Long Term Operation of Concrete Infrastructures

A joint-effort by EDF & EPRI

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OUTLINE

• Does concrete matter?
• Aging Management Issues
• R&D Joint Programs
• Conclusions
... MADE WITH LOCAL RAW PRODUCTS...
IN INTERACTION WITH STEEL...
AND SUBJECTED TO DIFFERENT ENVIRONMENTS!
A CONCRETE LIFE: GROWING UP AND GETTING OLD...

- cement
- aggregates
- water
- concrete

**Initial mixture**

**Hydration** (chemical/physical process) with heat release

- setting
- hardening
- hours

**Physical properties**
- thermal conductivity
- diffusion...

**Mechanical properties**
- elasticity, strength, creep...

**Aging** (ambient exposure, loading, internal attack...)

- solid percolation threshold
- aggressive species diffusion
- internal pressure

**Upscaling**

- months
- years

**Morphological changes**

- decades

**Dissolution** (microscale)

- cracking (meso/microscale)

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Concrete infrastructures may not last forever!

Ferrybridge, 1965

Minneapolis, 2007
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Civil Structures of Interest

1 – Cooling Towers
2 – Containments
3 – Spent Fuel Pools/Transfer Canal
4 - Buried (Prestressed) Concrete Pipe
5 – Intake Structure

2 Unit Nuclear Plant (PWRs)
Degradation Causes of Interest for LTO

A NON RANKED LIST

• Chronic radiation exposure (biological shielding and RPV supports)
• Chronic exposure to high temperature (containment near steam generators and steam penetrations)
• Chloride attack and re-bar corrosion (generic – throughout plant)
• Boric acid leaching of concrete and attack of rebar (spent fuel pools, transfer canals)
• Corrosive soil attack (foundations, buried pipes, raft)
• Effects of concrete damage on post-tensioning system integrity (containment)
• Creep (containment)
• Internal swelling (ASR, DEF... massive structures)
• .........
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EPRI & EDF Strategy

2009
SOFTWARE DEVELOPMENT (400K)
- structural & materials modeling

EDF Reference Manual Input

PILOT PROJECT 1 – Leaking Spent Fuel Pools

COMPILATION OF DATA AND MATERIALS CHARACTERIZATION STUDIES

AGING CONCRETE STRUCTURES REFERENCE MANUAL
Operational Issues
Aging Mechanisms
- Basic mechanisms
- Detection/characterization/NDE
- Modeling

AGING ISSUES MATRIX

2010

2011+
CIVIL INFRASTRUCTURE LTO TOOLBOX PLATFORM
(Continuously Updated, Available to Utilities)

RADIATION DAMAGE

CHLORIDE ATTACK

TENDON MONITORING

PILOT PROJECT ‘n’ (TBD)

ADVANCED NDE FOR CONCRETE

2011

Funding to be designated
(EPRI/DOE/MAI/Utilities)

EPRI LTO/TI Funded

MAI Funded

DOE Funded
(Project approved but funding not committed yet)
EPRI & EDF Strategy: Aging Issue Matrix

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- AGING ISSUES MATRIX
  - RADIATION DAMAGE
  - CHLORIDE ATTACK
  - TENDON MONITORING
  - PILOT PROJECT ‘n’ (TBD)

FERC Funded
- DOE Funded
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- MAI Funded
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Ranking Priorities and Gaps Identification

- Basic mechanism
- Detection and simple model
- Characterization and refined model

- Infrastructure susceptibility
- Knowledge of the degradation
- On-going parallel projects: EPRI/MAI and NRC/DOE/E-PMDA
- TENTATIVE ONLY!
EPRI & EDF Strategy: Software development

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strategy for modeling concrete

2 strategies

3D modeling

build 3D microstructure from initial cement particles distribution and virtual hydration

0D modeling

build 0D microstructure (volume fraction) from initial cement composition and virtual hydration

microscale cement paste

mesoscale mortar & concrete

R&D purpose

feed

practical purpose
EPRI & EDF Strategy: Pilot Projects

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Example of a recent success at EDF
QUANTITATIVE ESTIMATION OF NPP CONTAINMENT RESIDUAL LIFE WITH REGARDS TO DELAYED STRAINS

MATERIALS SCIENCE
- basic mechanisms
- lab tests

MONITORING
- feed-back
- bayesian approach

COMPUTATION
TH-M FEA

FEM/MONITORING PREDICTION

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Chloride attack and corrosion of prestressed reinforced concrete

**step 0**
lab test
(crack vs. corrosion patterns, NDE...)

**step 1**
degradation of refurbished materials
(crack vs. corrosion patterns, NDE...)

**step 2**
NDE benchmark during outage

**step 3**
probability-based structural assessment

[Mullard & Stewart, 2011] experiment
### EPRI & EDF Strategy: LTO Toolbox Platform

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<th>2009</th>
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#### RADIATION DAMAGE
- Detection/characterization/NDE
- Modeling

#### CHLORIDE ATTACK
- Detection/characterization/NDE
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#### TENDON MONITORING
- Detection/characterization/NDE
- Modeling
Aging Management

#1 safety

#2 economically viable operation
THE THREE PILLARS OF DECISION...

Structural Analysis

Decision Making

Inspection

Material Aging
THE THREE PILLARS OF DECISION...

Structural Analysis

- Code Requirement
- Replacement
- Non Destructive Characterization

Decision Making

- Localized Maintenance
- Strengthening/Additional monitoring
- Material Simulation

Inspection

- Visual Inspection
- Non Destructive Detection

Material Aging

- Degradation Mechanism
- Lab testing

Computational analysis

Analytical Calculation

growing cost/complexity

Material Characterization

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WHAT ABOUT LTO?

LTO Computational analysis

Structural Analysis
- Code Requirement
- Replacement
- Strengthening/Additional monitoring

Decision Making
- Material Simulation
- Localized Maintenance

Material Aging
- Lab testing
- Degradation Mechanism

Inspection
- Visual Inspection
- Non Destructive Detection

Non Destructive Characterization
- Non Destructive Characterization

'routine'
- Routine Inspection

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Some important reminders

1. Recent major events regarding concrete:
   - tritium contamination of site groundwater
   - large outer containment delamination

2. Costs associated to Civil Infrastructures can be huge
   - CR3 shutdown for nearly 1 ½ yr.
   - FHWA estimation $8.3B/yr (bridges)

3. There are generic degradation modes but each concrete/environment is specific

4. Effective aging management programs require basic materials knowledge, inspection techniques and structural analyses

5. Not all issues find their answers in ‘expertise-based’ qualitative analysis