

J. Marchand

Montreal – November 29, 2006



**Research Center
on Concrete Infrastructure**

Fonds de recherche
sur la nature
et les technologies
Québec 





Research Center on Concrete Infrastructure



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LOCATIONS TO SERVE YOU

- Pasco, WA
- Quebec City, Canada
- San Leandro, CA
- New York City, NY
- Monroeville, PA
- Manassas, VA
- Holmes Beach, FL



Sustainability ↔ Durability

The National Bridge Inventory indicates that 480 000 bridges serve U.S. highways. Half of these bridges are made of reinforced concrete.



According to the FHWA:

- 10% are considered structurally deficient or dangerous;
- 160 000 bridges are listed as substandard;
- Degradation is predominantly related to overloading and exposure to environmental conditions!

Annual direct cost for rehabilitation \approx 8 B\$

Source: FHWA-RD-04-093



Sustainability ↔ Durability

Durability problems are not limited to bridges but affect a wide range of structures exposed to various conditions.

Annual cost for repair, rehabilitation and strengthening of US concrete structures:

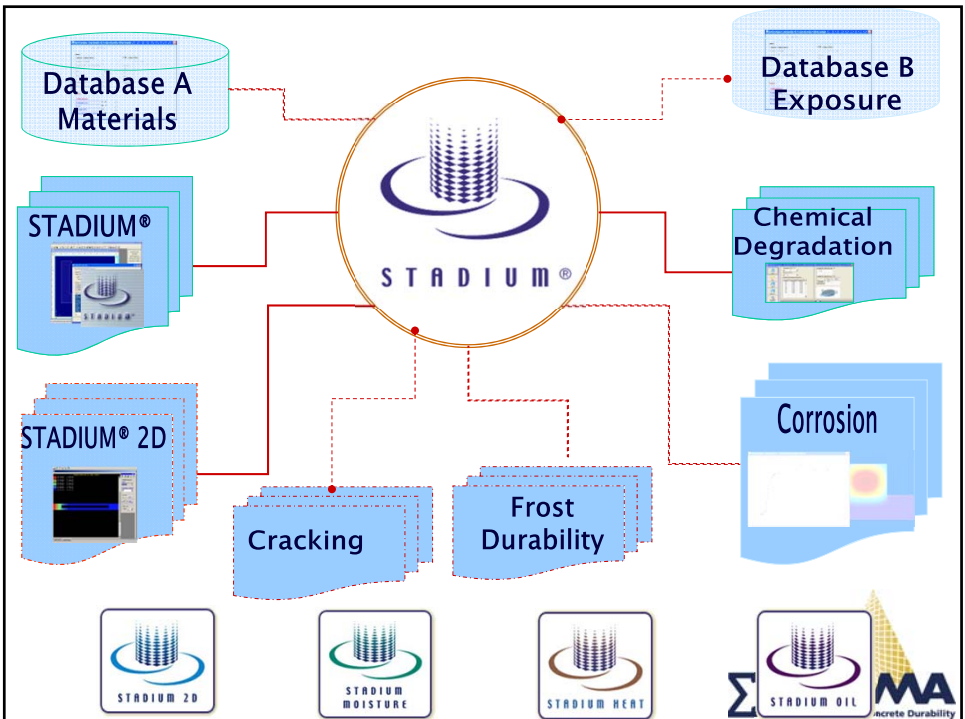
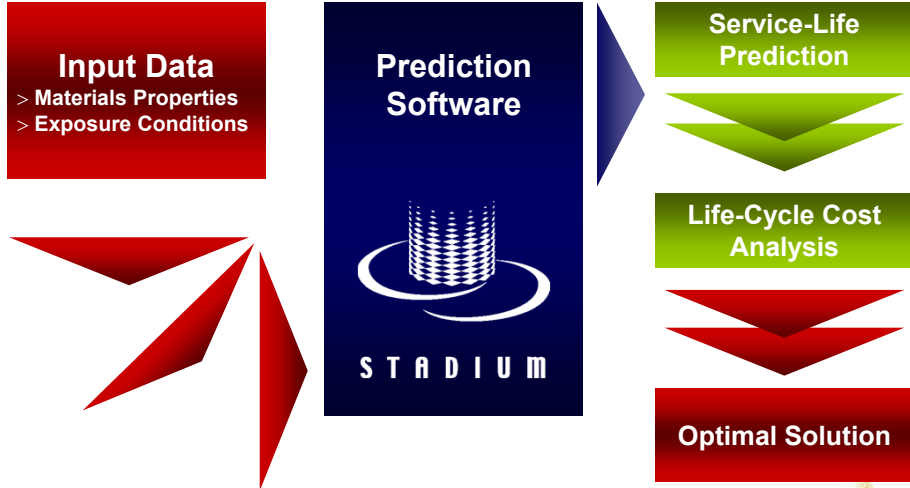
- Piers and wharves = 0.2 B\$
- Roadways = 4 B\$
- Buildings = 2 B\$
- Parking structures = 0.5 B\$
- Industrial facilities = 2B\$
- Dams and locks = 0.2 B\$
- Residential construction = 0.3 B\$



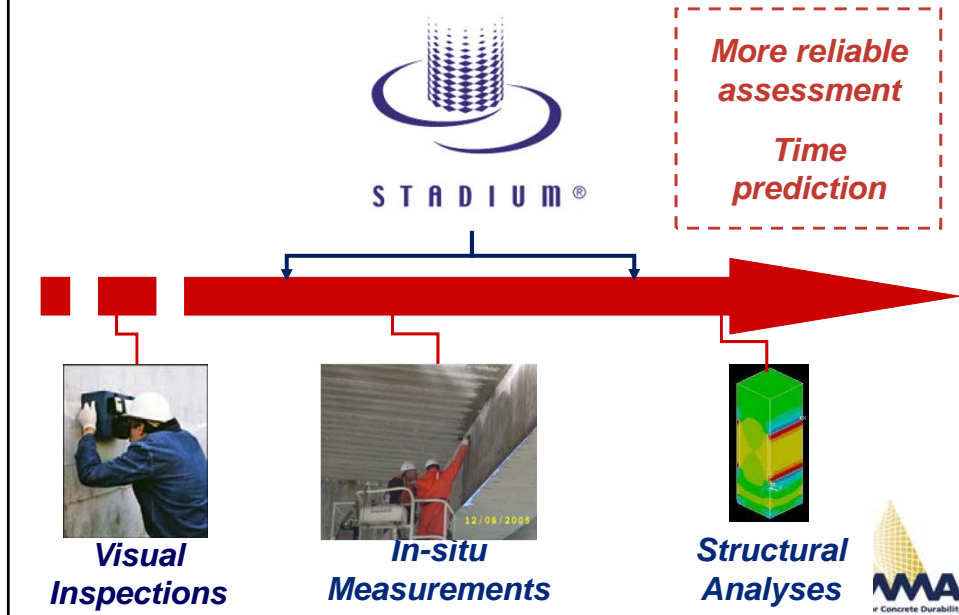
Source: Vision 2020 (ACI/ICRI)



A Comprehensive Approach



Inspection and Maintenance

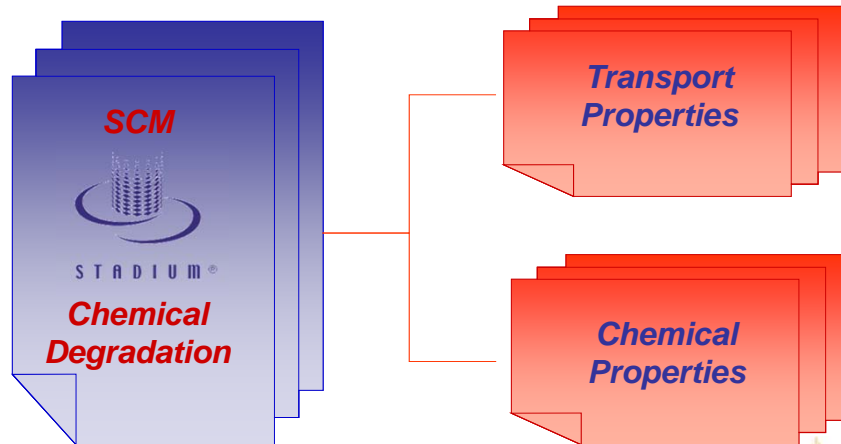


SUMMA Consortium - Members

The SUMMA Consortium members are represented by the following logos:

- NAVFAC**: Naval Facilities Engineering Command
- Holcim**
- LAFARGE**
- GRACE**: Construction Products
- BASF**: The Chemical Company
- Sika**
- SUMMA**: Numerical Model for Concrete Durability
- U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION**
- MMFX**: TECHNOLOGIES CORP.
- US Army Corps of Engineers**
- Transports Québec**

Influence of SCM



STADIUM® Interface

Material List
Concrete 2.2 - 0.35 w/b Type I Cement +20% Fly Ash Type C Experimental Procedure... Hide Advanced... OK Cancel Help

Mixture Proportions | Transport Properties | Binder Chemical Composition | Validate Data with Expert System Show Message

Cement Composition:

| | | |
|--|------|-------------------|
| Cement content: | 340 | kg/m ³ |
| Binder Density: | 3070 | kg/m ³ |
| CaO: | 62.4 | % |
| SiO ₂ : | 19.3 | % |
| Al ₂ O ₃ : | 5 | % |
| SO ₃ : | 4 | % |
| Degrees of hydration: | 0.85 | (0-1) |
| Al ₂ O ₃ Substituted in CSH: | 3.00 | % |

SCM Composition:

Fly Ash (type C)

| | | |
|----------------------------------|------|-------------------|
| Amount: | 85 | kg/m ³ |
| CaO: | 27.7 | % |
| SiO ₂ : | 32.5 | % |
| Al ₂ O ₃ : | 19.2 | % |
| SO ₃ : | 2.76 | % |
| Hydration: | 0.4 | (0-1) |

Solid Phases:

| | | |
|------------------------|-------|---|
| Portlandite (CH): | 23.03 | % |
| C-S-H: | 17.44 | % |
| Etnnate (AFt): | 2.05 | % |
| Monosulfatoaluminates: | 28.6 | % |

Cement Composition

CaO 62.4%
SiO₂ 19.3%
Al₂O₃ 5.0%
SO₃ 4.0%
Others 9.3%

*** EXPERT SYSTEM - RULES EVENTS ***



STADIUM[®] Interface

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Mixture Details

| | | | |
|---------------------|-----------------------|-----------------------|---------------------|
| Water/Binder ratio: | 0.35 | Specific gravity | |
| Cement Type | Type I / 10 / GU | 340 kg/m ³ | γ _c 3.15 |
| SCM #1 | Fly Ash (type C) | 85 kg/m ³ | γ _f 2.75 |
| SCM #2 | None | 00 kg/m ³ | γ _s 0.0 |
| Fine Aggregates | 815 kg/m ³ | γ _{fa} | 2.68 |
| Coarse aggregates | 925 kg/m ³ | γ _{ca} | 2.67 |

Computed Quantities

| | | | |
|------------------|------------------------|----------------|---------------------|
| Total Binder | 425 kg/m ³ | Mixture Volume | 0.94 m ³ |
| Total Aggregates | 1740 kg/m ³ | | |
| Binder Density | 3070 kg/m ³ | | |
| Water | 149 kg/m ³ | | |
| Material Density | 2314 kg/m ³ | | |
| Paste Volume | 28.7 % | | |

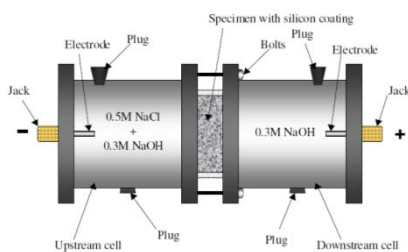
Binder Composition

EXPERT SYSTEM - RULES EVENTS



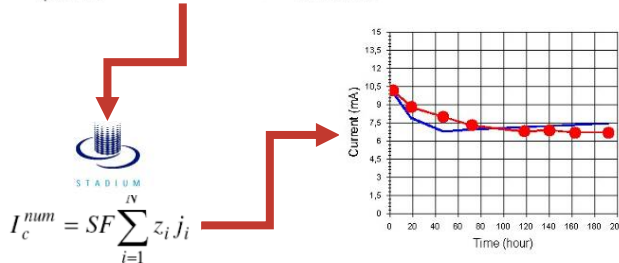
ASTM C 1202 - Modified

Experimental Procedure:



Evaluation of the diffusion coefficients for all ionic species:

- OH
- Na
- K
- SO4 ...



STADIUM® Interface

[Slab] - Material Name Concrete 2.2 - 0.35 w/b Type I Cement +20% Fly Ash Type C

Material List
 Concrete 2.2 - 0.35 w/b Type I Cement +20% Fly Ash Type C Experimental Procedure... Hide Advanced... Ok Cancel Help

Mixture Proportions | Transport Properties | Binder Chemical Composition | Validate Data with Expert System Show Message

| | |
|---|---------|
| OH ⁻ diffusion coefficient: (e-11 m²/s): 6.7 | 6.7 |
| Water diffusivity A (e-11 m²/s): 1.000 | 1.000 |
| Water diffusivity B: 25.00 | 25 |
| Age of first exposure (days): 28.0 | 28.0 |
| Thermal conductivity (W/mK): 2.00 | 2 |
| Specific heat (J/(kgK)): 1000 | 1000 |
| Reference Temperature (°C): | 23 |
| Porosity (%): 10.0 | |
| Age of lab testing (days): 28.0 | 28.0 |
| Hydration parameter - a: 0.66 | |
| Hydration parameter - alpha: 0.01541 | 0.01541 |

Hydration Function - a=0.66 - Alpha=1.54E-2

$$H(t) = \frac{a}{1 + (a-1)e^{-\alpha(t-t_0)}}$$

*** EXPERT SYSTEM - RULES EVENTS ***



STADIUM® Interface

Exposure Conditions for: PARKING - [Slab]

Location: Quebec STRUCTURE: [PARKING] Type of Exposure: [Deicing salts - NaCl]

Temperature: Mean value: 12 °C, Amplitude: 23 °C
 Humidity (air): Mean value: 55 [%], Amplitude: 0 [%]
 Humidity (ground): Mean value: 0 [%], Amplitude: 0 [%]

Sodium Chloride: NaCl = 12000 [mmol/L], Duration = 40 days
 Magnesium Sulfate: MgSO4 = [mmol/L]
 Calcium Chloride: CaCl2 = [mmol/L]
 Sodium Sulfate: Na2SO4 = [mmol/L]
 Potassium Chloride: KCl = [mmol/L]

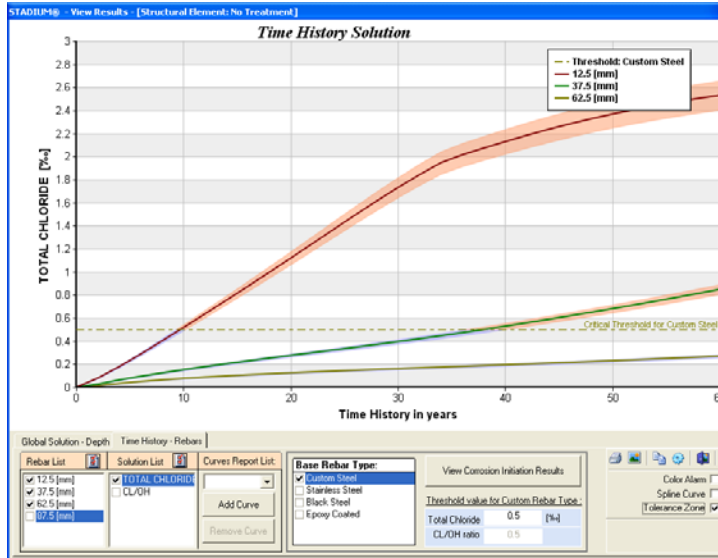
[Slab] - Exposure condition at x=0

Locations: Quebec - Exposition type: Deicing salts - NaCl - Element type: Slab

Ok Cancel Help White Back Color Round Corner View Border



Output Data



Typical Applications





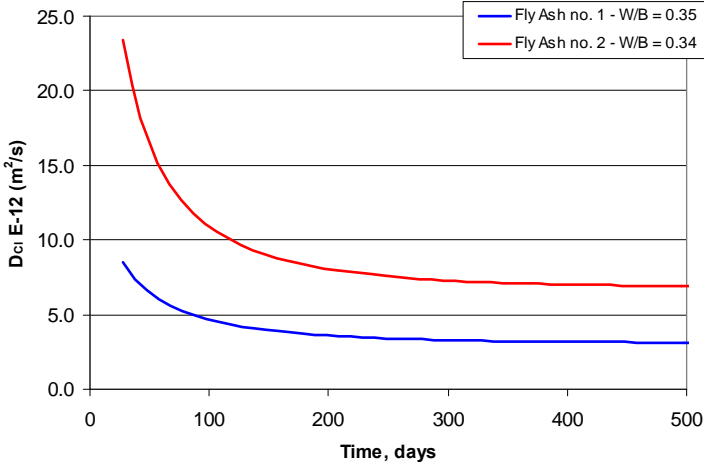
Mixture Characteristics

| Materials | Manufacturer | | |
|---|--------------|---------|-----------|
| | A | B | C |
| W/B ratio: | 0.27 | 0.34 | 0.28 |
| Type of binders: | | | |
| – Cement (ASTM C 150) | Type II/IV | Type I | Type I/II |
| – Fly Ash (ASTM C 1260) | Class F | Class F | Class F |
| Binder contents: | | | |
| – 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 |
| Heat curing: | No | Yes | Yes |





Influence of Fly Ash on Transport Properties

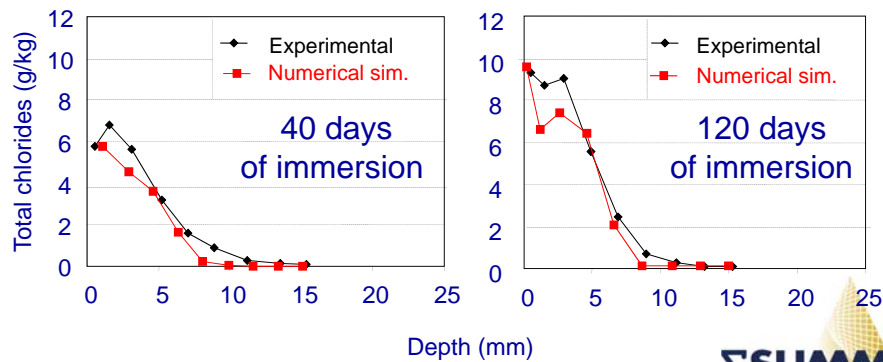


Validation Experiments

Chloride Immersion Tests



Producer C – Curing 56 days



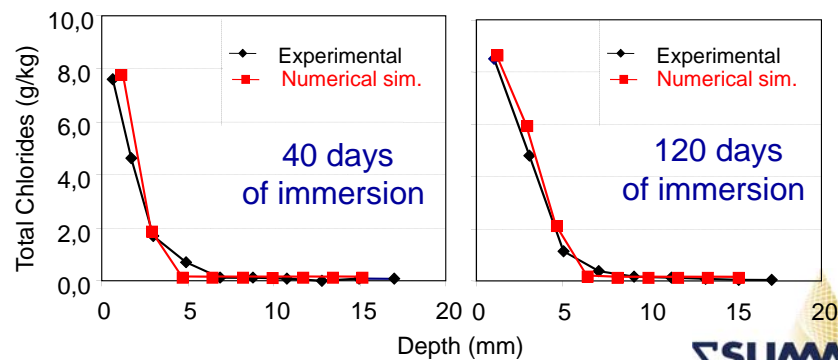
SUMMA
Numerical Model for Concrete Durability

Validation Experiments

Chloride Immersion Tests

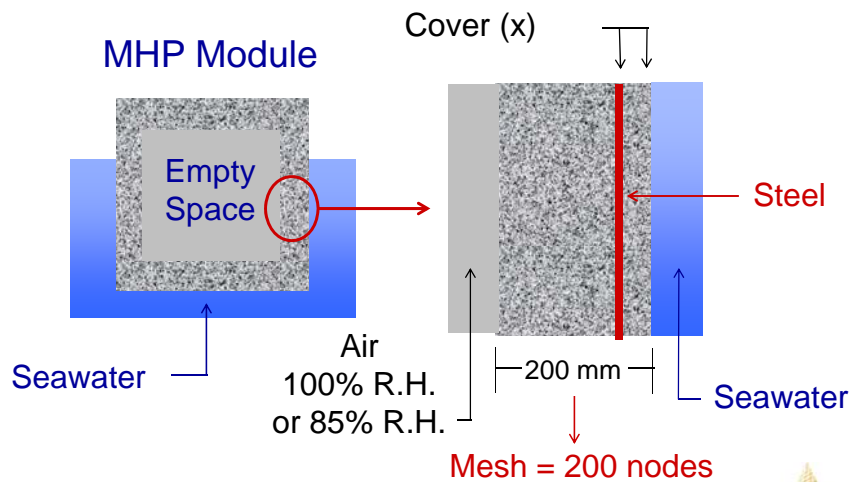


Producer C – Curing 365 days



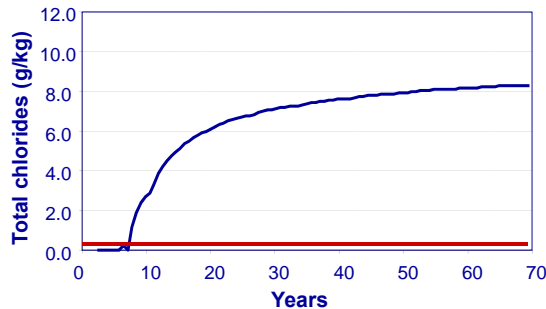
SUMMA
Numerical Model for Concrete Durability

Numerical Simulations – Exposure Conditions



Time to Initiate Corrosion – Black Steel

Chloride threshold value = 0.5 g/kg of concrete
(Bentur et al., 1999; Alonso et al. 2000)



| Cover (mm) | Time (years) |
|------------|--------------|
| 12 | 1.0 |
| 25 | 8.5 |
| 30 | 12.5 |
| 50 | 38.5 |





University of Kentucky



- Total cost of the project = 24 M\$
- Total cost for concrete = 1.3 M\$
- **Savings resulting from STADIUM® = 250 K\$**



In Summary

- Tools are now available to predict the durability of concrete structures.
- These tools can be used in support of more classical analyses to design durable concrete structures and optimize the maintenance of existing ones.
- They can also be used to optimize the selection of materials and produce more durable and greener concrete.

