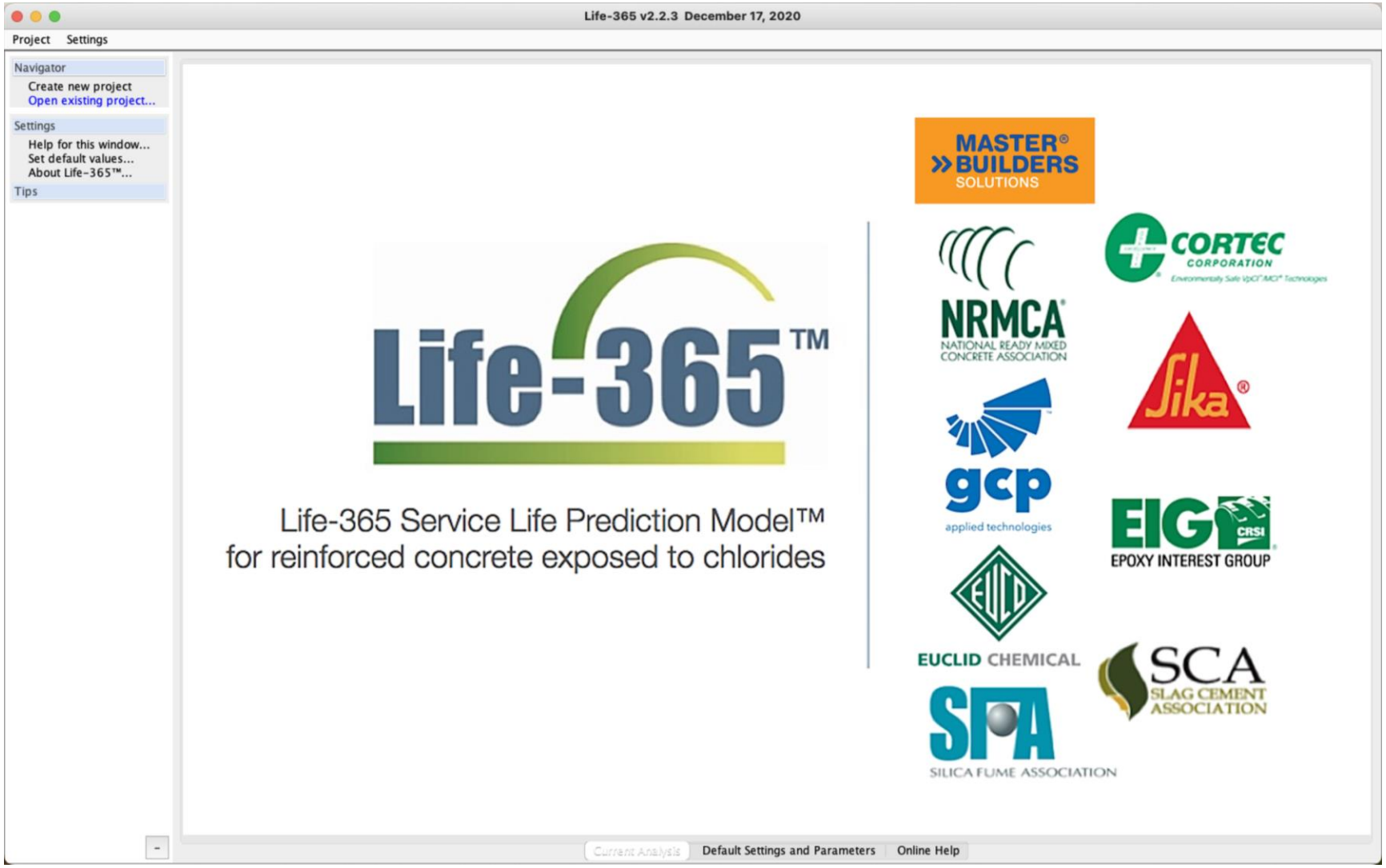


ACI Convention: Boston – November 1, 2023

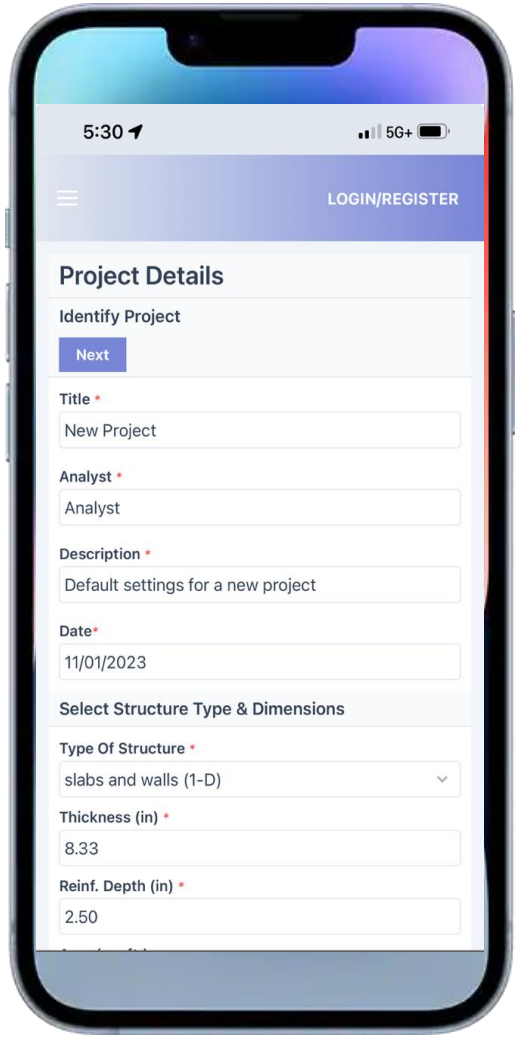
Mark A. Ehlen, Ph.D., for the Silica Fume Association

Today

- Quick overview of what it is, how it got here
  - Chloride transport model with life-cycle costing
  - Provides some exposure and mixture presets, but can override
  - Comparative analysis tool
  - Open specification: ACI Subcommittee A on Service Life; detailed Technical Manual
- Service life estimates of three mixtures:
  - How used to estimate these (initiation + propagation)
  - Control, SF-8, HP-20
  - Uncertainty estimates

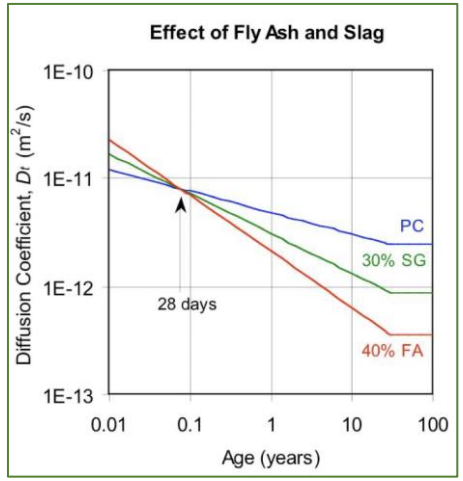
How did it get here

- ACI Subcommittee A – Concrete Service Life
  - Goal: durability - Michael Thomas and Evan Bentz (University of Toronto)
  - Software implementation – Evan Bentz (University of Toronto)
  - Service life uncertainty estimates – Evan Bentz (University of Toronto)
  - Life-cycle costs, software verification, updated manual – Mark Ehlen (NIST)
  - ASTM C1556 –surface concentration estimates, apparent diffusion coefficient.
  - Concrete/diffusion relationships based on: NT BUILD 443, ASTM G 109, AASHTO T260, NCHRP 244 Series II; see References for others.
- Widely analyzed, published, compared (Google Scholar)
- Web version on the way (run with your thumb)



Documentation

- Mathematical chloride diffusion specification (finite differencing)
- Lab tests to support base estimates
- Service life uncertainty estimation
- How to use (and not use)



3. Interior (c) points are solved for using the following modified version:

$$(1+2r)u_{i,j}^{t+1} - \frac{r}{2}\left(u_{i-1,j}^{t+1} + u_{i-1,j}^{t+1} + u_{i,j-1}^{t+1} + u_{i,j+1}^{t+1}\right) = (1-2r)u_{i,j}^{t} + \frac{r}{2}\left(u_{i-1,j}^{t} + u_{i-1,j}^{t} + u_{i,j-1}^{t} + u_{i,j+1}^{t}\right)$$

4. Interior (d) points are solved for using the following modified version:

$$(1+2r)u_{i,j}^{t+1} - \frac{r}{2}\left(u_{i-1,j}^{t+1} + u_{i-1,j}^{t+1} + u_{i,j-1}^{t+1} + u_{i,j-1}^{t+1}\right) = (1-2r)u_{i,j}^{t} + \frac{r}{2}\left(u_{i-1,j}^{t} + u_{i-1,j}^{t} + u_{i,j-1}^{t} + u_{i,j-1}^{t}\right)$$

Life-365™ Service Life Prediction Model™

and Computer Program for Predicting the Service Life and Life-Cycle Cost of Reinforced Concrete Exposed to Chlorides

Version 2.2.3

December 23, 2020

Produced by the Life-365™ Consortium III

Built-in Model Validation

Filters

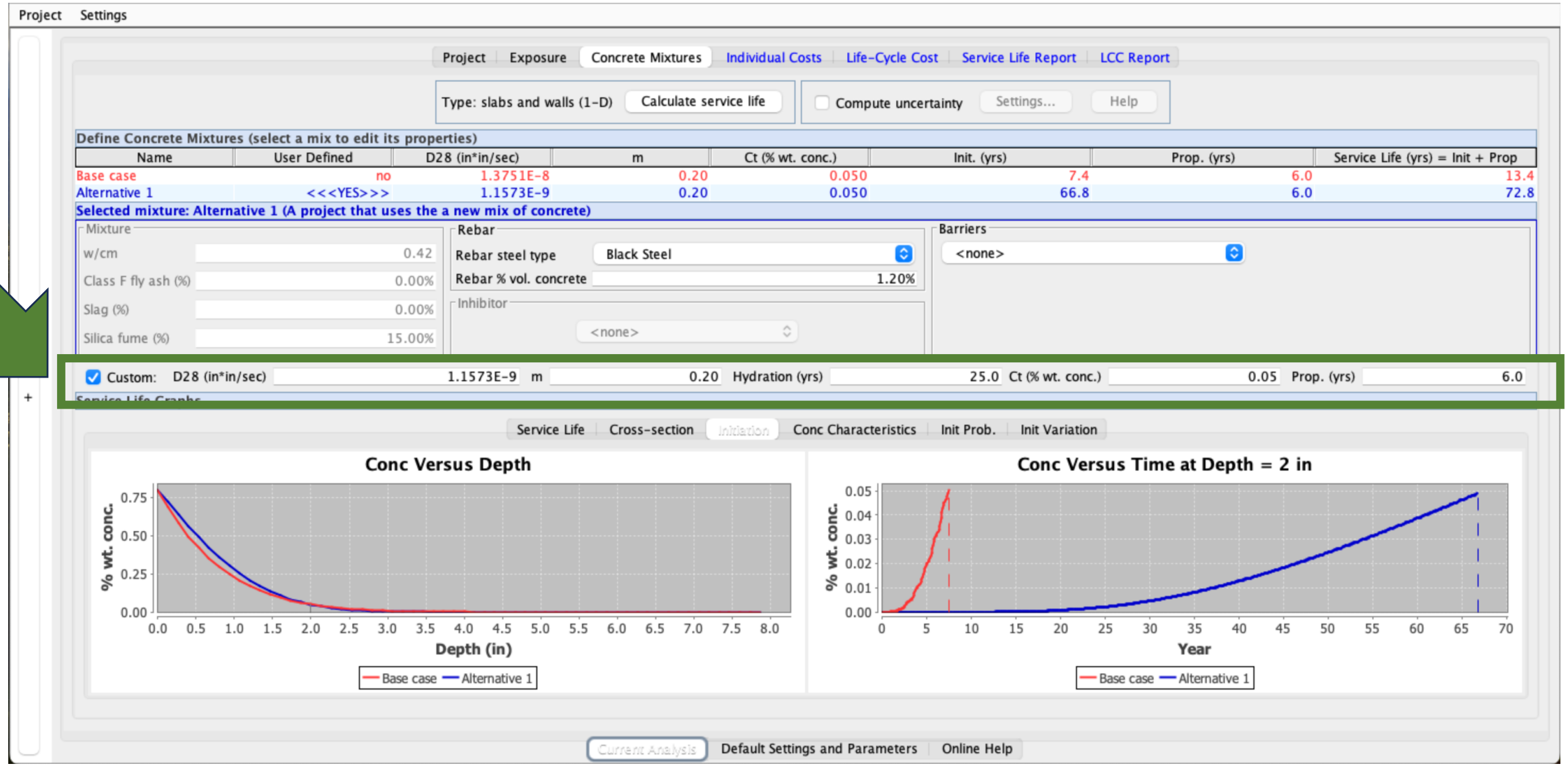
Units <all> Conc. <all> Max. conc. <all> Depth <all> Reinf. <all> w/cm <all>

Fly ash <all> Slag <all> Silica fume <all> Barrier <all> Inhib. <all>

Run Tests Reset

Units	Conc.	Max. conc.	Depth	Reinf.	w/cm	Fly ash	Slag	Silica fume	Barrier	Inhib.	m_v2	m_v1	ct_v2	ct_v1	D28_v2	D28_v1	Init_v2	Init_v1	% diff	Comments
SI metric	% wt. conc.	1	200	60	0.4	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.2	2.1	3.1%	
SI metric	% wt. conc.	1	200	60	0.35	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	6.0256E...	6.03E-12	3.0	3	0%	
SI metric	% wt. conc.	1	200	60	0.3	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	4.5709E...	4.57E-12	4.2	4.1	1.6%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	0	<none>	Ca Nitrit...	0.20	0.2	0.15	0.15	7.9433E...	7.94E-12	3.9	3.8	3%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	10	<none>	<none>	0.20	0.2	0.05	0.05	1.5255E...	1.53E-12	16.0	15.7	1.9%	
SI metric	% wt. conc.	1	200	60	0.4	10	0	0	<none>	<none>	0.28	0.28	0.05	0.05	7.9433E...	7.94E-12	2.8	2.6	5.5%	
SI metric	% wt. conc.	1	200	60	0.4	0	10	0	<none>	<none>	0.26	0.26	0.05	0.05	7.9433E...	7.94E-12	2.6	2.5	3.2%	
SI metric	% wt. conc.	1	200	60	0.4	10	10	10	<none>	<none>	0.34	0.34	0.05	0.05	1.5255E...	1.53E-12	35.1	34.8	0.8%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	0	Membrane	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	3.8	4.2	12%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	0	Sealer	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.6	2.5	3.2%	
SI metric	% wt. conc.	1	200	60	0.4	0	70	0	<none>	<none>	0.60	0.6	0.05	0.05	7.9433E...	7.94E-12	11.4	10.5	8%	
SI metric	% wt. conc.	1	200	60	0.4	50	0	0	<none>	<none>	0.60	0.6	0.05	0.05	7.9433E...	7.94E-12	11.4	10.5	8%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	15	<none>	<none>	0.20	0.2	0.05	0.05	6.6853E...	6.73E-13	43.2	42.6	1.5%	
SI metric	% wt. conc.	1	200	60	0.4	50	0	15	<none>	<none>	0.60	0.6	0.05	0.05	6.6853E...	6.73E-13	452.2	459	1.5%	
SI metric	% wt. conc.	1	200	60	0.4	0	58	12	<none>	<none>	0.53	0.53	0.05	0.05	1.0967E...	1.10E-12	173.5	175.6	1.2%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	0	<none>	Ca Nitrit...	0.20	0.2	0.32	0.32	7.9433E...	7.94E-12	7.2	7.2	0.7%	
SI metric	% wt. conc.	1	200	60	0.4	0	0	0	<none>	Ca Nitrit...	0.20	0.2	0.40	0.4	7.9433E...	7.94E-12	9.4	9.4	0.2%	
SI metric	% wt. conc.	1	200	60	0.4	50	0	15	<none>	Ca Nitrit...	0.60	0.6	0.40	0.4	6.6853E...	6.73E-13	500.0	500+	-	
SI metric	% wt. conc.	1	200	60	0.4	0	58	12	<none>	Ca Nitrit...	0.53	0.53	0.40	0.4	1.0967E...	1.10E-12	500.0	500+	-	
SI metric	% wt. conc.	1	200	60	0.4	25	0	7.5	<none>	Ca Nitrit...	0.40	0.4	0.40	0.4	2.3044E...	2.31E-12	135.8	135.4	0.3%	
SI metric	% wt. conc.	1	200	60	0.4	0	29	6	<none>	Ca Nitrit...	0.37	0.37	0.40	0.4	2.9515E...	2.96E-12	83.6	81.3	2.7%	
Centimet...	% wt. conc.	1	20	6	0.4	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.2	2.1	3.1%	
Centimet...	kg/cub. ...	23.5	20	6	0.4	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.2	2.1	3.1%	
US units	% wt. conc.	1	7.874	2.362	0.4	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.2	2.1	3.1%	
US units	lb/cub. ...	39.5	7.874	2.362	0.4	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.2	2.1	3.1%	
Centimet...	% wt. conc.	1	20	6	0.4	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.2	2.1	3.1%	
Centimet...	% wt. conc.	1	20	6	0.35	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	6.0256E...	6.03E-12	3.0	3	0%	
Centimet...	% wt. conc.	1	20	6	0.3	0	0	0	<none>	<none>	0.20	0.2	0.05	0.05	4.5709E...	4.57E-12	4.2	4.1	1.6%	
Centimet...	% wt. conc.	1	20	6	0.4	0	0	0	<none>	Ca Nitrit...	0.20	0.2	0.15	0.15	7.9433E...	7.94E-12	3.9	3.8	3%	
Centimet...	% wt. conc.	1	20	6	0.4	0	0	10	<none>	<none>	0.20	0.2	0.05	0.05	1.5255E...	1.53E-12	16.0	15.7	1.9%	
Centimet...	% wt. conc.	1	20	6	0.4	10	0	0	<none>	<none>	0.28	0.28	0.05	0.05	7.9433E...	7.94E-12	2.8	2.6	5.5%	
Centimet...	% wt. conc.	1	20	6	0.4	0	10	0	<none>	<none>	0.26	0.26	0.05	0.05	7.9433E...	7.94E-12	2.6	2.5	3.2%	
Centimet...	% wt. conc.	1	20	6	0.4	10	10	10	<none>	<none>	0.34	0.34	0.05	0.05	1.5255E...	1.53E-12	35.1	34.8	0.8%	
Centimet...	% wt. conc.	1	20	6	0.4	0	0	0	Membrane	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	3.8	4.2	12%	
Centimet...	% wt. conc.	1	20	6	0.4	0	0	0	Sealer	<none>	0.20	0.2	0.05	0.05	7.9433E...	7.94E-12	2.6	2.5	3.2%	

Basic + Advanced Modes



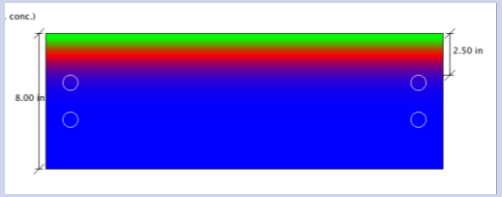
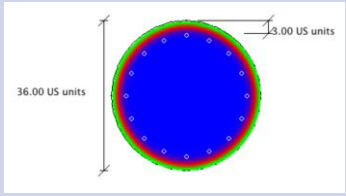
Using Life-365 to Estimate the Three

	CTRL	SF-8	Hyaloclastite Pozzolan-20
Cement, Type I/II (lb/yd^3)	658	605	526
Silica Fume (lb/yd^3)	0	53	0
Hyaloclastite Pozzolan (lb/yd^3)	0	0	132
Fine Aggregate (lb/yd^3)	1279	1263	1273
3/4" Crushed Coarse Aggregate (lb/yd^3)	1815	1815	1680
Total Water (lb/yd^3)	250	250	250
w/cm	0.38	0.38	0.38
Design Air (%)	6	6	6

Use these mixtures to make these structures

	Case 1	Case 2	Case 3
	Boston, MA		
Element	Bridge Deck	Marine Pile	Marine Wall
Thickness/Diameter	8 in	36 in	8 in
Exposure	Deicing Salt	Submerged	Splash
Target Initiation Time with 90% Confidence	100 years		
Cover	2.5 in	3.0 in	3.0 in
Maximum Surface Concentration	5500 ppm	8000 ppm	10000 ppm
Black Bar Initiation Threshold	735 ppm		
Enhanced Initiation Threshold	2500 ppm		
Hydration Time	8 years		

Using Life-365 to Estimate the Three

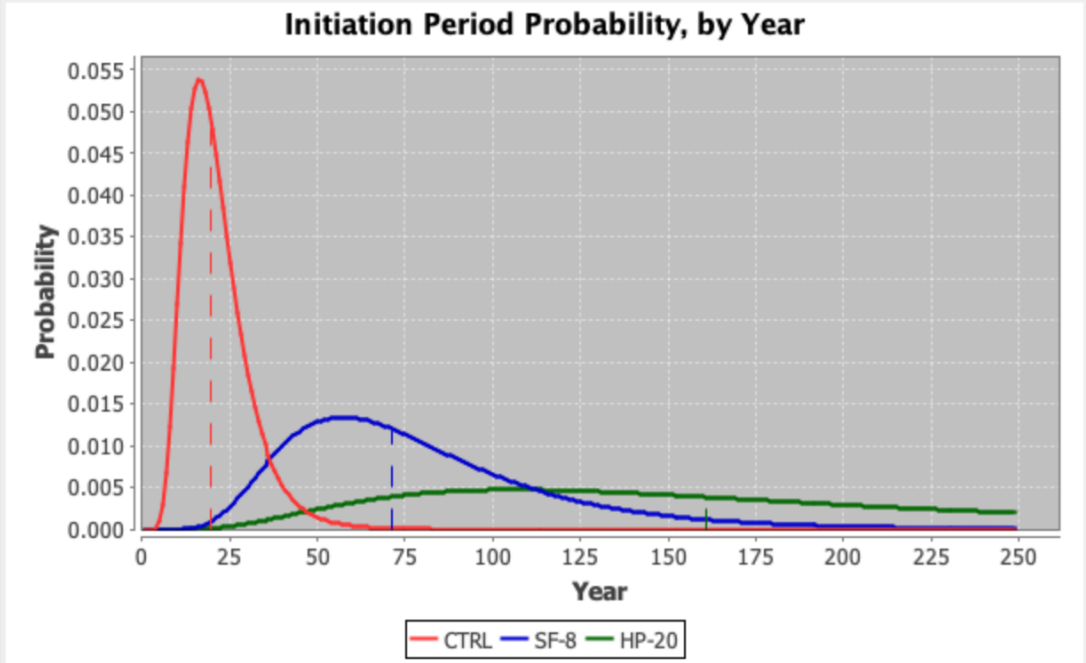
Life-365 Setting	Case 1 – Bridge Deck	Case 2 – Marine Pier	Case 3 – Marine Wall
Structure Type	Concrete slab (1D diffusion 	Concrete column (2D) 	Tilted concrete slab (1D) 
Dimension + depth to cover	Provided structural dimensions size matters; changing overall depth/width will change the estimates (finite differencing)		
Monthly Temperature	Use Life-365 Boston as default values		
Exposure to salt	Deicing salt: buildup time	Buildup immediate	Buildup immediate
Black bar initiation threshold C_t	Use provided test value (50% larger than Life-365 default)		
Study period	250 years (long enough to see uncertainty estimates)		
Life-cycle costing	Nope; great-great-great(…) grandchildren will all be on Mars by then		
Analysis strategy	Use first estimates + sensitivity/uncertainty analysis to inform larger decision		

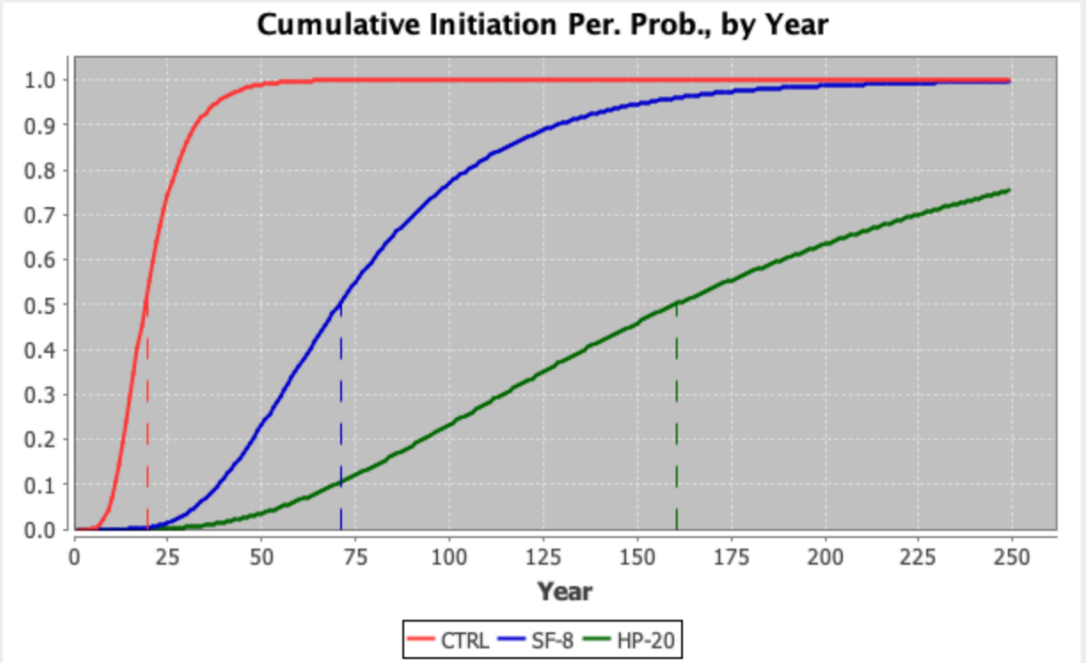
Using Life-365 to Estimate the Three

Mix Parameter	CTRL	SF-8	HP-40
Cement type	Don’t use; Use Life-365 defaults		
Mix Design Proportions	Don’t use; Use Life-365 defaults		
Binder Chemical Compositions	Don’t use; Use Life-365 defaults		
w/c	Set in Life-365		
Laboratory Test Results	-	-	Use C1556-based apparent diffusion
Effects of silica fume	-	Compute replacement %	-
Effects of HP	-	-	Use apparent diffusion
Concentrations	Convert ppm values to “%wt conc.”		
Analysis strategy	Use first, second, third estimates + sensitivity/uncertainty analysis to inform larger decision		

Results: Service Life Years

Case	CTRL	SF-8	HP-40
Case 1: Bridge Deck	25	77	167
Case 2: Marine Pier	19	65	146
Case 3: Marine Wall	19	67	152





Discussion

- Questions?
- Road ahead
  - ACI Subcommittee A – update “standard model” definition?
  - User extensions – “Life-365 Plus” – extends most common use cases and new materials?
- Can provide Life-365 project files used herein