

Concrete Expert Panel Workshop

February 24-25, 2015 Rockville, MD



- Enhance the existing technical bases related to Dry Cask Storage Systems (DCSSs) for evaluating:
 - Concrete degradation modes
 - Concrete inspection and monitoring techniques
 - Functional assessment
- Identify relevant knowledge and practices from nonnuclear concrete structures
- Identify potential information needs
 - NRC
 - Overall



Schedule

Time Slot	February 24	February 25
0830-0845	Introduction and Welcome	Introduction and Recap
0845-1015	Degradation Mechanisms	Inspection and Monitoring
1030-1200	Degradation Mechanisms, continued	Aging Management Programs
1300-1415	Prevention and Mitigation Strategies	Time Limited Aging Analyses
1430-1530	Inspection Techniques and Technologies	Remediation, Repair, and Replacement
1530-1615	Public Comment Period	Public Comment Period
1615-1630	Recap, Flex, and Conclusion	Recap, Flex, and Conclusion



EXPERT PANELISTS



Neal Berke



- Tourney Consulting Group, LLC
 - Vice President, Research
- Concrete technology and durability
- Corrosion
- FACI, FASTM, FNACE



Larry Jacobs



- Georgia Institute of Technology
 - Professor and Associate
 Dean for Academic Affairs
- Quantitative nondestructive evaluation methodologies
 - Non-linear ultrasound
 - Microstructure
 - Damage



Randy James



- ANATECH
 - Senior Associate and Director of Structures
- Structural Analyses
 - Impact
 - Seismic
 - Failure
 - Degraded Concrete
 Capacity
- Numerical Methods
 - ANACAP



Hamlin Jennings



- Massachusetts Institute
 of Technology
 - Executive Director,
 Concrete Sustainability
 Hub
- Cement Based Materials
 - Micro-, Nanostructure
 - Hydration
 - Mechanics
 - Mechanisms of Creep and shrinkage



John Popovics



- University of Illinois, Urbana-Champaign
 - Associate Professor, Civil and Environmental Engineering
- Non-destructive evaluation, sensing and imaging
- Mechanical properties of cement-based infrastructure materials



Yunping Xi



- University of Colorado, Boulder
 - Professor, Civil,
 Environmental, and
 Architectural Engineering
- Long-term durability for concrete structures
- Evaluation of existing nuclear power plant structures



Motivation

- DCSSs are required to operate longer than anticipated
 - Up to 60 years for first license renewal
 - From 60-300 years for analysis of extended storage and transportation
- Concrete structures may degrade in these timeframes
- NRC requires adequate technical basis to demonstrate that concrete structures will perform their intended safety functions during the licensing period



Degradation Mechanisms

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Technical Information Needs Report



- Commission Directed in expectation of extended use of DCSS
- "This report presents the results of NRC staff evaluation of the technical information needs for continued extended dry storage . . . focuses on the degradation phenomena that may affect dry storage systems, and how these phenomena may affect the ability of the systems to fulfill their regulatory functions."



Concrete Degradation

Protecting People and the Environment

Degradation	Initiation Time	Propagation Rate	Mechanism Termination	Inspection Capability
Shrinkage	H	H	Н	Visual
Creep	Н	Н	Н	Visual
Fatigue	Н	Н	Н	Visual
Corrosion	Н	М	L	Vis, Elect-Chem
Carbonation	Μ	М	L	Vis, Core
Leaching	Н	Н	Н	Visual
Sulfate Attack	Н	Н	М	Vis, Petro
ASR	Н	М	L	Vis, Petro
Radiation	н	Μ	Μ	Vis, Radiation
Freeze-Thaw	Н	М	М	Vis, Petro
Desiccation	Μ	М	L	Testing
Ther. Deg.	М	М		Testing
Coupled	Μ	М	Ľ	Vis, Petro 14



Salt Scaling

Observations

- Identified by several experts:
 - Jacobs
 - Popovics
 - Berke
- Mechanisms are not fully understood
 - Crystallization pressure
 - Interdependence with ice pressure
- Causes surface deterioration

- Is salt addition required or are environmental salt sources enough?
- Is this cosmetic or is there structural significance?
- Can this phenomenon occur on vertical surfaces?



Acid / Ion Attack

Observations

- Aggressive lons of many types can negatively affect concrete health
- Many other mechanisms are "Ion Attack" (e.g. sulfate attack)
- Mg, Acids, Chloride, others
- Tied to concrete transport properties

- How widespread is this issue for other structures?
- Are aggressive ions commonly found in soil, or is another source needed?
- What "ionic criteria" lead to problems?



Delayed Ettringite Formation

Observations

- Sulfate phases are prevented from forming during curing or are dissolved
- Later precipitate as ettringite with large net volume change
- Elevated temperature plays a key role

- Are any components precast / steam cured?
- Monosulfoaluminate dissolution from canister heat load?



Thermal Desiccation

Observations

- Temperatures not high enough to degrade chemically bound or gel water, but could dry pore water
- This drying could precede other transport related mechanisms
- Thermally induced cracking

- Are there any other known consequences of moderate drying?
- Could significant moisture or thermal gradients form in high humidity environments?



Creep

Observations

- Creep rate
- Repair and subsequent load changes
- Potential for coupling with other mechanisms
- Creep rate slows with age

- Would time dependent deformation of the concrete be a significant degradation mode?
- Has concrete creep been a primary cause of problems in other structures?



Alkali-Silica Reactivity

Observations

- ASR has received much attention
 - Seabrook
 - Transportation structures
- Ongoing NRC sponsored research at NIST
- Much research in the transportation industry

- Can ASR confidently be excluded through testing?
- Do we know the structural effects of ASR?
- Would ASR be functionally limiting for DCSSs?



Radiation

Observations

- The mechanisms of radiation damage seem poorly understood
- The dose levels in DCSSs are lower than bio shield walls
- Recent NUREG/CR 7171
- Evidence of coupling with ASR

- Are total fluence limits adequate to ensure performance?
- Could radiation couple with other mechanisms?



Freeze-Thaw

Observations

- Expansion from freezing pore water creates tensile pressure in the pore network which can cause cracking
- Typically linked with cycles of freezing and thawing, not just one deep freeze
- Micro-diffusion, pore size distribution vs saturation
- Differential CTE

- How does this integrate with Salt Scaling?
- What are the concrete parameters influencing freeze thaw susceptibility?
- Is this a candidate for coupling with other mechanisms?



Corrosion

Observations

- Steel section loss and cover delamination
- Medium to high w/c ratios
- Cover thickness likely not designed for 300 year life
- Coupled with thermal desiccation

- What are the key parameters for initiation and progression of corrosion?
- What are the structural consequences of corrosion?



Coupled Mechanisms

Observations

- Coupling of mechanisms seems under-developed in the literature
- Linkage between micro cracking and increased transport
- Coupling of stimuli is also relevant

- Is there any active research on linked or coupled degradation?
- Which mechanisms would likely precede other mechanisms?



Prevention and Mitigation Strategies

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Prevention vs Mitigation

Prevention

- Actions taken during construction or installation in response to potential or expected degradation
- "Best Practices"
- Influenced by design life

Mitigation

- Actions taken once a problem is identified
- Different than remediation, repair and replacement



Prevention Strategies

- Concrete mix design
 - w/c
 - Supplementary cementitious materials
 - Aggregate selection
 - Admixtures
- Construction practices
 - Detailing
 - Cover thickness
 - Precast vs Cast in place



Mitigation Strategies

- Exclusion strategies
 - De-watering
 - Moisture barriers, coatings etc.
- Chemical Mitigation
 - Lithium application (ASR)
 - Cathodic protection (Corrosion)
- Others



Inspection Techniques and Technologies

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Inspection Technique Categories

- Visual
 - Imaging
 - Walk-downs
- Chemical Analysis
 - Surface pH
 - Corrosion potential
 - Various chemical tests on core samples
 - Laser Induced Breakdown Spectroscopy

- Mechanical
 - Impact echo
 - Ultrasound (some techniques)
 - Mechanical testing of cores
- Non-visual imaging
 - Ultrasound (numerous techniques)
 - Radar
 - Microwave
- Acoustic Monitoring



Understanding Limitations

Protecting People and the Environment

Quality of Information

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	High Information Quality Low Technological Maturity	High Information Quality High Technological Maturity
	Low Information Quality Low Technological Maturity	Low Information Quality High Technological Maturity

Technological Maturity



Inspection and Monitoring

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- Probability of detection
 - Threshold size, energy, etc.
 - Techniques generally confirm problems, not soundness
- Access issues
 - Radiation, dose
 - Below grade structures
 - Steel plate features



Strategic Monitoring

- Certain techniques are better suited to monitoring than others
 - E.g. Acoustic Monitoring
- Others best suited to targeted inspection
- Are there examples from other industries of monitoring strategies?

- Can our theoretical understanding of mechanisms help to create strategies?
- Is there adequate knowledge to use temporal trending of data for decision making?



Aging Management Programs

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Lead System / Targeted Inspection

- Should be the "worst" system to ensure that the state is bounded
- Any known problems should be considered
- Environmental conditions
- Age/Loaded Age
- Perhaps more than one system
- Statistics based

- Could a degradation ranking metric be determined?
- Could a logic tree or flow chart be used?



Frequency

- ACI 349.3R inspection frequencies:
 - 5 year for above grade, inaccessible
 - 10 year for below grade
- Should increase when:
 - A problem is detected
 - Adverse conditions are detected

 Are there examples of concrete degradation progressing more rapidly than these proposed inspection frequencies?



A Proposed AMP

- Visual per ACI 349.3R
- Groundwater Chemistry Monitoring
- Radiation Surveys
- May not be sensitive to
 - Internal damage
 - Initiation of degradation

- How might the monitoring and detection portion of this proposed AMP be augmented?
 - Methods
 - Frequencies
 - Decision trees



Time Limited Aging Analyses

Protecting People and the Environment

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Radiation TLAA

- ACI 349.3R cumulative limits:
 - 1x10¹⁷ Neutrons/m²
 - 10¹⁰ Gy
- Conservative with respect to limits from literature
- Potential coupling:
 - Thermal
 - Environmental
 - Aging

- Is better understanding of the coupled effects with radiation needed?
- Despite the lack of physics based models, is this an expected limiting factor for extended storage?



Other TLAA Possibilities

- Many degradation mechanisms are driven by chemical reactions with unique reaction kinetics
 - ASR
 - Carbonation

- Could any other
 mechanisms be
 addressed through
 TLAA?
 - Adequate modeling
 - Necessary data to support modeling
- Are any mechanisms likely not suitable for TLAA?



Repair Remediation and Replacement

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Repair, Remediation, and Replacement

- Corrective actions could take many forms
 - Patching
 - Partial demolition and replacement of material
 - External shoring or bracing
 - Total replacement
- Licensee decision, but NRC must be able to evaluate any corrective action in the context of the license

- How could the effectiveness of a repair be evaluated?
 - Prescriptive or methods based
 - Performance based
- Are there methods from other industries for evaluating repair quality and the contribution to performance life?



Capacity Quantification

