STADIUM®

A software solutions to concrete problems

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Service d'Expertise en Matériaux inc.

Concrete Industry Partnership

NAVFAC, Holcim, GRACE Construction Products, BASF The Chemical Company, LAFARGE, US Army Corps of Engineers, State of Florida Department of Transportation, ECOSMART CONCRETE, Sika, Transports Québec, State of New Jersey Department of Transportation, MMFX Technologies Corp, Transports Canada, Transport Canada, MOFFATT & NICHOL

Nuclear Engineering Industry

U.S. Department of Energy, U.S.NRC, VANDERBILT UNIVERSITY, SIMCO Technologies inc., NIST National Institute of Standards and Technology, SRNL

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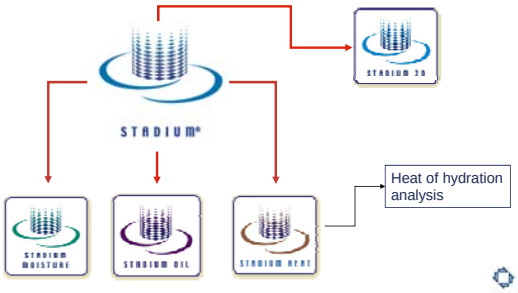
STADIUM®

STADIUM® is a numerical tool dedicated to the prediction of chloride ingress and concrete degradation of structures exposed to harsh environments.



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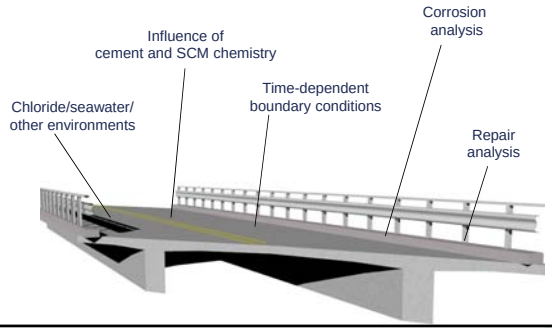
Global Durability Approach

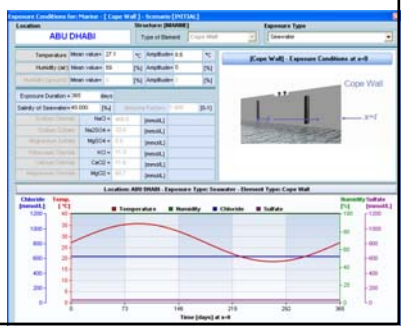
A highly flexible tool:



Parameters: environment

The model considers local climate fluctuations (temperature and humidity)

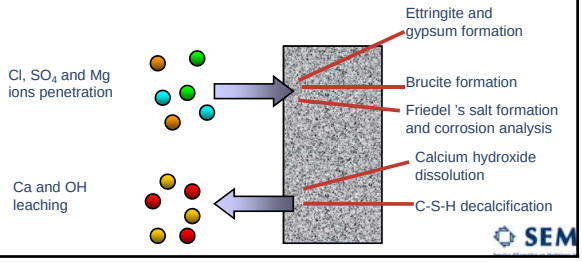
Example – Abu Dhabi :



Parameters: environment

The model can consider complex environments involving multiple deterioration mechanisms.

Example - Marine environment :



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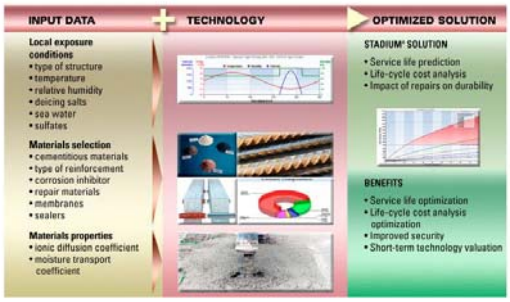
Global Durability Approach



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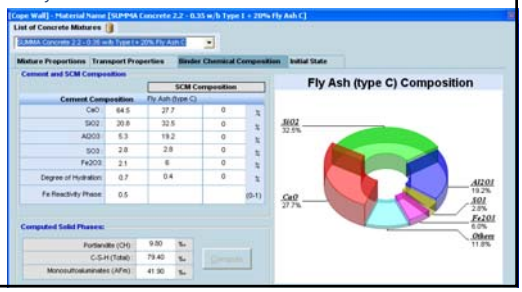
Parameters: binder chemistry

The durability analysis takes into consideration of the chemical composition of cement and that of supplementary cementing materials.

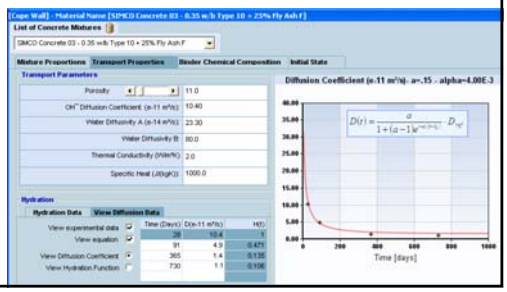
Example – Fly ash concrete :



Parameters: transport properties

The software also takes into account the evolution of concrete properties with continuous hydration

Example – Fly ash concrete :



A comprehensive approach

	STADIUM®	Others
Ionic transport	✓	± (Cl⁻ only)
Moisture transport	✓	
Fluct. exp. conditions	✓	±
2-D problems	✓	
Corrosion analysis	✓	✓
Sulfate and seawater	✓	
Other type degradation	✓	
Reliable database	✓	
Experimental protocol	✓	

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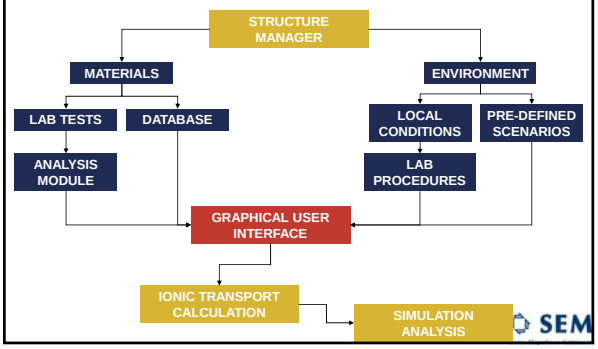
Global Durability Approach

STADIUM® - Integrated environments to analyze different cases



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Durability analysis

Multiple-degradation mechanism analysis:

STADIUM®

Click to start animation

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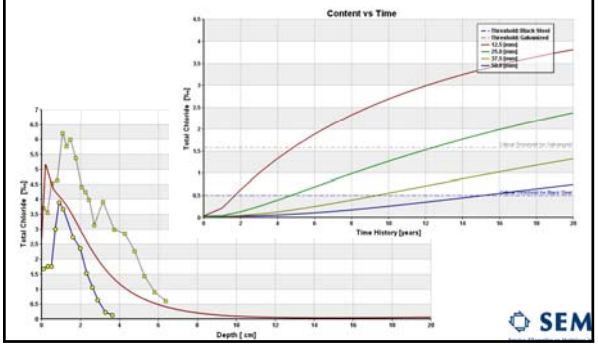
Durability analysis

Chloride ingress and corrosion analysis:



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Example 1 – Modular Hybrid Pier – US Navy

SEM

Example 1 – Modular Hybrid Pier – US Navy

In the second phase of the project, a concrete mixture had to be designed to achieve a 100-year service-life.

Three different mixtures were tested:

Materials	Producer		
	A	*B*	*C*
W/B ratio	0.27	0.34	0.28
Binders:			
- Cement (kg/m^3)	475.6	335.3	391.2
- Fly Ash (normal) (kg/m^3)	158.7	110.6	107.0
- Fly Ash (ultra fine) (kg/m^3)	0	0	29.7
Aggregates:			
- Coarse (kg/m^3)	546.6	612.4	540.0
- Fine (kg/m^3)	674.4	728.9	734.0

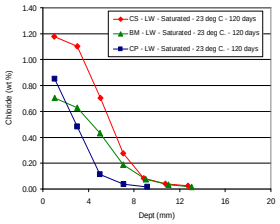
SEM

Example 1 – Modular Hybrid Pier – US Navy

Laboratory tests were performed to evaluate the transport properties of the different mixtures.

Separate exposure tests were also performed to validate the transport parameters and chemical behavior of the fly ash mixtures.

The mixtures clearly exhibited different resistance to chloride ingress:



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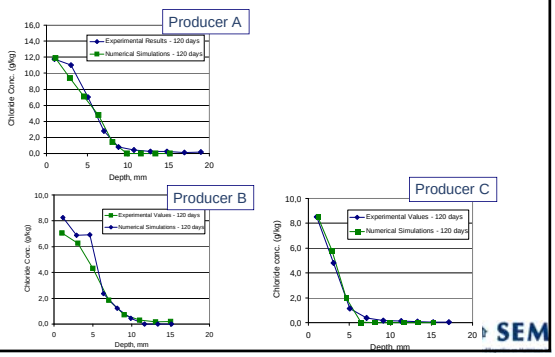
Example 1 – Modular Hybrid Pier – US Navy

STADIUM® - Numerical validation:



SEM

Example 1 – Modular Hybrid Pier – US Navy

Service life prediction:

STADIUM® was used to predict the initiation of corrosion for different types of rebar in the structure:

Mixture	Rebar Type		
	Black steel	Epoxy coated	Stainless
Producer A	13	14	22
Producer B	11	21	32
Producer C	34	37	70

* Rebar position: 50 mm

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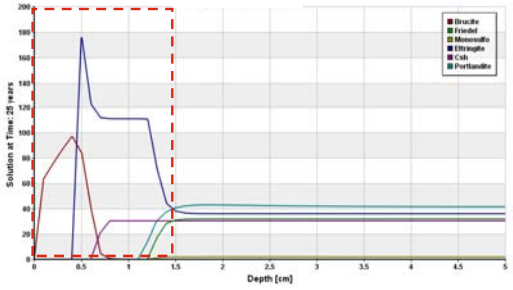
Example 1 – Modular Hybrid Pier – US Navy

Simulation results after 25 years - Solid phase profiles:



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Example 2 – Dry dock analysis

Dry dock durability analysis

SEM

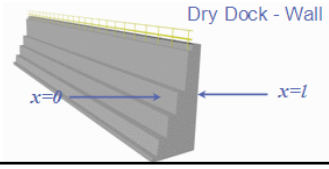
Example 2 – Dry dock analysis

In other cases, the exposure to ionic species is combined with time-dependant boundary conditions

This second analysis focuses on a **dry dock** located in Bremerton (WA).

The walls are exposed to seawater for less than 2 weeks per year. For the remainder of the time, the ships are repaired.

The dock is 44 years-old.



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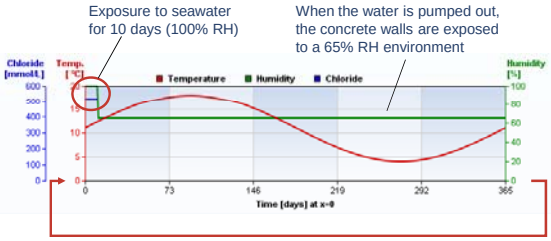
Example 2 – Dry dock analysis

Time-dependent boundary conditions:



After a one-year cycle, the model goes back to the beginning of the year. The cycle is repeated 44 times.

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Example 2 – Dry dock analysis

Concrete analysis

- Cores are taken from the wall for chloride profile measurements.
- Tests are performed on companion samples from cores to evaluate the transport properties:
  - Porosity: ASTM C642
  - Diffusion coefficient: migration tests (modified ASTM C1202)
  - Pore extraction
  - Water diffusivity: drying test procedure
- The parameters are used as input data in **STADIUM®** to simulate the dry dock service-life.

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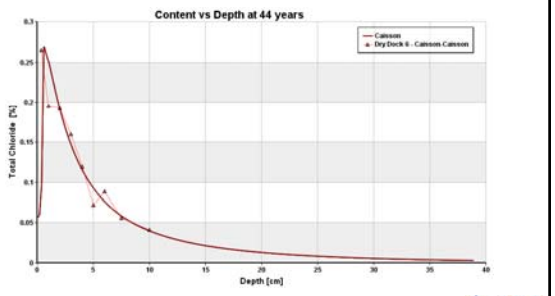
Example 2 – Dry dock analysis

Simulation results:



SEM

Example 2 – Dry dock analysis

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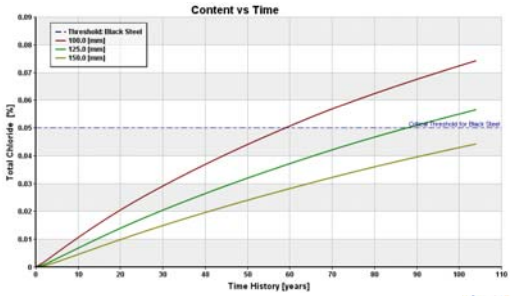

SEM

Example 2 – Dry dock analysis

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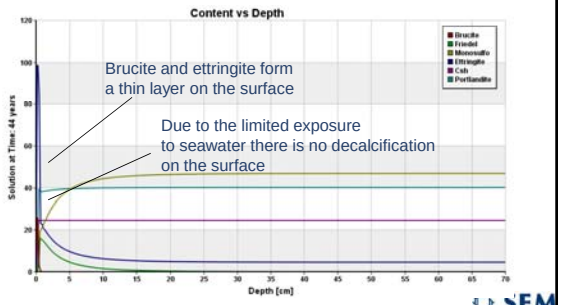

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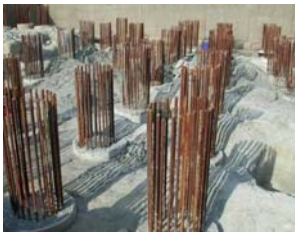
Local applications

US Embassy – Abu Dhabi:



Chloride = 2 230 mmol/L
Sulfate = 67 mmol/L
Sodium = 2 064 mmol/L
Calcium = 26 mmol/L
Magnesium = 123 mmol/L

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Local applications

Central Market – Abu Dhabi:

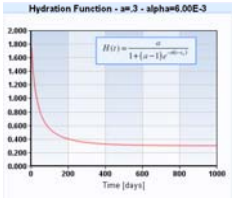
Local applications

Prediction of chloride ingress and corrosion initiation
for concrete mixtures incorporating slag.

Mixture characteristics

Ingredient	Quantity
Cement	128 kg/m^3
Slag	298 kg/m^3
Fine + Coarse aggregates	1730 kg/m^3
Water	149 L/m^3
Superplasticizer	2 L/m^3
Air content	6 %

Hydration Function -
Evolution of the transport properties



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Thank you!

Questions?