INTEROFFICE MEMORANDUM

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(per S4, ENG.51)

Recommended Modeling Inputs for Evaluating SDU Concrete Mix 3B, Based on the Reports from Vendors

Purpose

The purpose of this memorandum is to provide a summary of recommended chemical and material properties to use as model inputs for evaluating concrete Mix 3B.

Background

Decontaminated salt solution, processed from tank farm waste, is mixed with dry grout feeds to create a waste form called saltstone. After mixing, the wet saltstone slurry is pumped into saltstone disposal units (SDUs) at the Saltstone Disposal Facility (SDF). Once the slurry cures within the SDUs, saltstone becomes a solid, low permeability waste form designed to immobilize waste.

Construction of SDUs at the SDF is an ongoing activity and SDU Design Authority Engineers are considering revising the design mix for the SDU concrete to incorporate lessons learned. The SDU Design Authority Engineers have developed a potential alternative design mix (Mix 3B) for the concrete and have had vendors perform a series of tests to provide information with respect to the material properties.

Prior to employing Mix 3B in the construction of future SDUs, an evaluation must be performed to ensure that the use of the material will not compromise the performance of the SDUs or invalidate conclusions of the SDF Performance Assessment (PA) (SRR-CWDA-2019-00001).

Discussion of Concrete Mixes

The design specifications for SDU 7 are documented in C-SPP-Z-00015. Note that the title of this document changed between revisions: Revisions 0 and 1 of C-SPP-Z-00015 explicitly identify SDU 7 as the saltstone disposal site specified (Title: *Saltstone Disposal Unit 7 – SDU 7*) whereas Revisions 2 and 3 are more general to provide flexibility for construction to proceed with building additional SDUs (Title: *Saltstone Disposal – SDU Disposal Tanks*). Regardless, Revision 3 of C-SPP-Z-00015 provides the most current design specifications for SDU construction.

Within C-SPP-Z-00015, Section 03300 provides the design specifications for cast-in-place concrete. High-quality concretes (HQC) are used for the construction of the SDU upper mud mat, floor, walls, roof, and roof-support columns. Two design mixes are specified in Attachment B and Attachment C of C-SPP-Z-

00015. These are reproduced below (Table and 1 and Table 2). In addition to the design mixes, the various percent-weights are also provided. Both of these design mixes have a water-to-cementitious materials ratio (WCR) of 0.38. Note that the WCR is a mass-based ratio.

Table 1: Concrete Mix Design E 6000-8-PS-2-ABC (SDU Wall, Column, and Roof)

Material	Quantity per Cubic Yard	Specific Gravity of Material	Percent of Cementitious Materials by Weight	Percent of Total Solids by Weight	Percent of Total Liquids by Weight
Type V Cement [a]	213 lbs	3.15	30%	6.0%	N/A
Slag Grade 120 [b]	284 lbs	2.89	40%	8.0%	N/A
Class F Fly Ash [c]	163 lbs	2.25	23%	4.6%	N/A
Silica Fume	50 lbs	2.20	7%	1.4%	N/A
Sand	1091 lbs	2.63	N/A	30.7%	N/A
Aggregate (#67 Stone [d])	1750 lbs	2.64	N/A	49.3%	N/A
AEA [e]	5.5 oz	1.03	N/A	N/A	0.1%
HRWRA [f]	56.8 oz	1.03	N/A	N/A	1.3%
SRA [g]	96.0 oz	0.92	N/A	N/A	2.2%
Potable Water	264 lbs	1.00	N/A	N/A	96.4%

Notes:
SOURCE: C-SPP-Z-00015, Rev. 3, Attachment 03300-B.

a) Type V Cement is cement with a high resistance to sulfate concentrations and has slower strength gain than other types of cement (ASTM C150/C150M).
b) Slag Grades are a measure of the “slag activity index” which roughly corresponds to a comparison of the average 28-day compressive strengths of slag-reference cement cubes versus slag-free reference cement cubes (SRR-CWDA-2015-00057).
c) There are three types of Fly Ash: Class C which is both pozzolanic and has self-cementing properties, Class F which is pozzolanic but has little or no self-cementing value, and Class N which is composed of raw or calcined natural pozzolans (ASTM C618).
d) #67 Stone is stone or gravel material sized between ¾ inch and 0.187 inch (4.75 mm) or smaller (ASTM C33/C33M).
e) AEA = Air Entraining Admixture
f) HRWRA = High Range Water Reducing Admixture
g) SRA = Shrinkage Reducing Admixture

Table 2: Concrete Mix Design E 6000-8-PS-3-ABC (SDU Floor, Upper Mud Mat)

Material	Quantity per Cubic Yard	Specific Gravity of Material	Percent of Cementitious Materials by Weight	Percent of Total Solids by Weight	Percent of Total Liquids by Weight
Type V Cement [a]	213 lbs	3.15	30%	6.0%	N/A
Slag Grade 120 [b]	284 lbs	2.89	40%	8.0%	N/A
Class F Fly Ash [c]	163 lbs	2.25	23%	4.6%	N/A
Silica Fume	50 lbs	2.20	7%	1.4%	N/A
Sand	1046 lbs	2.63	N/A	29.5%	N/A
Aggregate (#4 Stone [d])	435 lbs	2.64	N/A	12.3%	N/A
Aggregate (#67 Stone [d])	1360 lbs	2.64	N/A	38.3%	N/A
AEA [e]	5.5 oz	1.03	N/A	N/A	0.1%
HRWRA [f]	63.9 oz	1.03	N/A	N/A	1.5%
SRA [g]	96.0 oz	0.92	N/A	N/A	2.2%
Potable Water	264 lbs	1.00	N/A	N/A	96.2%

Notes:
SOURCE: C-SPP-Z-00015, Rev. 3, Attachment 03300-C.

a) Type V Cement is cement with a high resistance to sulfate concentrations and has slower strength gain than other types of cement (ASTM C150/C150M).
b) Slag Grades are a measure of the "slag activity index" which roughly corresponds to a comparison of the average 28-day compressive strengths of slag-reference cement cubes versus slag-free reference cement cubes (SRR-CWDA-2015-00057).
c) There are three types of Fly Ash: Class C which is both pozzolanic and has self-cementing properties, Class F which is pozzolanic but has little or no self-cementing value, and Class N which is composed of raw or calcined natural pozzolans (ASTM C618).
d) #4 Stone is stone of gravel material sized between 1 ½ inch and ¾ inch. #67 Stone is stone or gravel material sized between ¾ inch and 0.187 inch (4.75 mm) (ASTM C33/C33M).
e) AEA = Air Entraining Admixture
f) HRWRA = High Range Water Reducing Admixture
g) SRA = Shrinkage Reducing Admixture

For PA modeling, the material properties for these two design mixes were assumed to be identical to the material properties of the SDU concrete used in the construction of the 150-foot diameter SDUs (i.e., SDUs 2A, 2B, 3A, 3B, 5A, and 5B) as well as the first 375-foot diameter SDU (i.e., SDU 6). This assumption is supported due to the similarities in the design mixes (compare Table 3 to Tables 1 and 2). The design mix for this concrete is documented in Attachment 03300-B of C-SPP-Z-00008, Rev. 4. Hereafter this mix is referred to as "V2C" (short for "Vault 2 Concrete") as SDUs 2A and 2B were the first SDUs constructed with this mix.

Table 3: V2C Mix Design D 5000-8-S-2-AB (Previous HQC Concrete Used for SDUs)

Material	Quantity per Cubic Yard	Specific Gravity of Material	Percent of Cementitious Materials by Weight	Percent of Total Solids by Weight	Percent of Total Liquids by Weight
Type V Cement [a]	213 lbs	3.15	30%	6.0%	N/A
Slag Grade 100 [b]	284 lbs	2.90	40%	8.0%	N/A
Class F Fly Ash [c]	163 lbs	2.20	23%	4.6%	N/A
Silica Fume	50 lbs	2.20	7%	1.4%	N/A
Sand	991 lbs	2.63	N/A	27.9%	N/A
Aggregate (#67 Stone [d])	1850 lbs	2.64	N/A	52.1%	N/A
AEA [e]	3.91 oz	1.03 [h]	N/A	N/A	0.1%
WRA [f]	42.6 oz	1.03 [h]	N/A	N/A	1.0%
HRWRA [g]	34.1 oz	1.03 [h]	N/A	N/A	0.8%
Potable Water	269 lbs	1.00	N/A	N/A	98.2%

Notes:
SOURCE: C-SPP-Z-00008, Rev. 4, Attachment 03300-A.

a) Type V Cement is cement with a high resistance to sulfate concentrations and has slower strength gain than other types of cement (ASTM C150/C150M).
b) Slag Grades are a measure of the "slag activity index" which roughly corresponds to a comparison of the average 28-day compressive strengths of slag-reference cement cubes versus slag-free reference cement cubes (SRR-CWDA-2015-00057).
c) There are three types of Fly Ash: Class C which is both pozzolanic and has self-cementing properties, Class F which is pozzolanic but has little or no self-cementing value, and Class N which is composed of raw or calcined natural pozzolans (ASTM C618).
d) #67 Stone is stone or gravel material sized between ¾ inch and 0.187 inch (4.75 mm) (ASTM C33/C33M).
e) AEA = Air Entraining Admixture
f) WRA = Water Reducing Admixture
g) HRWRA = High Range Water Reducing Admixture
h) Specific Gravities assumed based on similar information from C-SPP-Z-00015, Rev. 3.

Conversely, the new proposed design mix (Mix 3B) represents a new design mix that has been previously untested. This design mix is provided in Table 4, based on the *SDU 7 Concrete Mixture Testing – Mixture 3B Final Report – 365 Days* (SIMCO_03-19-2020). While not explicitly discussed in the SIMCO report, the design mix also includes admixtures, as needed to support construction (*Mix 3B.pdf*). As with the other concrete mixes, Mix 3B has a documented WCR of 0.38 ± 0.02.

Aside from the introduction of the shrinkage reducing admixture (SRA), the largest differences between Mix 3B and the other concrete mixes are that (1) Mix 3B uses Type II cement (moderate sulfate resistance) instead of Type V cement (high sulfate resistance); (2) Mix 3B includes the use of metakaolin (a clay-based pozzolan) instead of fly ash and silica fume; and (3) the new mix has a lower nominal air content (3% versus 4.5%).

Table 4: High Quality Concrete Mix 3B

Material	Quantity per Cubic Yard	Specific Gravity of Material	Percent of Cementitious Materials by Weight	Percent of Total Solids by Weight	Percent of Total Liquids by Weight
Type I/II Cement [a]	337 lbs	3.152	47.5%	9.4%	N/A
Slag Grade 120 [b]	284 lbs	2.877	40.0%	7.9%	N/A
Metakaolin	89 lbs	2.660	12.5%	2.5%	N/A
Sand	1020 lbs	2.63 [d]	N/A	28.5%	N/A
Aggregate (#57 Stone [c])	1369 lbs	2.64 [d]	N/A	38.2%	N/A
Aggregate (#8 Stone [c])	481 lbs	2.64 [d]	N/A	13.4%	N/A
Potable Water	276.9 lbs	1.00	N/A	N/A	96.6%
AEA [e]	5.5 oz	1.03 [d]	N/A	N/A	0.1%
HRWRA [f]	53.3 oz	1.03 [d]	N/A	N/A	1.2%
SRA [g]	96.0 oz	0.92 [d]	N/A	N/A	2.1%

Notes:
SOURCES: SIMCO_03-19-2020, Tables 1 and 2 and *Mix 3B.pdf*.

a) Type I Cement has no special properties associated with it. Type II Cement is cement with a moderate resistance to sulfate concentrations (ASTM C150/C150M). Type I/II is a designation used to indicate that the cement meets the requirements of both types I and II cement and can be used when either type is required.
b) Slag Grades are a measure of the “slag activity index” which roughly corresponds to a comparison of the average 28-day compressive strengths of slag-reference cement cubes versus slag-free reference cement cubes (SRR-CWDA-2015-00057).
c) #57 Stone is stone or gravel material sized between approximately 1 inch (25 mm) and 0.187 inches (4.75 mm). #8 Stone is stone or gravel material sized between approximately 3/8 inch (9.5 mm) and 0.93 inch (2.36 mm) (ASTMC33/C33M).
d) Specific Gravities assumed based on similar information from C-SPP-Z-00015, Rev. 3.
e) AEA = Air Entraining Admixture
f) HRWRA = High Range Water Reducing Admixture
g) SRA = Shrinkage Reducing Admixture

Concrete Material Properties

V2C (i.e., Mix D 5000-8-S-2-AB) was analyzed and described in the 2012 SIMCO document *Report – Vault Concrete Characterization* (SIMCO_03-01-2012). Subsequently, a summary of recommended modeling values for use in PA modeling was issued (SRR-CWDA-2018-00004). These recommendations were based on a literature review as well as data from more recent testing.

Similarly, Mix 3B was analyzed and described in the 2020 SIMCO document *SDU 7 Concrete Mixture Testing – Mixture 3B Final Report – 365 Days* (SIMCO_03-19-2020). Table 5 summarizes the previous material property recommendations and provides new recommendations for use when modeling future SDUs assuming that Mix 3B will be used. Following Table 5 is additional data supporting the recommendations for the Mix 3B material properties.

Table 5. Comparison of Recommended Material Properties

Parameter	Unit	V2C	SDU7	Mix 3B	Justification for Mix 3B Recommendation
Global Values - For All Modeling					
Dry Bulk Density	g/mL	2.18	2.18	2.25	Values based on average measurements from SIMCO_03-19-2020, and interpretation of data based on the application of methods described in ASTM C642.
Solid Phase (Particle) Density	g/mL	2.45	2.45	2.58	
Porosity	unitless	0.11	0.11	0.129	
Compliance Value - For Compliance Case					
Initial Saturated Hydraulic Conductivity (K_{sat})	cm/sec	1.4E-10	7.8E-10	1.0E-09	Arithmetic Mean of all measured values, rounded up to one sig. fig., recommended for Compliance Values
				1.1E-13	Geometric Mean of all estimates (including sample 3B-27**), rounded to two sig. fig., recommended compliance value. (Based on SIMCO_03-19-2020)
Initial Effective Diffusion Coefficient (D_e)	cm^2/sec	5.3E-08	5.3E-08	1.30E-07	Geometric mean of the Best Estimate values and the Conservative Estimate values, rounded up to two significant figures.
Best Estimate - For Realistic Case					
Initial Saturated Hydraulic Conductivity (K_{sat})	cm/sec	1.0E-10	6.4E-10	7.0E-10	Geometric Mean of the last recorded values* for each sample, rounded down to one sig. fig., recommended for Best Estimate (Based on AFW_09-10-2018).
				7.5E-14	Geometric Mean of the 365 day estimates (excluding sample 3B-27**), rounded to two sig. fig., recommended best estimate value. (Based on SIMCO_03-19-2020)
Initial Effective Diffusion Coefficient (D_e)	cm^2/sec	3.5E-08	3.5E-08	8.00E-08	Geometric mean of all diffusion coefficients measured at 180 days and 365 days (i.e., ignores initial shorter term values at 56 days and 91 days), rounded up to one significant figure. (Based on data from SIMCO_03-19-2020.)
Conservative Estimate - For Pessimistic Case					
Initial Saturated Hydraulic Conductivity (K_{sat})	cm/sec	3.2E-10	9.1E-10	2.0E-09	Maximum of all measured values, rounded up to one sig. fig., recommended for Conservative Estimate (Based on AFW_09-10-2018).
				2.2E-13	Max of all estimates, rounded to two sig. fig., recommended conservative estimate value. (Based on SIMCO_03-19-2020)
Initial Effective Diffusion Coefficient (D_e)	cm^2/sec	6E-08	6E-08	2.00E-07	Maximum of all measured diffusion coefficients, rounded up to one significant figure. (Based on SIMCO_03-19-2020.)

*Based on the recorded test duration times, the last recorded values are not necessarily the longest duration values, as it appears that data was entered non-consecutively. It is assumed that this may be an error in data entry so the last recorded values are assumed to represent the longest duration measurements.
** Sample 3B-27 is identified as "an outlier" in SIMCO_03-19-2020.

The solid phase (or particle) density used in PA modeling is approximately equivalent to the apparent density as measured by SIMCO (SIMCO_03-19-2020). Similarly, the porosity value used in PA modeling is approximately equivalent to the percent of permeable voids as measured by SIMCO. Both of these properties were measured by SIMCO and documented in Table 4 of *SDU 7 Concrete Mixture Testing – Mixture 3B Final Report – 365 Days* (SIMCO_03-19-2020). These values are reproduced here as Table 6. This table shows that these two parameters exhibit relatively little variability. The recommended values provided in Table 5 assume the average of all the data.

Table 6. SIMCO Measurements of Density and Void Space

Cylinder ID	Age (days)	Sample volume (cm3)	Apparent density (g/cm3)	Water absorption (%)	Volume of permeable voids (%)
3B – 1	56	403	2.575	6.0	13.3
3B – 2		425	2.590	5.7	12.8
3B – 3		425	2.593	5.7	12.9
3B – 4		416	2.563	5.9	13.1
3B – 5		414	2.579	5.7	12.9
3B – 15	91	417	2.582	5.7	12.8
3B – 16		408	2.583	5.8	13.0
3B – 17		413	2.585	5.8	13.0
3B – 18		408	2.590	5.4	12.3
3B – 19		405	2.583	5.7	12.9
3B – 20	180	412	2.600	5.3	12.1
3B – 21		414	2.573	5.8	13.0
3B – 22		406	2.575	5.8	13.0
3B – 23		420	2.576	5.5	12.5
3B – 24		426	2.580	5.5	12.4
3B – 25	365	417	2.587	6.1	13.7
3B – 26		414	2.585	6.2	13.9
3B – 27		418	2.598	6.0	13.4
3B – 28		414	2.589	5.6	12.7
3B – 29		424	2.595	5.6	12.8
Averages	56 day	Average	2.58	5.8	13.0
	91 day	Average	2.58	5.7	12.8
	180 day	Average	2.58	5.6	12.6
	365 day	Average	2.59	5.9	13.3
	All Data	**Average**	**2.58**	**5.7**	**12.9**

Next, to find the average dry bulk density (2.25 g/mL), the relationship shown in Equation 1 was used along with the average values from Table 6.

$$\rho_b = \rho_s(1 - \frac{\eta}{100}) \quad \text{Eq. 1}$$

Where:

ρ_b is the dry bulk density (g/mL)

ρ_s is the solid phase density (g/mL), and

η Is the porosity (%).

Next, for the saturated hydraulic conductivity, two sets of values were analyzed: one set derived from permeability modeling performed by SIMCO (Table 7) (SIMCO_03-19-2020), and one set based on laboratory measurements (per ASTM D5084) as performed by Amec Foster Wheeler (Table 8) (AFW_09-10-2018). Due to the four orders of magnitude differences between the two sets of values, two sets of recommendations were developed as provided in Table 5.

Table 7. SIMCO Estimates for Saturated Hydraulic Conductivities

Cylinder ID	Age (days)	Saturated Hydraulic Conductivity (cm/s)
3B – 1	56	1.47E-13
3B – 2		1.41E-13
3B – 3		1.31E-13
3B – 4		1.63E-13
3B – 5		1.47E-13
3B – 15	91	1.15E-13
3B – 16		1.29E-13
3B – 17		1.13E-13
3B – 18		1.25E-13
3B – 19		1.48E-13
3B – 20	180	8.00E-14
3B – 21		8.50E-14
3B – 22		8.10E-14
3B – 23		8.90E-14
3B – 24		8.20E-14
3B – 25	365	7.40E-14
3B – 26		7.20E-14
3B – 27*		2.19E-13*
3B – 28		8.80E-14
3B – 29		6.70E-14
Geometric Mean	56 day	1.45E-13
	91 day	1.25E-13
	180 day	8.33E-14
	365 day*	7.49E-14
	All Data*	**1.05E-13**

Note: * SIMCO_03-19-2020 Table 8 identifies sample 3B-27 as an outlier. This outlier was not included in the calculation of the geometric means.

Table 8. Amec Foster Wheeler Estimates for Saturated Hydraulic Conductivities

Sample 180018B (Mix 3B) (top)		Sample 180018B (Mix 3B) (bottom)		Sample 180018A (Mix 3B)	
Time (s)	**Ksat (cm/s)**	**Time (s)**	**Ksat (cm/s)**	**Time (s)**	**Ksat (cm/s)**
24360	1.75E-09	15660	1.16E-09	22980	1.30E-09
82440	9.98E-10	22620	1.03E-09	26340	1.21E-09
4260	1.39E-09	25980	1.02E-09	85020	8.39E-10
13860	7.74E-10	29640	9.67E-10	88860	8.20E-10
18000	6.65E-10	88620	9.77E-10	93540	8.21E-10
23700	5.92E-10	9360	7.36E-10	99240	8.37E-10
27600	5.82E-10	13380	7.40E-10	102780	8.08E-10
Average	**9.6E-10**	**Average**	**9.5E-10**	**Average**	**9.5E-10**
Geometric Mean	**8.9E-10**	**Geometric Mean**	**9.4E-10**	**Geometric Mean**	**9.3E-10**

Figure 1 shows each of the reported the saturated hydraulic conductivities from SIMCO (SIMCO_03-19-2020) and Figure 2 shows each of the reported the saturated hydraulic conductivities from Amec Foster Wheeler (AFW_09-10-2018). Both figures show that, in general, the saturated hydraulic conductivity appears to decrease over time. This is consistent with earlier studies that assert that the curing process for cementitious materials can continue over relatively long periods of time (SRR-CWDA-2018-00004). Based on this observation, the Best Estimate values in Table 5 were derived from samples that have been aged (or cured) the longest. The Compliance Values are based on all of the data and use either the arithmetic mean or the geometric mean as the recommended value. Finally, the Conservative Estimate values are based on the single highest value from each data set.

Figure 1. SIMCO Estimated Values for Saturated Hydraulic Conductivity of Mix 3B

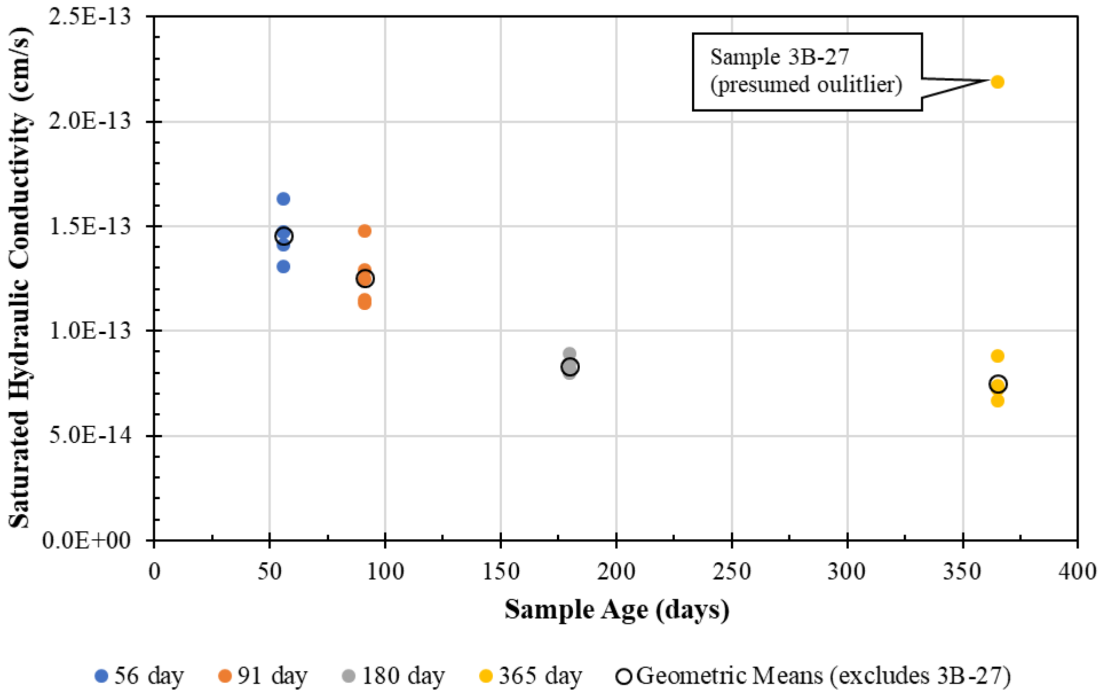
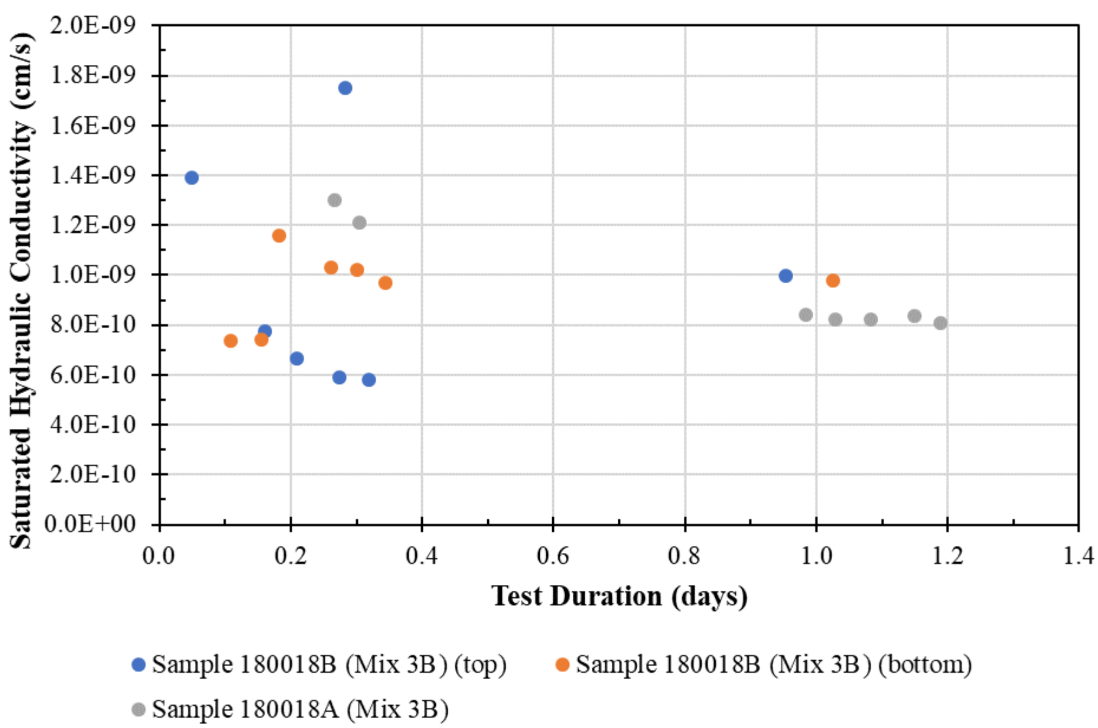


Figure 2. Amec Foster Wheeler Measured Values for Saturated Hydraulic Conductivity of Mix 3B



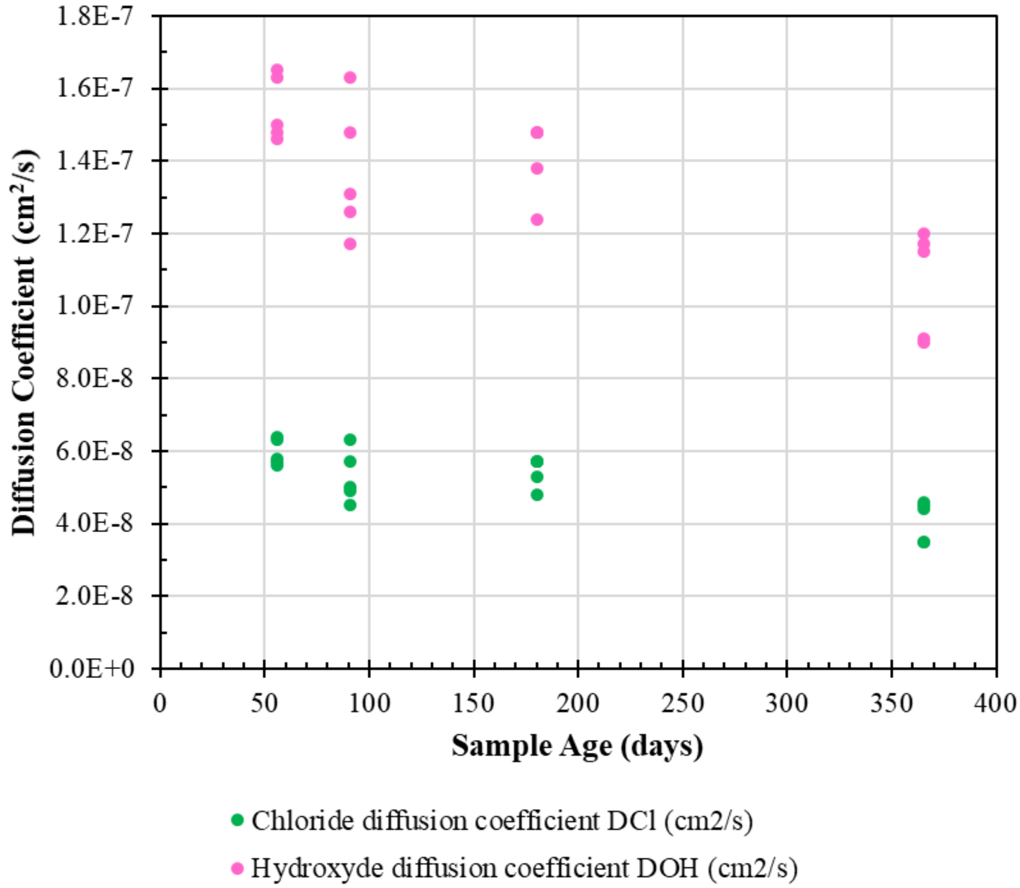
Finally, the effective diffusion coefficients were developed based on the values derived by SIMCO using ASTM C1202, as documented in Table 6 *of SDU 7 Concrete Mixture Testing – Mixture 3B Final Report –*

365 Days (SIMCO_03-19-2020). These values are reproduced here as Table 7 and illustrated in Figure 3. As with the saturated hydraulic conductivities, these effective diffusion coefficients also gradually decrease as the material continues to cure.

Table 7. SIMCO Derived Values for Diffusion Coefficients

Cylinder ID	Age (days)	Chloride diffusion coefficient DCl (cm^2/s)	Hydroxyde diffusion coefficient DOH (cm^2/s)
3B – 1	56	6.30E-08	1.63E-07
3B – 2		5.80E-08	1.50E-07
3B – 3		5.70E-08	1.48E-07
3B – 4		5.60E-08	1.46E-07
3B – 5		6.40E-08	1.65E-07
3B – 15	91	5.00E-08	1.31E-07
3B – 16		5.70E-08	1.48E-07
3B – 17		4.50E-08	1.17E-07
3B – 18		4.90E-08	1.26E-07
3B – 19		6.30E-08	1.63E-07
3B – 20	180	5.70E-08	1.48E-07
3B – 21		5.70E-08	1.48E-07
3B – 22		4.80E-08	1.24E-07
3B – 23		5.30E-08	1.38E-07
3B – 24		5.70E-08	1.48E-07
3B – 25	365	4.40E-08	1.15E-07
3B – 26		4.60E-08	1.20E-07
3B – 27		3.50E-08	9.10E-08
3B – 28		4.50E-08	1.17E-07
3B – 29		3.50E-08	9.00E-08
Geometric Mean	56 day	5.95E-08	1.54E-07
	91 day	5.24E-08	1.36E-07
	180 day	5.43E-08	1.41E-07
	365 day	4.07E-08	1.06E-07
	All Data	**5.12E-08**	**1.33E-07**

Figure 3. SIMCO Derived Values for the Diffusion Coefficients of Mix 3B



References

AFW_09-10-2018, *Amec Foster Wheeler Testing of Mix 2A and Mix 3B for Saturated Hydraulic Conductivity*, Amec Foster Wheeler, September 2018.

ASTM C33/33M, *Standard Specification for Concrete Aggregates*, American Society for Testing and Materials.

ASTM C150/C150M, *Standard Specification for Portland Cement*, American Society for Testing and Materials.

ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, American Society for Testing and Materials.

ASTM C642, *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*, American Society for Testing and Materials.

ASTM C1202, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*, American Society for Testing and Materials.

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