elevation D

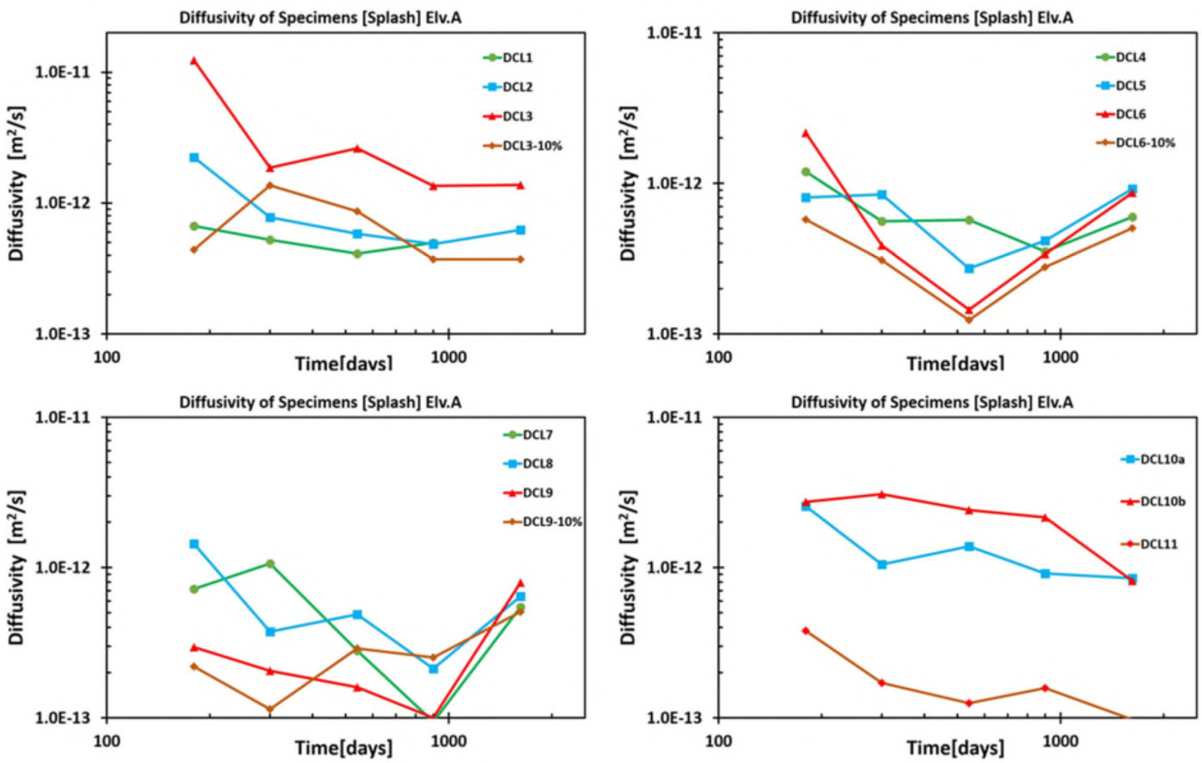


Figure 218. Splash elevation A

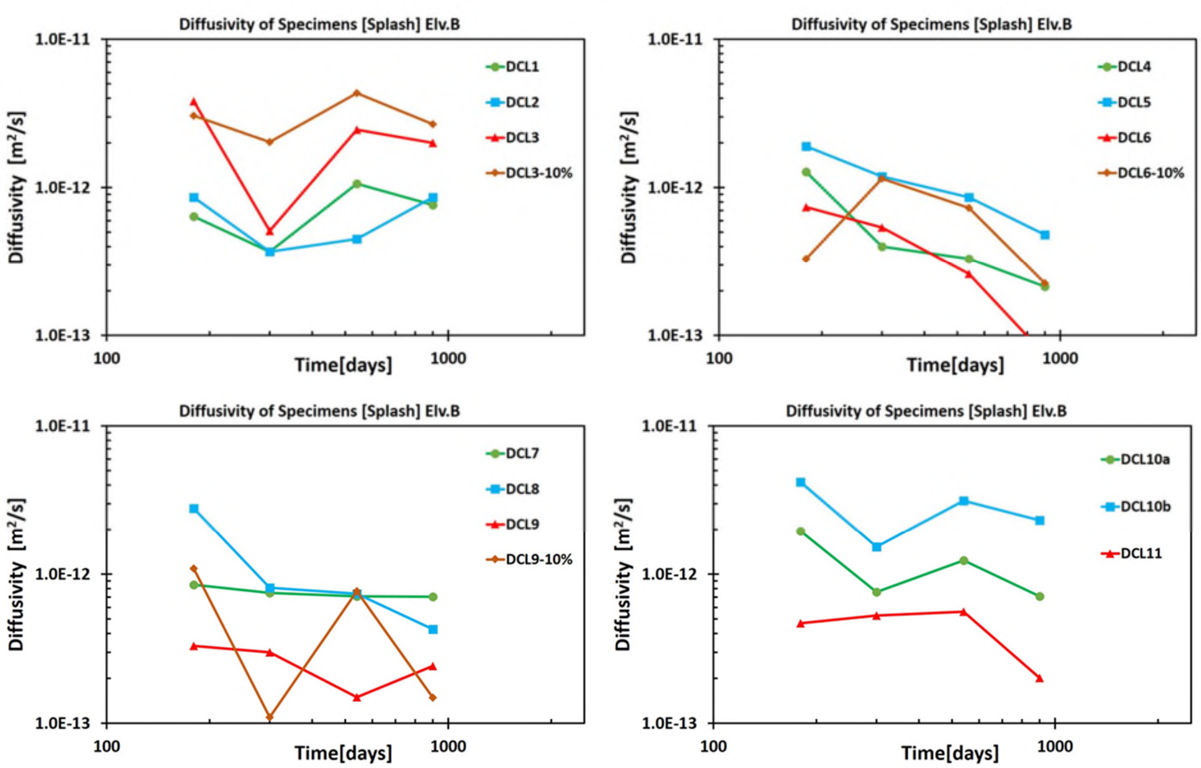


Figure 219. Splash elevation B

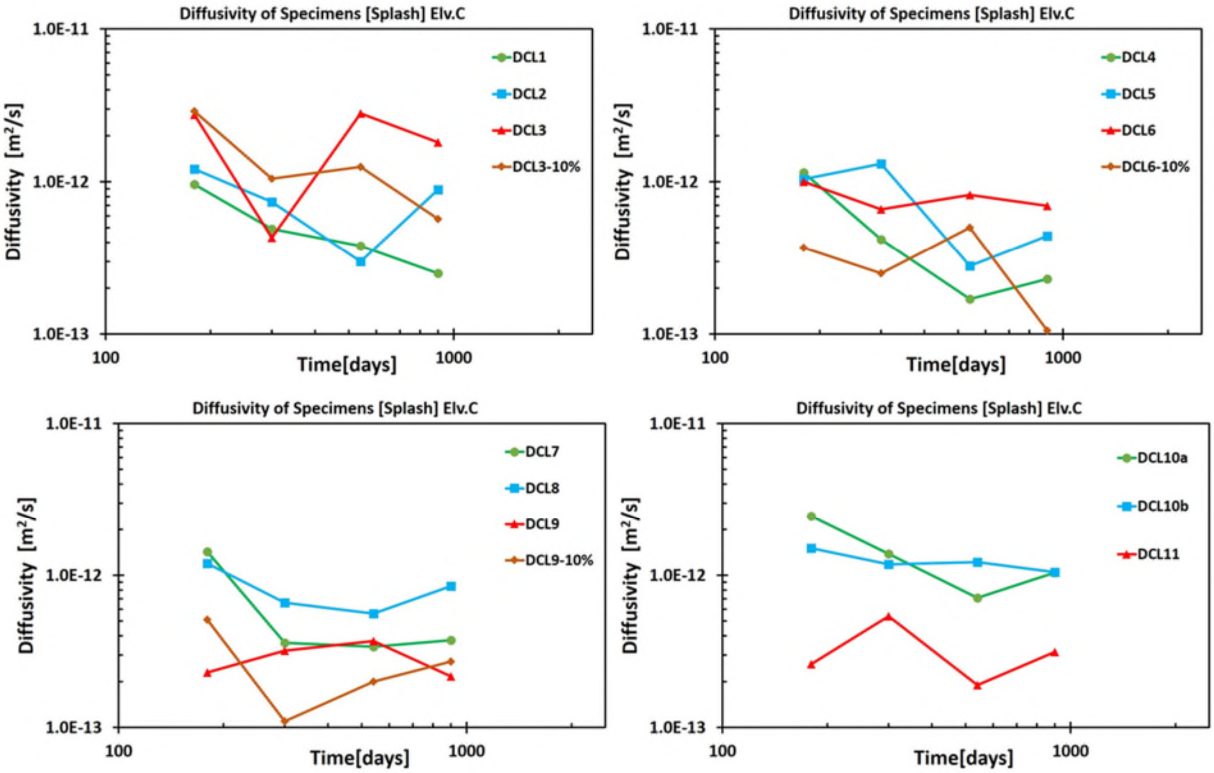


Figure 220. Splash elevation C

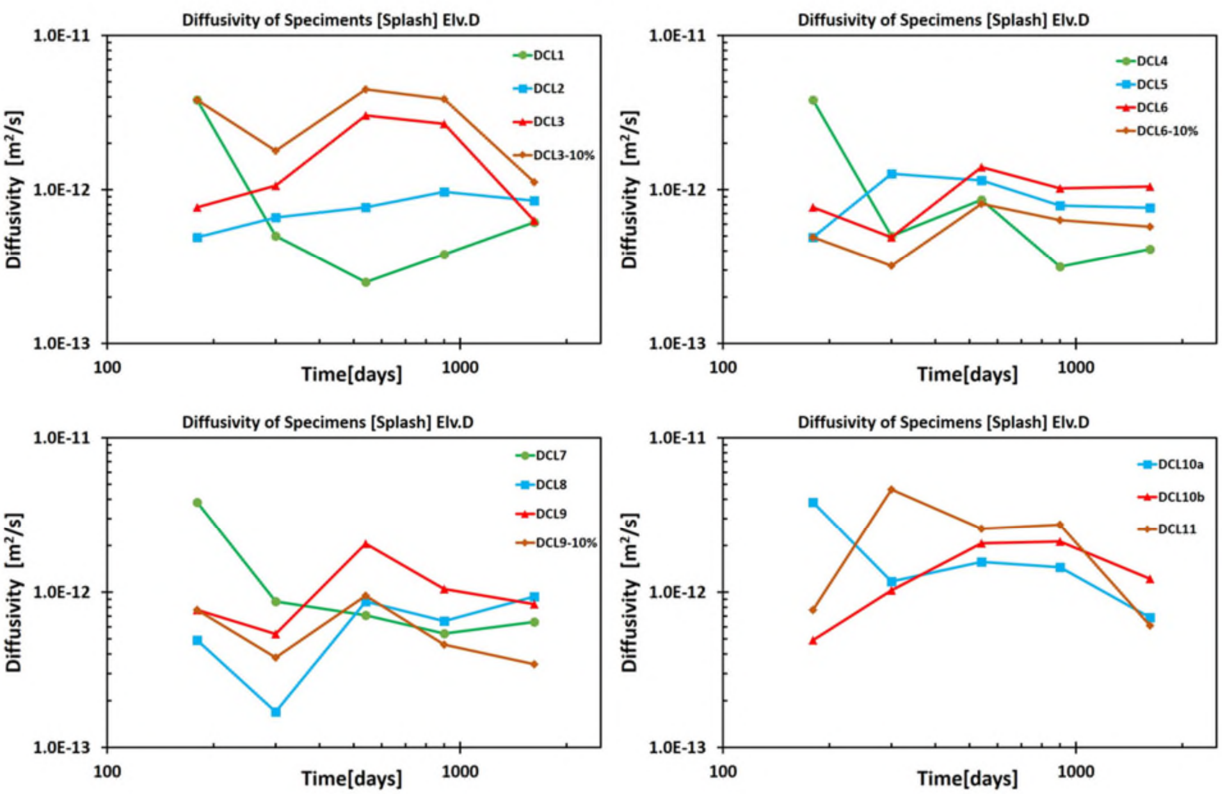


Figure 221. Splash elevation D

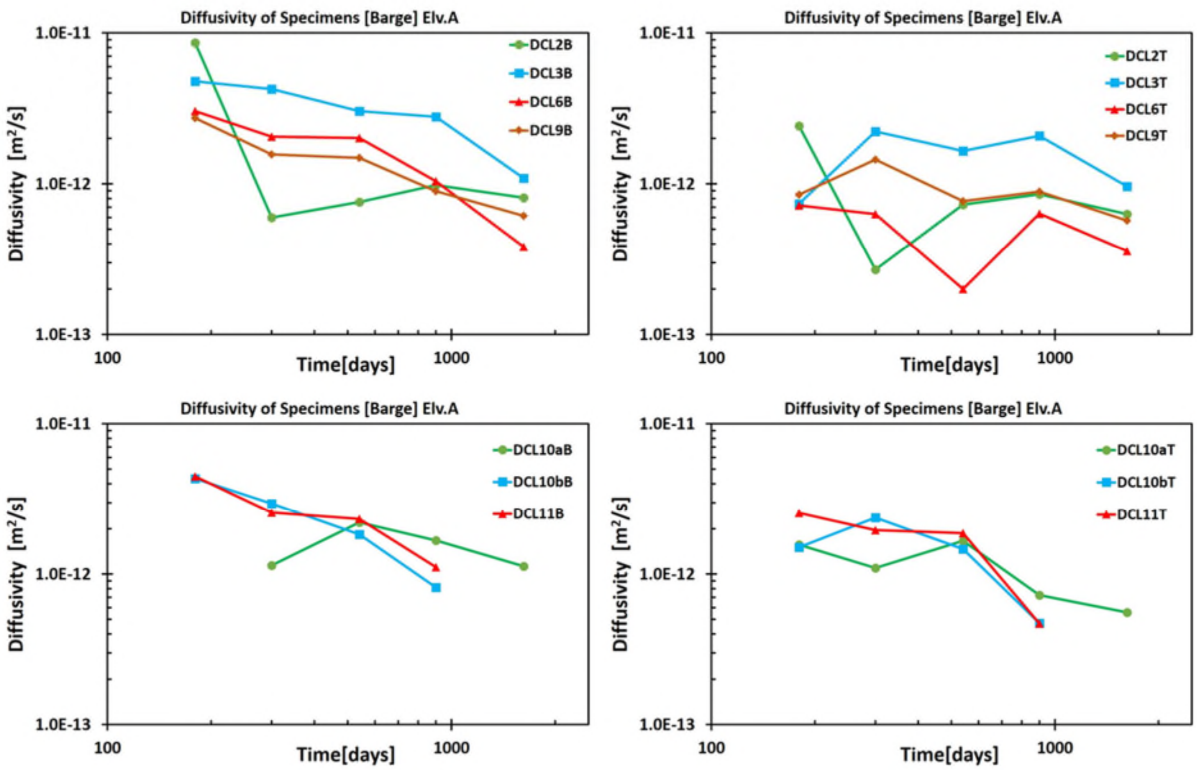


Figure 222. Barge elevation A

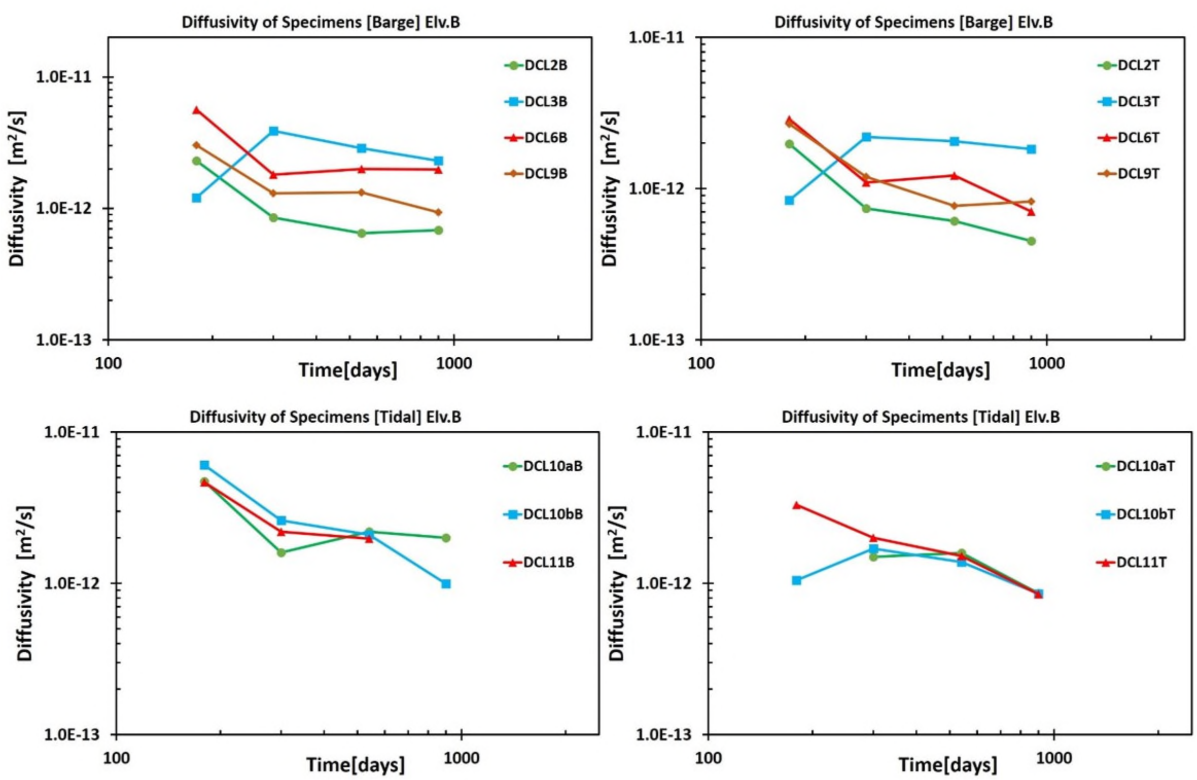


Figure 223. Barge elevation B

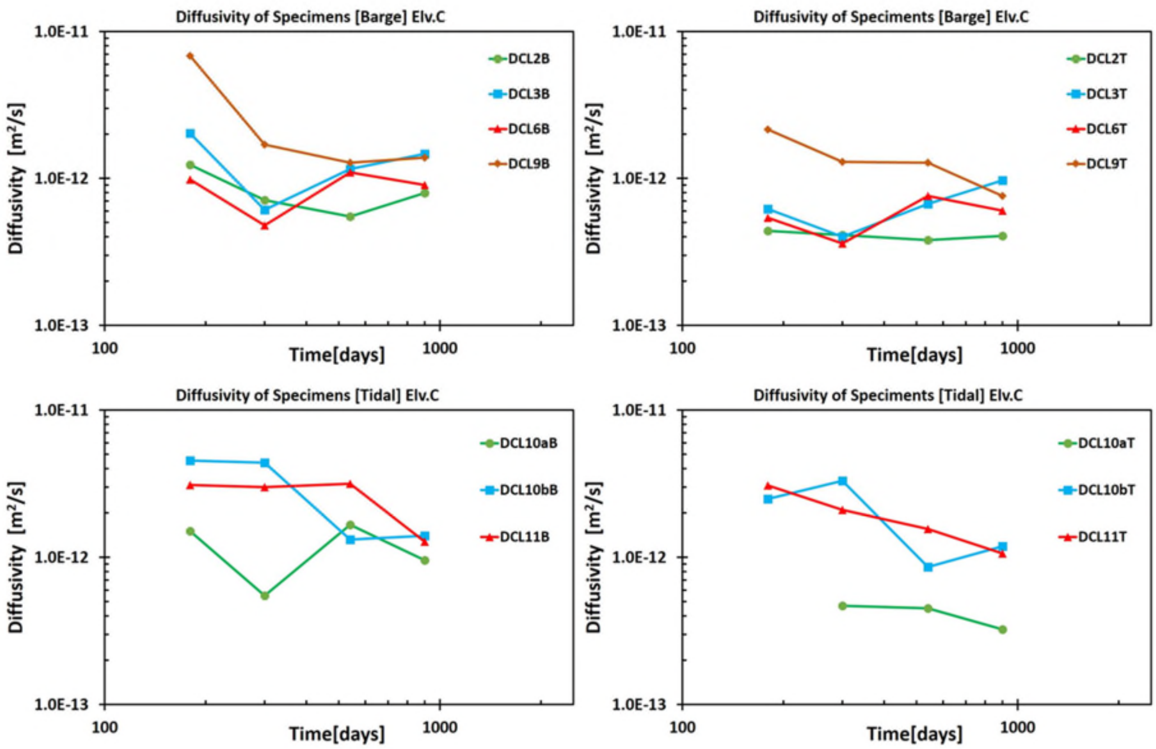


Figure 224. Barge elevation C

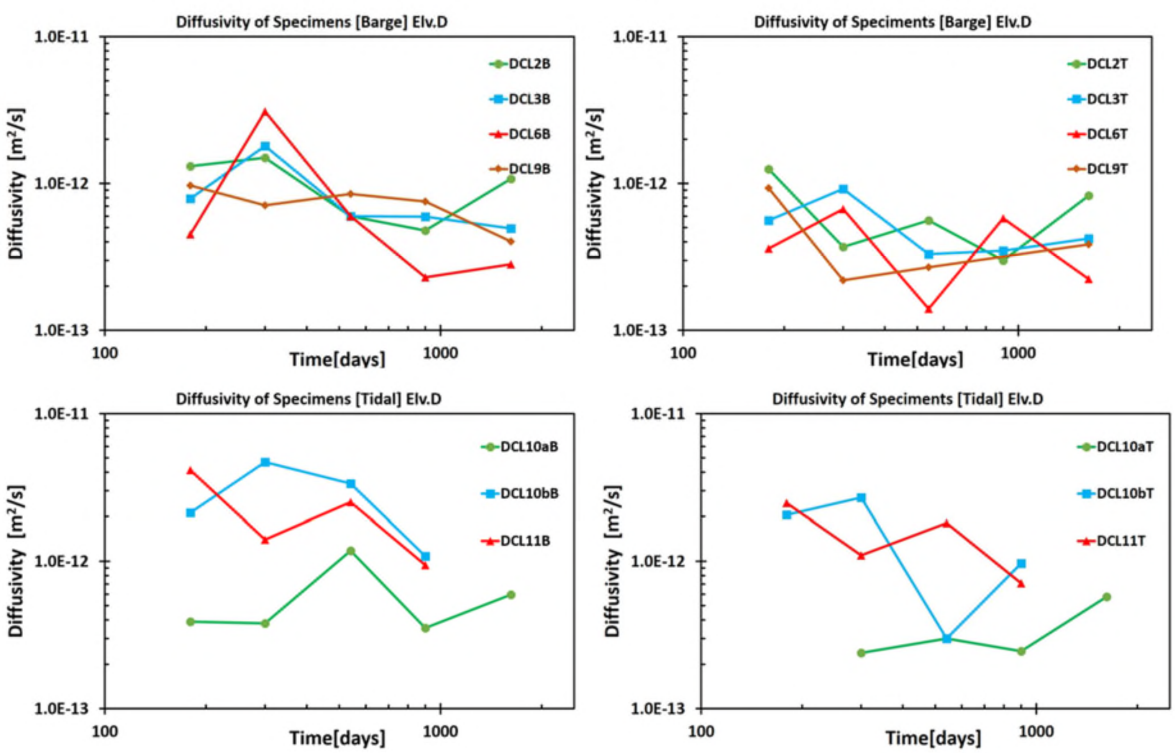


Figure 225. Barge elevation D

Appendix R – m Values (Elevations B, C and D)

R.1 Elevation B: m values

Table 73. m values: tidal elevation B

Tidal	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1B	0.71	0.98	0.75	0.97
DCL1T	0.71	0.67	0.74	0.66
DCL2B	0.59	0.39	0.63	0.38
DCL2T	0.33	0.11	0.35	0.11
DCL3B	0.06	0.01	0.06	0.01
DCL3T	0.10	0.02	0.11	0.03
DCL4B	0.49	0.93	0.51	0.92
DCL4T	0.60	0.79	0.64	0.81
DCL5B	0.61	0.98	0.64	0.97
DCL5T	0.68	0.93	0.72	0.93
DCL6B	0.53	0.41	0.57	0.42
DCL6T	0.60	0.92	0.63	0.92
DCL7B	0.43	0.93	0.46	0.92
DCL7T	0.88	1.00	0.94	0.99
DCL8B	0.50	0.64	0.52	0.63
DCL8T	0.74	0.78	0.79	0.78
DCL9B	0.52	0.80	0.55	0.80
DCL9T	0.05	0.00	0.05	0.00
DCL10aB	1.00	0.85	1.07	0.85
DCL10aT	0.78	0.84	0.85	0.84
DCL10bB	0.62	0.92	0.65	0.92
DCL10bT	0.70	0.94	0.74	0.93
DCL11B	0.65	0.96	0.69	0.97
DCL11T	0.46	0.78	0.48	0.78

Table 74. m values: barge elevation B

Barge	**Exposure time**		**W/Curing time**	
Mix	m	R^2	m	R^2
DCL2B	0.72	0.73	0.78	0.71
DCL2T	0.85	0.86	0.92	0.85
DCL3B	0.29	0.17	0.31	0.16
DCL3T	0.41	0.42	0.44	0.40
DCL6B	0.55	0.51	0.59	0.50
DCL6T	0.75	0.80	0.81	0.79
DCL9B	0.64	0.80	0.70	0.79
DCL9T	0.73	0.81	0.79	0.79
DCL10aB	0.41	0.37	0.43	0.35
DCL10aT	0.49	0.63	0.53	0.64
DCL10bB	1.04	0.95	1.13	0.94
DCL10bT	0.15	0.13	0.18	0.14
DCL11B	0.77	0.81	0.84	0.80
DCL11T	0.80	0.98	0.87	0.98

Table 75. m values: splash elevation B

Splash	**Exposure time**		**W/Curing time**	
Mix	m	R^2	m	R^2
DCL1	0.31	0.24	0.33	0.24
DCL2	0.04	0.00	0.05	0.01
DCL3	0.04	0.00	0.03	0.00
DCL4	1.02	0.87	1.09	0.86
DCL5	0.82	0.98	0.88	0.98
DCL6	1.41	0.93	1.52	0.93
DCL7	0.11	0.85	0.12	0.83
DCL8	1.04	0.85	1.12	0.85
DCL9	0.31	0.38	0.33	0.37
DCL10a	0.45	0.46	0.48	0.45
DCL10b	0.18	0.09	0.19	0.08
DCL11	0.45	0.44	0.49	0.45

Table 76. m values: splash elevation B – 10%SW

Splash %10	**Exposure time**		**W/Curing time**	
Mix	m	R^2	m	R^2
DCL3	0.08	0.03	0.08	0.03
DCL6	0.30	0.08	0.35	0.09
DCL9	0.70	0.18	0.76	0.18

R.2 Elevation C: m values

Table 77. m values: tidal elevation C

Tidal	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1B	0.52	0.25	0.53	0.23
DCL1T	0.30	0.50	0.31	0.49
DCL2B	0.27	0.18	0.31	0.19
DCL2T	0.61	0.91	0.65	0.90
DCL3B	0.13	0.22	0.13	0.21
DCL3T	0.00	0.00	0.00	0.00
DCL4B	0.35	0.73	0.38	0.74
DCL4T	0.64	0.95	0.67	0.95
DCL5B	0.84	0.89	0.90	0.88
DCL5T	0.95	0.91	1.02	0.91
DCL6B	0.09	0.01	0.11	0.02
DCL6T	0.21	0.27	0.23	0.27
DCL7B	0.65	0.57	0.70	0.58
DCL7T	0.77	1.00	0.81	1.00
DCL8B	0.37	0.81	0.40	0.79
DCL8T	0.32	0.93	0.35	0.93
DCL9B	0.32	0.59	0.35	0.60
DCL9T	0.21	0.35	0.23	0.37
DCL10aB	0.86	0.58	0.93	0.59
DCL10aT	1.27	0.75	1.37	0.75
DCL10bB	0.56	0.74	0.60	0.75
DCL10bT	0.42	0.43	0.44	0.43
DCL11B	0.20	0.66	0.22	0.68
DCL11T	0.46	0.94	0.48	0.94

Table 78. m values: barge elevation C

Barge	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL2B	0.29	0.37	0.31	0.35
DCL2T	0.06	0.50	0.07	0.48
DCL3B	0.05	0.01	0.04	0.00
DCL3T	0.35	0.45	0.38	0.46
DCL6B	0.12	0.05	0.13	0.05
DCL6T	0.21	0.22	0.23	0.23
DCL9B	0.93	0.69	1.00	0.67
DCL9T	0.58	0.89	0.63	0.89
DCL10aB	0.03	0.00	0.03	0.00
DCL10aT	0.33	0.81	0.35	0.81
DCL10bB	0.89	0.81	0.96	0.81
DCL10bT	0.67	0.57	0.73	0.57
DCL11B	0.47	0.57	0.52	0.58
DCL11T	0.64	0.99	0.70	0.99

Table 79. m values: barge elevation C

Splash	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1	0.79	0.96	0.84	0.95
DCL2	0.35	0.17	0.37	0.16
DCL3	0.15	0.01	0.17	0.02
DCL4	1.06	0.78	1.13	0.76
DCL5	0.78	0.57	0.83	0.56
DCL6	0.15	0.33	0.16	0.32
DCL7	0.75	0.57	0.79	0.55
DCL8	0.22	0.22	0.23	0.20
DCL9	0.00	0.00	0.01	0.00
DCL10a	0.61	0.65	0.64	0.64
DCL10b	0.19	0.79	0.21	0.78
DCL11	0.11	0.03	0.12	0.03

Table 80. m values: splash elevation C -10%SW

Splash %10	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL3	0.86	0.80	0.94	0.79
DCL6	0.55	0.32	0.61	0.33
DCL9	0.22	0.06	0.23	0.05

R.3 Elevation D: m values

Table 81. m values:-tidal elevation D

Tidal	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1B	0.28	0.08	0.31	0.09
DCL1T	0.56	0.55	0.61	0.57
DCL2B	0.53	0.11	0.54	0.11
DCL2T	0.63	0.38	0.67	0.37
DCL3B	0.01	0.00	0.02	0.00
DCL3T	0.44	0.27	0.48	0.28
DCL4B	0.27	0.14	0.27	0.12
DCL4T	0.06	0.00	0.07	0.01
DCL5B	0.27	0.81	0.29	0.82
DCL5T	0.35	0.52	0.37	0.52
DCL6B	0.17	0.13	0.18	0.13
DCL6T	0.38	0.26	0.40	0.26
DCL7B	0.06	0.00	0.07	0.01
DCL7T	0.07	0.00	0.06	0.00
DCL8B	0.00	0.00	0.01	0.00
DCL8T	0.14	0.03	0.15	0.03
DCL9B	0.49	0.83	0.52	0.83
DCL9T	0.04	0.00	0.05	0.00
DCL10aB	0.46	0.40	0.49	0.39
DCL10aT	0.09	0.02	0.10	0.02
DCL10bB	0.01	0.00	0.01	0.00
DCL10bT	0.22	0.05	0.23	0.05
DCL11B	0.34	0.17	0.36	0.18
DCL11T	0.08	0.16	0.09	0.16

Table 82. m values: barge elevation D

Barge	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL2B	0.28	0.23	0.29	0.22
DCL2T	0.17	0.07	0.17	0.06
DCL3B	0.38	0.42	0.41	0.43
DCL3T	0.28	0.34	0.30	0.34
DCL6B	0.49	0.22	0.54	0.23
DCL6T	0.37	0.30	0.40	0.30
DCL9B	0.31	0.63	0.33	0.64
DCL9T	0.24	0.13	0.24	0.11
DCL10aB	0.15	0.06	0.15	0.06
DCL10aT	0.44	0.60	0.47	0.61
DCL10bB	0.44	0.23	0.49	0.25
DCL10bT	0.85	0.37	0.92	0.36
DCL11B	0.69	0.56	0.75	0.56
DCL11T	0.58	0.55	0.63	0.55

Table 83. m values: splash elevation D

Splash	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL1	0.71	0.34	0.73	0.32
DCL2	0.27	0.78	0.08	0.01
DCL3	0.09	0.01	0.28	0.77
DCL4	0.88	0.59	0.92	0.58
DCL5	0.07	0.03	0.07	0.02
DCL6	0.25	0.31	0.27	0.31
DCL7	0.72	0.64	0.76	0.62
DCL8	0.49	0.38	0.52	0.39
DCL9	0.16	0.08	0.16	0.07
DCL10a	0.58	0.66	0.61	0.66
DCL10b	0.46	0.44	0.48	0.43
DCL11	0.20	0.04	0.23	0.05

Table 84. m values: splash elevation d -10% SW

Splash %10	Exposure time		W/Curing time	
Mix	m	R^2	m	R^2
DCL3	0.30	0.19	0.33	0.20
DCL6	0.19	0.22	0.20	0.22
DCL9	0.25	0.24	0.27	0.24