STADIUM Software Overview

Durability and Service Life of Concrete Structures

Eric Samson
Cementitious Barriers Partnership
SIMCO Technologies Inc.

August 2014
SIMCO is a specialized engineering firm entirely dedicated to the durability of concrete structures.
Who we are

Design Construction Maintenance Rehabilitation

Cumulative Damage

Time

CURRENT CONDITION

WITHOUT INTERVENTION

REPAIR

Hanford Training, August 2014
Who we are

EXPERTS IN CONCRETE INFRASTRUCTURE DURABILITY

Field Experience

Analysis & Predictive Tools

Specialized Lab Tests

Engineering Services

STADIUM® Software

Customized Software Solutions

Innovation R&D

Academic Training Tools

Extend the Service Life

Reduce Construction & Maintenance Costs

Ensure Safety
STADIUM® models the transport of chemical species in cementitious materials resulting from exchanges at the material/environment interface.

- **Transport** (dissolved species in pores)
- **Chemistry** (Interaction of dissolved species with hydrated cement)
Specific geometry of the structure

Influence of local materials

Influence of local exposure conditions

Multiple degradation phenomena

Rehabilitation analyses
The U.S. Department of Defense recognizes STADIUM® as the only accurate numerical solution for the prediction of long-term behavior of reinforced concrete structures exposed to marine environments.

Since 2010, STADIUM® is specified in the Unified Facilities Guide Specifications (UFGS).

It is used to select concrete mixtures for marine applications, based on specified performance targets.
The model is divided in 2 main modules:

- The transport module makes the species move during one time step,
- The chemistry module simulates the reactions between species in the pores and the hydrated paste.
Input parameters:
- Material properties
- Environment
- Geometry

Transport Module

Chemistry Module

End of calculation?

Next time step

Yes

Model output

No

- Coupled species diffusion
- Moisture/Temperature coupling
- Transport of main species
- Feedback effect
- Time-dependent transport properties (hydration)
- Time-dependent B.C.
Input parameters:
- Material properties
- Environment
- Geometry

Transport Module

Chemistry Module

End of calculation?

No

Yes

Next time step

Model output

- Local Equilibrium Assumption
- Dissolution/precipitation
- Solid solutions
- Chemical/Pitzer database in separate text file
- Effect of temperature on chemistry
Characterization of concrete mixtures

Evaluation of transport properties – Input to STADlUM®

- Drying test
  - Permeability
  - Moisture isotherm

- Migration test
  - Tortuosity
  - Diffusion coefficients
The test methods are part of Unified Facilities Guide Specifications (UFGS) 03 31 29 (February 2010) test protocol

- US Navy (NAVFAC ESC)
- USACE
- USAF
- NASA
Transport equations

<table>
<thead>
<tr>
<th>Mechanisms</th>
<th>Properties</th>
<th>Lab tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodiffusion of species</td>
<td>Diffusion coefficient</td>
<td>Migration test</td>
</tr>
<tr>
<td></td>
<td>Porosity</td>
<td>ASTM C642</td>
</tr>
<tr>
<td>Moisture transport (liquid &amp; vapor)</td>
<td>Permeability</td>
<td>Drying test</td>
</tr>
<tr>
<td></td>
<td>Moisture isotherm</td>
<td>Drying test</td>
</tr>
<tr>
<td>Heat conduction</td>
<td>Thermal conductivity</td>
<td>Estimated</td>
</tr>
<tr>
<td></td>
<td>Heat capacity</td>
<td>Estimated</td>
</tr>
</tbody>
</table>
Chemistry

INPUT TO CHEMISTRY MODULE

• Mix composition
• Cement chemistry
• SCMs chemistry
• Chemistry database
• Pitzer parameters

CALCULATED PARAMETERS

• Hydrated cement paste composition
• Pore solution composition
Time-dependent boundary conditions

Exposure to deicing salts during winter

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

Existing structures

Input values

Calculations

OUTPUT

Input values

Calculations

OUTPUT
Time to initiate corrosion

![Graph showing time to initiate corrosion]

- **Corrosion initiation**:
  - Current age of the structure
  - Time to initiate corrosion:
    - 10 years

- **Content vs Time**
  - Total Chloride [PPM]
  - Time History [years]

- **Critical Threshold for Black Steel (Modified G109)**:
  - 1.97 [in]
Maintenance options

**Chloride content at first rebar**

- **No Repair**
- **Membrane**
- **Overlay**
- **Patch Repair**
Simulating past exposure sequences

Cl Profile History

- Points measured (2013)
- Numerical simulation
- Corrosion initiation threshold

Year: 1957
Simulating past exposure sequences

CI Profile History

- Points measured (2013)
- Numerical simulation
- Corrosion initiation threshold

Original Concrete

Year: 1994
Simulating past exposure sequences
Using STADIUM – New Structures

Case Studies

Kentucky University – Concrete Mix Design
Using STADIUM – New Structures

STADIUM® Specified Kilo Wharf Extension

Kilo Wharf Extension | US NAVY, GUAM
Panama Canal – Third Set of Locks
Case Studies

Panama Canal – Third Set of Locks

Two Coring-Drill Diameter

0.5 - 1 m

High Water Mark

Chloride content (% dry mass concrete)

- PW-MID-3
- PW-MID-4
- PW-MID-5
- PW-MID-6
- PW-TOP-1
- PW-Tidal-Avg
A probabilistic engine can handle calculations considering the distribution of key parameters:

- Transport properties,
- Concrete cover,
- Exposure conditions,
- Corrosion threshold.

Diagram:

- Transport properties
- Exposure conditions
- NDT / Rebar depth

Proabilistic Layer
Rosenblueth point est.
Probabilistic approach
Probabilistic approach

TRANSPORT PROPERTIES → EXPOSURE MAP → REBAR DEPTH → STADIUM® Corrosion Simulations

Deck corrosion initiation probability

Time: 1 y
KMS - Kademuren Modellering Systeem
KMS - Kademuren Modelling Systeem

Inspection Request

037-KAD-001-A

Concrete

037-KAD-001-B

Coring
Visual Inspection

037-KAD-001-C

Corrosion Measurements
Pitting Evaluation

Mechanical Testing
STADIUM® Testing

STEP 1
KMS - Kademuren Modellering Systeem

Degradation Analysis per Zone and Element
Evaluate Degradation with STADIUM®

For each Zone/Element combination
Select the most critical Zone/Element combination

Schedule Next Inspection
Close Monitoring Required
Repair

Critical Year (Trigger/Intervention)
Maintenance Proposal

Post Treatment Analysis
Concrete in contact with saltstone

Concrete barrier

Waste material (saltstone)

Soil
Concrete in contact with saltstone

Minerals after 5000 years

- Portlandite
- CaH2SiO4
- Ettringite
- Monosulfate
- C4AH13
- Calcite
- Monocarboal

Position (cm)

Solid phase content (g/kg)
Concrete in contact with saltstone

Species (liquid phase) after 5000 years
Concrete in contact with saltstone

Sulfate concentration at the concrete/saltstone interface

Waste material (saltstone)

Concrete barrier

Soil

Time (years)

SO₄ Concentration (mmol/L)

0 10 20 30 40 50 60 70

1 10 100 1000 10000

x = L

x = 0

20 cm
Concrete in contact with saltstone

Position of the ettringite front

- 20 cm
- Waste material (saltstone)
- Concrete barrier
- Soil

Graph showing the position of the ettringite front over time (years).