Overview Of EPRI Concrete Projects

Ken Barry
Technical Executive
kbarry@epri.com

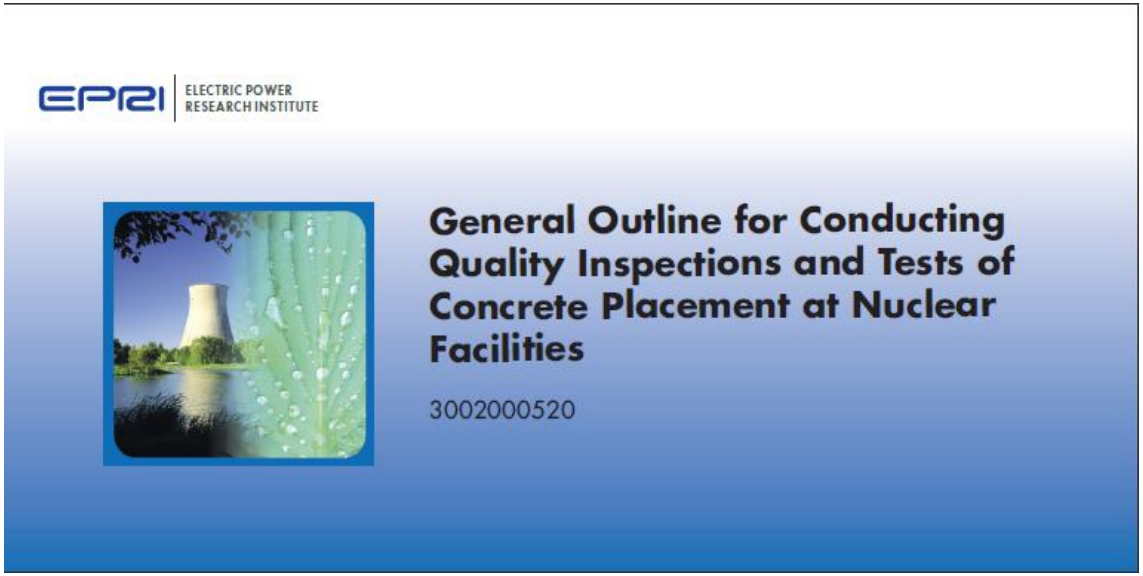
EPRI Team

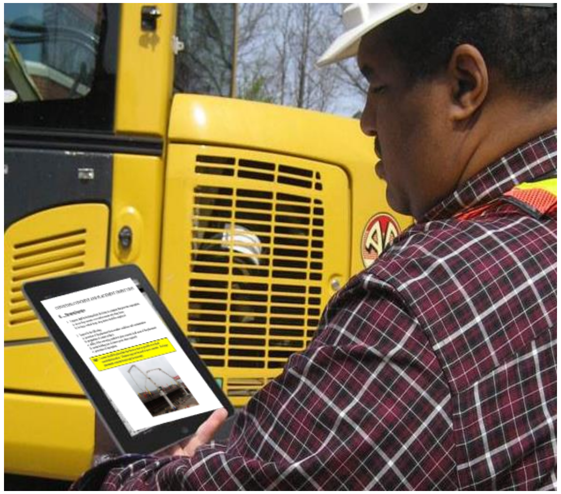
- Key People
  - EPRI Technical Leads: Ken Barry, kbarry@epri.com, Maria Guimareas, mguimaraes@epri.com

- Relevant EPRI Products
  - General Outline for Conducting Quality Inspections and Tests of Concrete Placement at Nuclear Facilities (3002000520)
  - Nondestructive Evaluation of Steel-Concrete Construction Mockups (3002000294)
  - Embedded Sensors in Concrete(1023006)
  - Quality Control of Concrete During Construction – Voids Detection (1025300)

Concrete Inspection Field Guide - published in pocketbook and iPad format

- Guidelines on quality control of new pours, addressed to utility engineers who will ultimately be responsible for the quality of the concrete placement.





Check that procedures are OK.

Surveillance – Oversight role

Readiness review document: List of items that need to be checked before, for example, “pouring concrete”

Concrete Inspection Field Guide

- **ACI - American Concrete Institute**
- SP-2, “ACI Manual of Concrete Inspection”
- ACI-311.4R, “Guide for Concrete Inspection”
- ACI 311.5R, “Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete”
- ACI 318, “Concrete Building Code”
- ACI 349, “Code Requirements for Nuclear Safety Related Concrete Structures”
- **ASME - American Society of Mechanical Engineers**
- Section III, Division 2, “Code for Concrete Containments” (ACI 359)
- Section III, Division 2, Mandatory Appendix V, “Qualifications of Concrete Inspection Personnel”
- NQA-1, Subpart 2.5, “Quality Assurance Requirements of Installation, Inspection, and Testing of Structural Concrete, Structural Steel, Soils, and Foundations for Nuclear Facilities
- **NRMCA - National Ready Mixed Concrete Association**
- QC Manual Section 3, “Plant Certification Checklist”

High Strength Rebar

- The use of higher strength rebar in the design and construction of safety related concrete structures will result in a decrease in reinforcement congestion which is the main cause of void problems during concrete placement, but it is not allowed in ACI 349 nor 359
    - Current Code limit is 60ksi steel
- Develop technical basis informing modifications to ACI codes 349 and 359 enabling use of high-strength rebar in safety-related structures.

- Project Duration: 2012-2017

Leverage from: Kansas University Transportation Research Institute - Concrete Reinforcing Steel Institute - Charles Pankow Foundation

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High Strength Reinforced Rebar

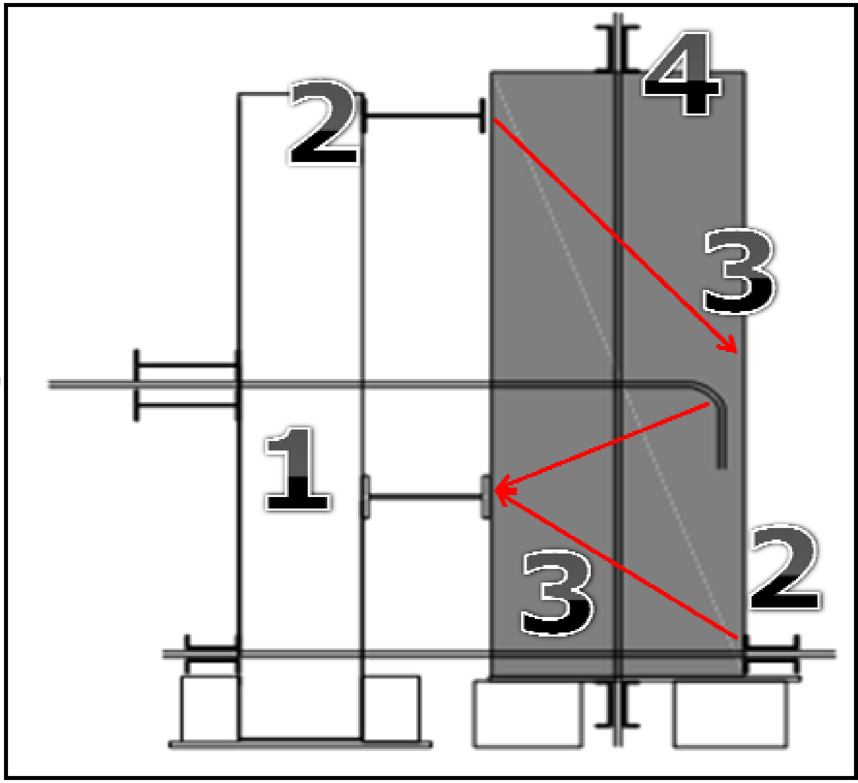
Project Details

- The goal of the experimental study is to gain a firm understanding of the variation in hook and head strength as a function of bar size, concrete strength, member geometry, and transverse reinforcement.
- Emphasis in the tests will be placed on No. 5, No. 8, and No. 11 hooked bars tested at bar stresses of 60, 80 and 100 ksi. A limited number of bars will be tested at stresses as high as 120 ksi.
- Concrete compressive strengths of 5000, 8000, 12,000 and 15,000 psi will be used.

High Strength Rebar Testing

<u>Design considerations included</u>

- (1) a compressive reaction simulating the compression zone of the beam,
- (2) reactions at the top and bottom of the specimen to prevent rotation of the specimen,
- (3) designing the specimen so that the compression struts from these reactions do not interfere with the hook,
- (4) simulating axial force in a normal column.



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Hooked Bar Testing

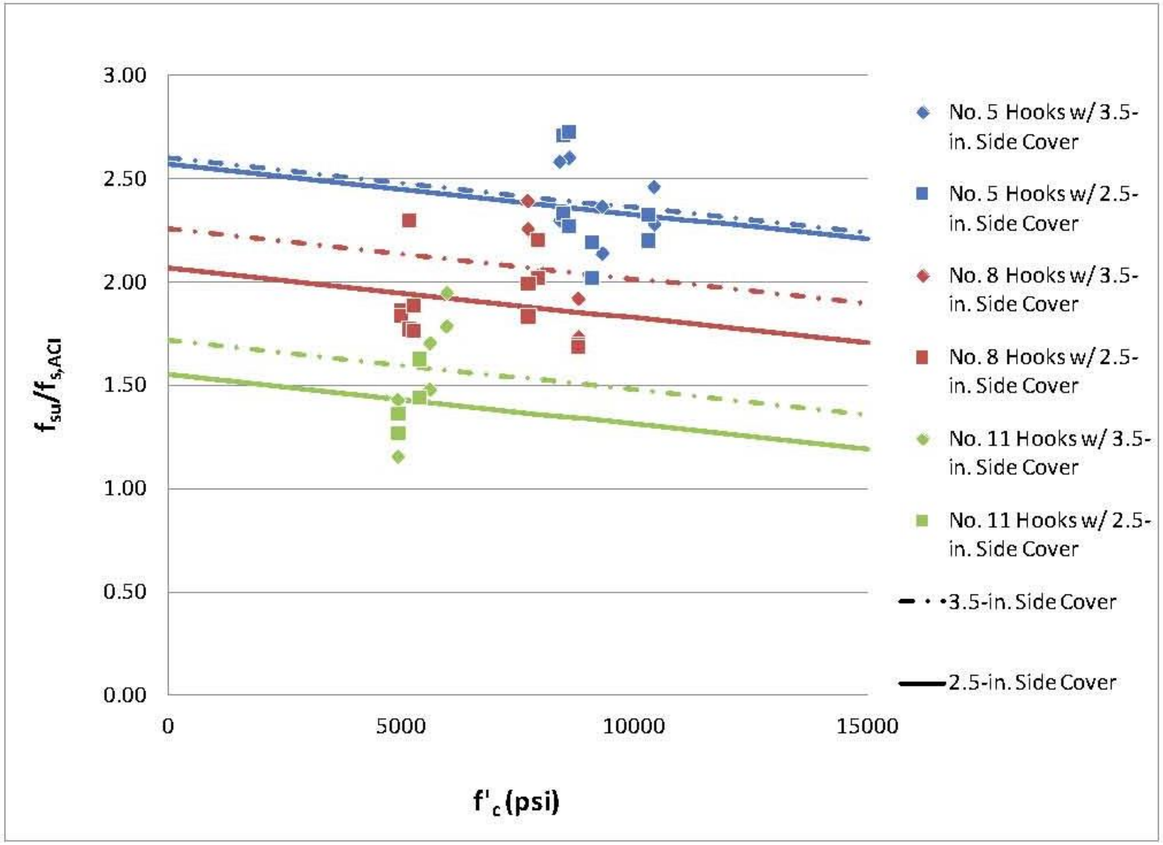

Figure 2: Ratio of measured to calculated stress for hooks without transverse reinforcement. Hooks inside column core

$$f_{s,ACI} = \frac{50\sqrt{f'_c}\,\ell_{eh}}{d_b} = 50\sqrt{5000}\,\frac{\ell_{eh}}{d_b}$$

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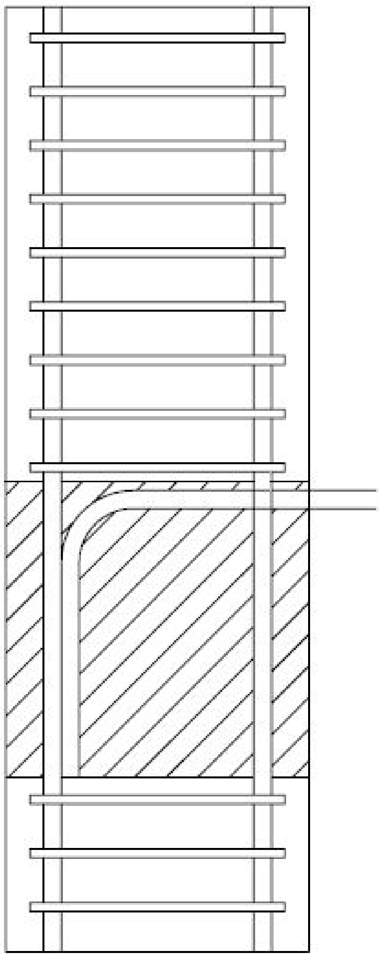
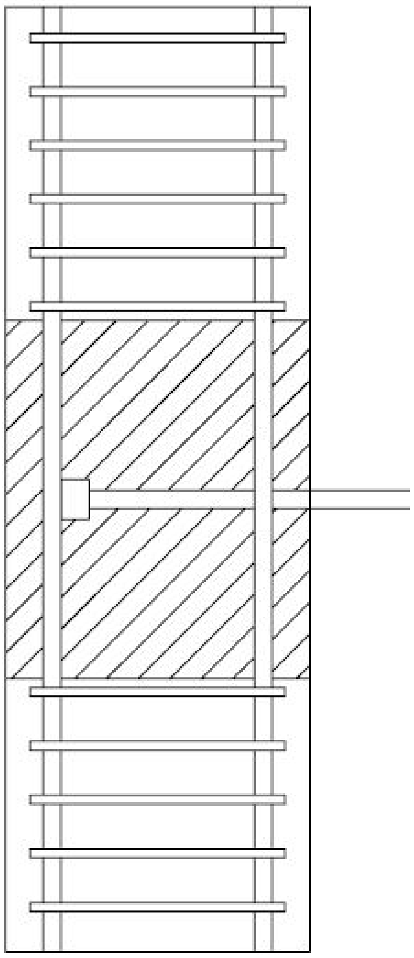
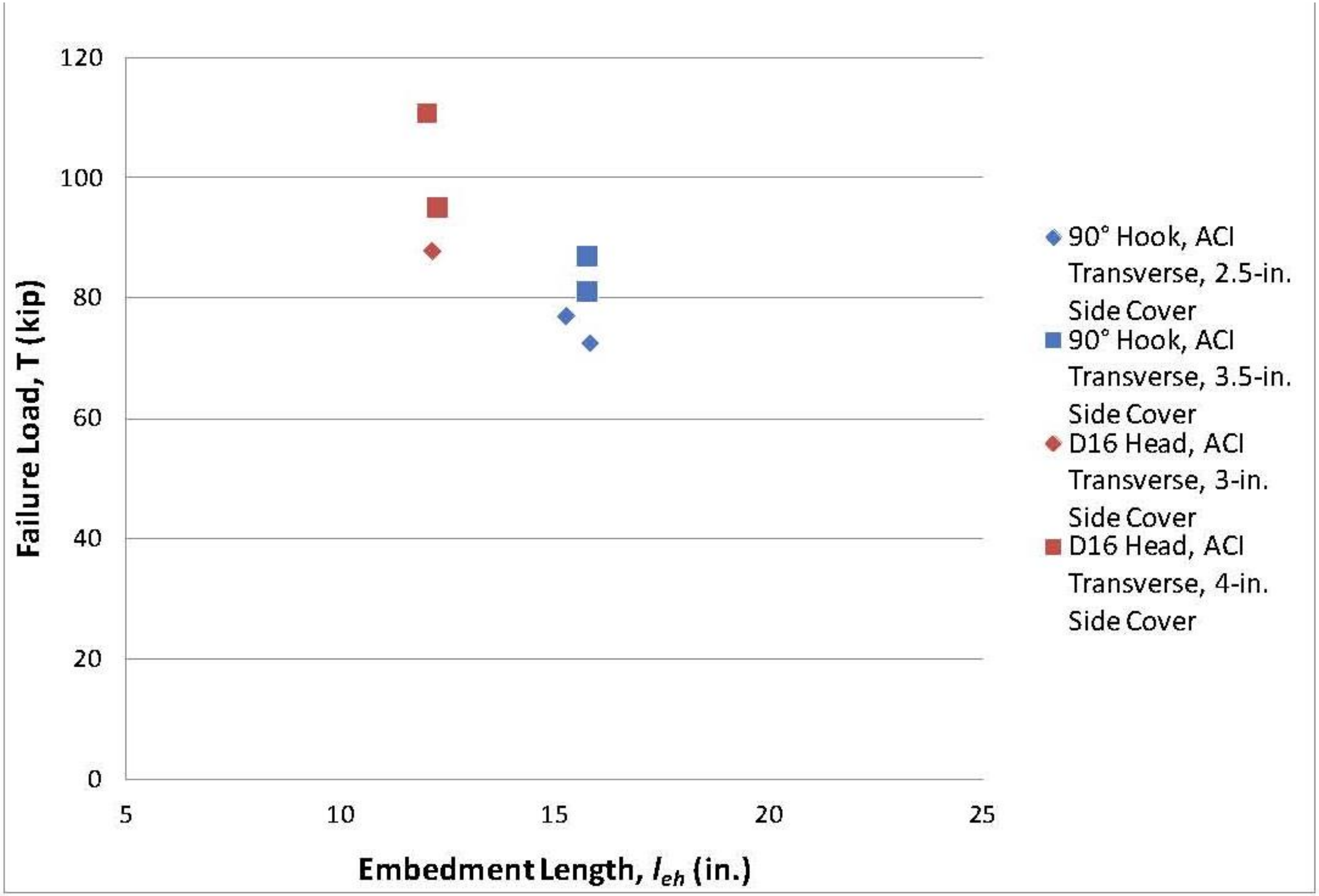
Specimens with hooked and headed bars without transverse reinforcement showing regions without ties





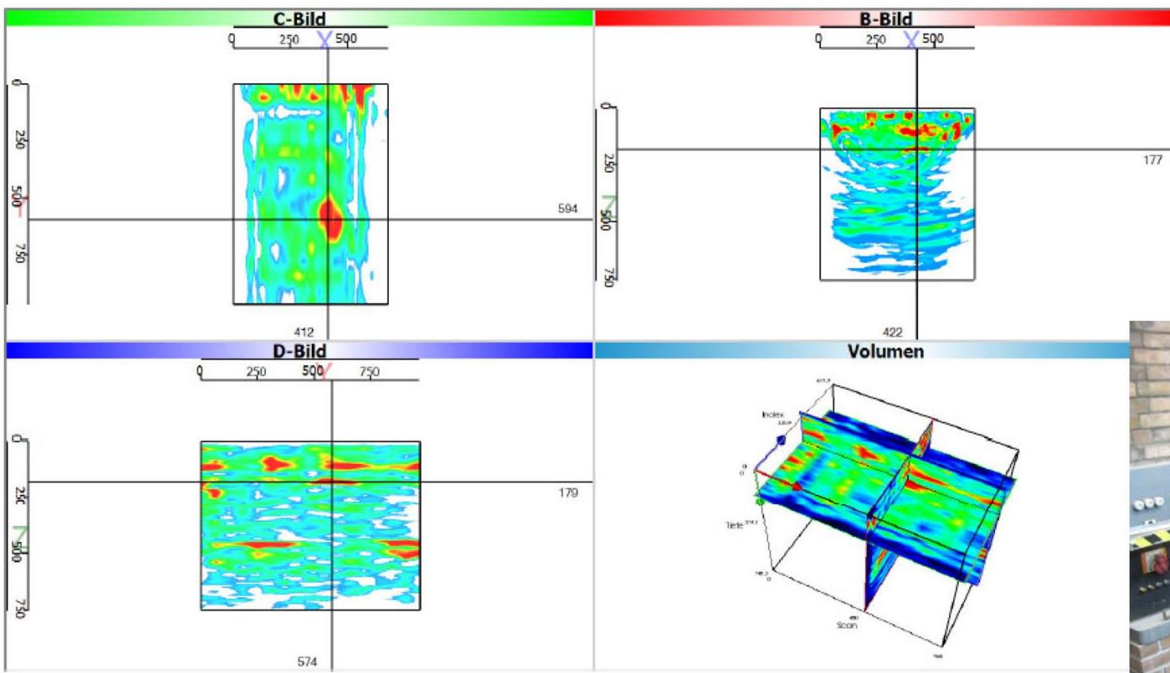
Anchorage strength of No. 8 hooked and headed bars in 5000 psi concrete with transverse reinforcement conforming to ACI 318 Section 12.5.3(b)

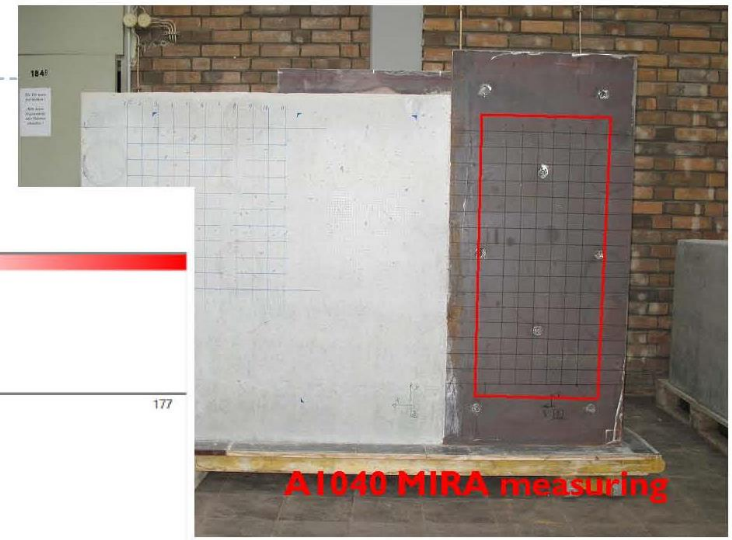


Void Detection with SC Construction

Steel – Concrete (SC) Construction Modules

Comment: Void in concrete behind steel layer, front side measured grid 60mm x 60 mm, 6x17 steps





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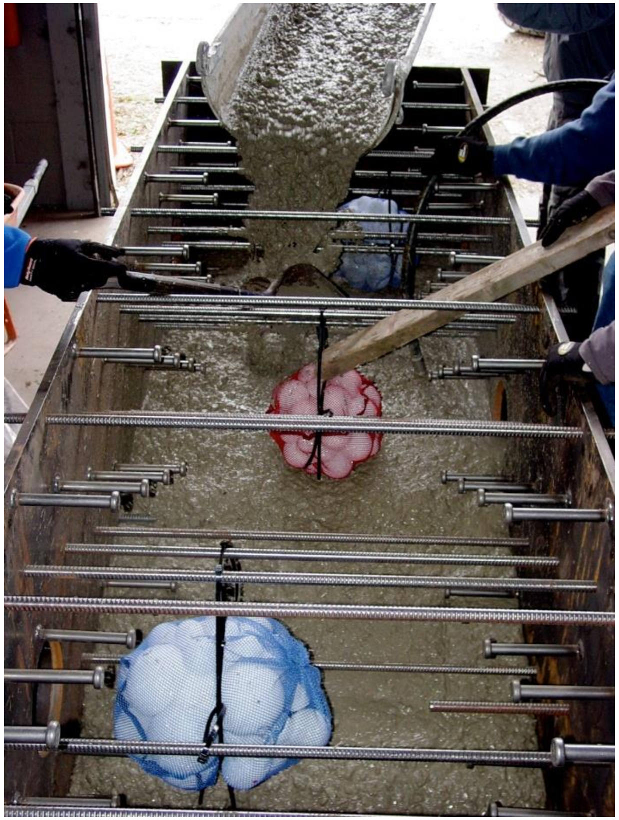
Void Detection with SC Construction

- 3' x 3' x 10' steel/concrete mockup fabricated
- Access from steel sides or concrete top
- Known voids/laminations installed



Void Detection with SC Construction

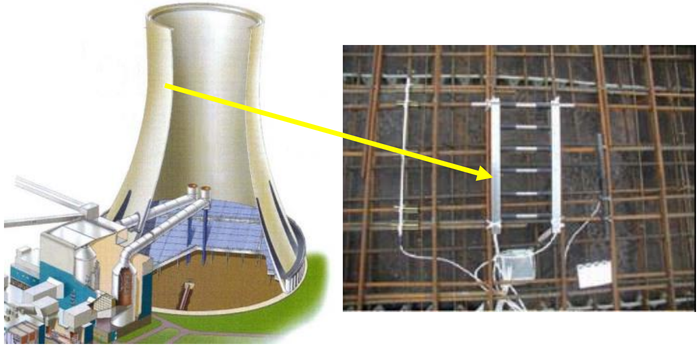
- 120 ton Steel/Concrete Composite Mockup
- Large voids installed at most probable locations
- Access from steel plates, concrete sides and vent lines

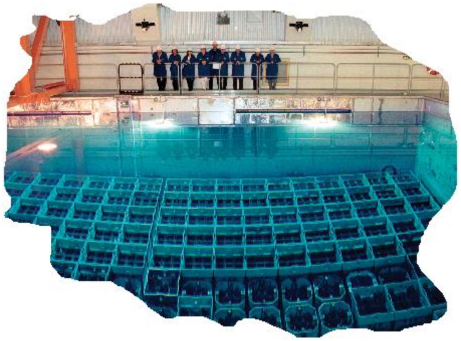
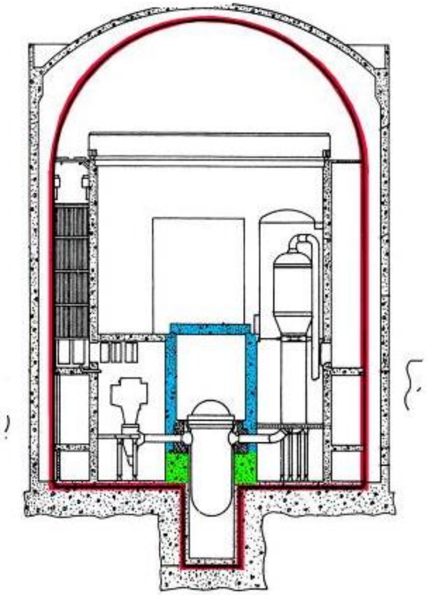
Void Detection with SC Construction

- Techniques Used
  - Pulse/Echo UT
  - Phased Array UT
  - Impact Echo Method
  - Ground Penetrating Radar (concrete face only)
- Tremendous quantity of data collected in 3 days
  - 5 methods, 14 separate locations
  - Pulse/Echo UT on concrete found all voids

Embedded sensors in new structures

Scoping study on the use of embedded sensors to monitor *aging* of concrete for new nuclear plants



Embedded Sensors - Concrete structures

Containments

Cooling Towers

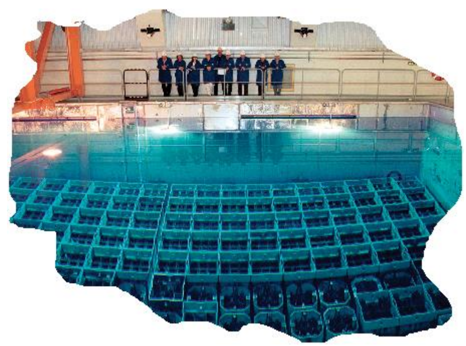
Spent Fuel Pool

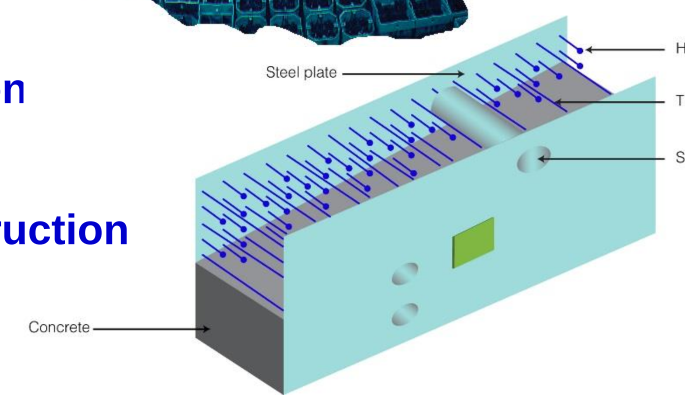
Foundations

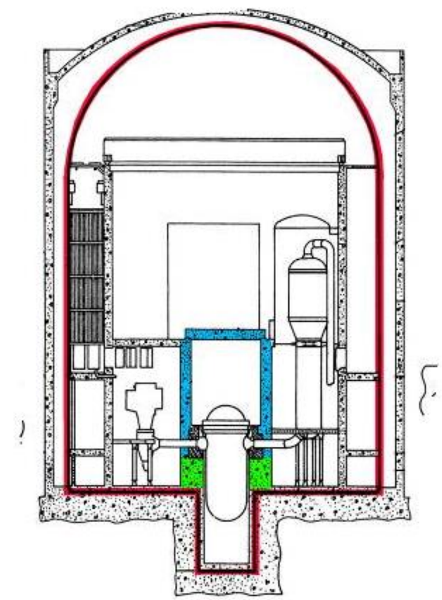
Hot penetration sleeves

Structures subjected to radiation

Concrete based modular construction







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Embedded Sensors - Parameters to monitor

Containments →	Strain	Extensive experience Korea and France
Cooling Towers →	Corrosion	Some experience Europe
Spent Fuel Pool →	Leaks	Development stage

Foundations…

Hot penetration sleeves

Structures subjected to radiation

Concrete based modular construction

} Future and Ongoing Research at EPRI

Concrete containments – Used before?

Plant / country	Reactor type PT	Durability (years)	Type of sensors	Sensor location	Number of sensors
EdF fleet **France**	PWR	30+	Vibrating Wire		32 / unit 24 / unit
Gentilly 2 **Canada**	CANDU	30+	Vibrating Wire	Dome, perimeter wall, ring beam, base slab, openings	132 sensors
Pont Lepreau **Canada**	CANDU	10+	Vibrating Wire Fiber Optic Sensor	VW in dome and cylinder FOS attached to surface between buttresses	11 sensors 4 sensors
Uljin **Korea**	Framatome – PWR	Not available	Fiber Optic Sensor	Attached to surface	n/a
		20+ 15-20% malfunct.	Strain Gauge	Dome, wall, base mat, gusset,	52 / unit 24 / unit
Wolsong **Korea**	CANDU	20+ 15-20% malfunct.	Vibrating Wire	Dome, perimeter wall, ring beam, base mat, hinge	118 / unit
Temelin **Czech Republic**	VVER – PWR **ungrouted**	10+	Vibrating Wire	Dome, cylindrical wall, ring beam	246 / unit 256/ unit

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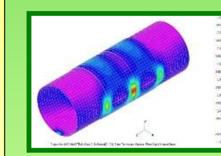
Embedded Sensors – Future Application

Needs today and tomorrow	Sensor Development	Power & Data Storage	Data Collection	Use of data
	corrosion moisture migration strain temperature etc…	wires batteries radio waves PC platforms	Wires Wireless	trend aging is coming!!!! 

www.hpschapters.org
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NDE for quality control for Fresh Concrete

Can we use NDE for quality control during construction/repairs?

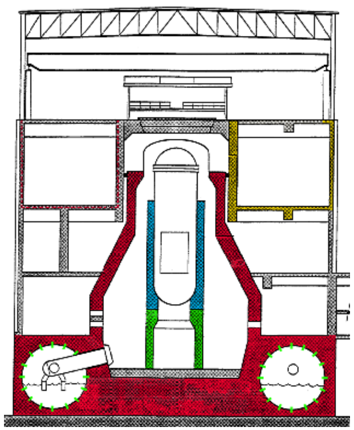
- Feasibility of using NDE in fresh concrete for quality control during construction. Several NDE techniques were tested.
  - Electrical conductivity
  - Electromagnetic permittivity
  - Mechanical - P-Wave velocity (acoustics)
  - Gamma
  - Thermal

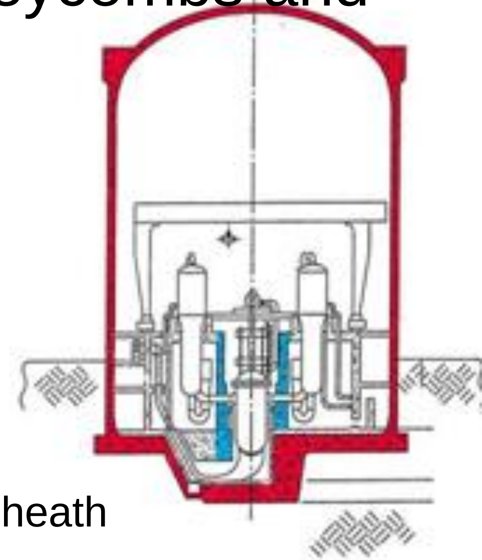
Summary of cases from early construction

- NUREG 4652 summarizes construction related delays in existing fleet.
- Out of ~90 reports, 32 deal with cases of honeycombs and voids

Structures affected

Foundation and basemat
wall – containment
wall - containment - equipment hatch
Wall - behind liner plate
ring girder - containment
concrete near tendon bearing plates
Wall - drywell





buttress /shell interface tendon sheath
basemat under sump plates
wall - fuel transfer canal
wall - primary shield cavity
wall - Aux building
wall - diesel generator building
reactor pedestal

Can We Detect the Voids Before the Concrete Sets?

Go – No-go indication on the presence of voids and honeycombs

The Future?

Multiple Probes Mounted on Vibrator

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NDE Techniques for Fresh Concrete Void Detection and Sizing

Tool	SNR	Implementability	Comments / Limitations
Gamma density	**4**	**<u>2</u>**	*license, certification, contamination*
Temperature	**<u>1</u>**	**3**	*very poor SNR*
P-wave velocity	**3**	**3**	*possible false-positives*
Mechanical Impedance	**<u>2</u>**	**4**	*data interpretation*
Electrical conductivity	**4**	**4**	
Permittivity - TDR based	**4**	**4**	
Permeability - Gas Flow	**3**	**3**	*emphasis on cementing fluids*

1 = worst

5 = best

SNR: signal-to-noise ratio

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NDE Techniques for Fresh Concrete Void Detection and Sizing

- **Time-domain reflectometry** (TDR) Permittivity can measure a discontinuity in homogenous substances by observing reflected waveforms.
- **P-wave velocity** - Ultrasonic longitudinal waves propagate in gases, liquids or solids. P-wave velocity measurements are very different between fresh concrete and air. Therefore, they have a potential to have large signal to noise ratio.
- **Electrical Conductivity** of curing cement changes over time and is directly dependant on temperature. The presence of a void is distinctly discernable.
- **Gamma Density** methods are based on selective absorption. Global absorption depends on the elemental absorption and mass fraction with amplitude decaying exponentially with distance ^{137}Cs is preferred for concrete-related applications.
- **Permeability – Gas Flow** - The injection pressure ideally approaches zero in honeycombs, and closes to the ‘hydro-static pressure’ of fresh concrete in paste-saturated fresh concrete.

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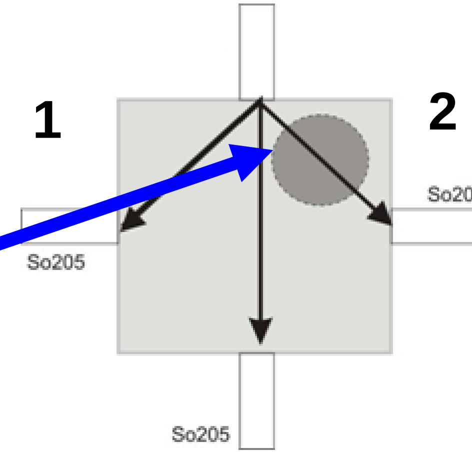
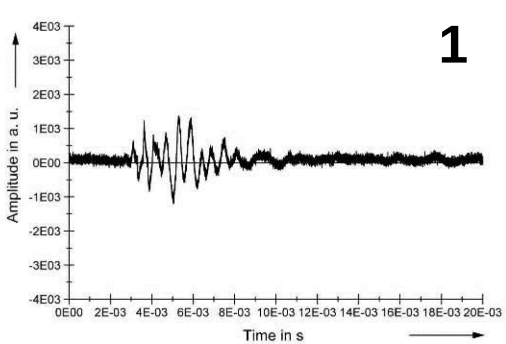
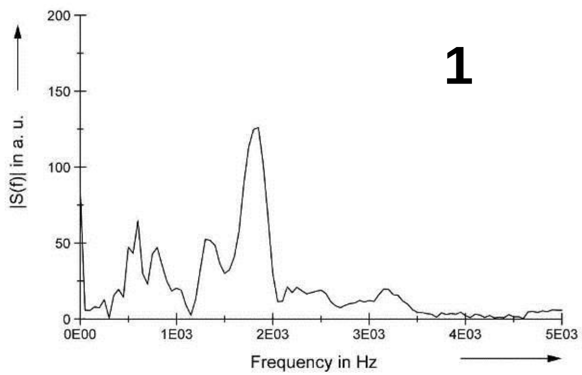
Exploratory Test - Ultrasonic

Artificial honeycomb

(**void**)





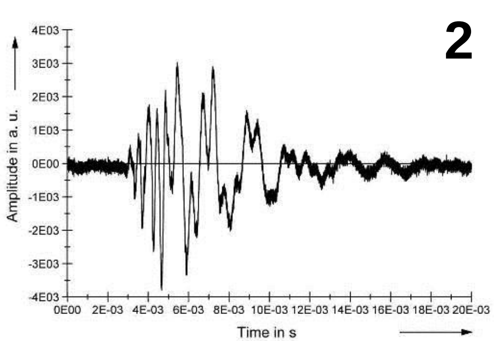


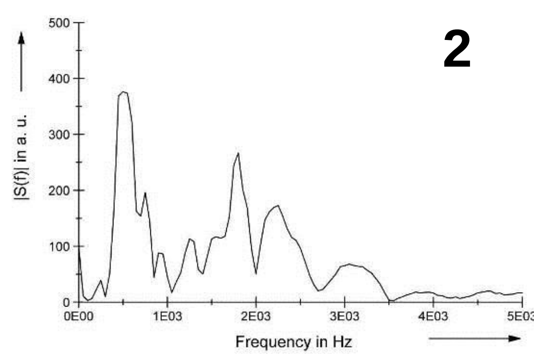
Left:

Received signal (without void)

Right:

FFT with peak at emitted frequency





Left:

Received signal (with void)

Right:

FFT with differing signal pattern

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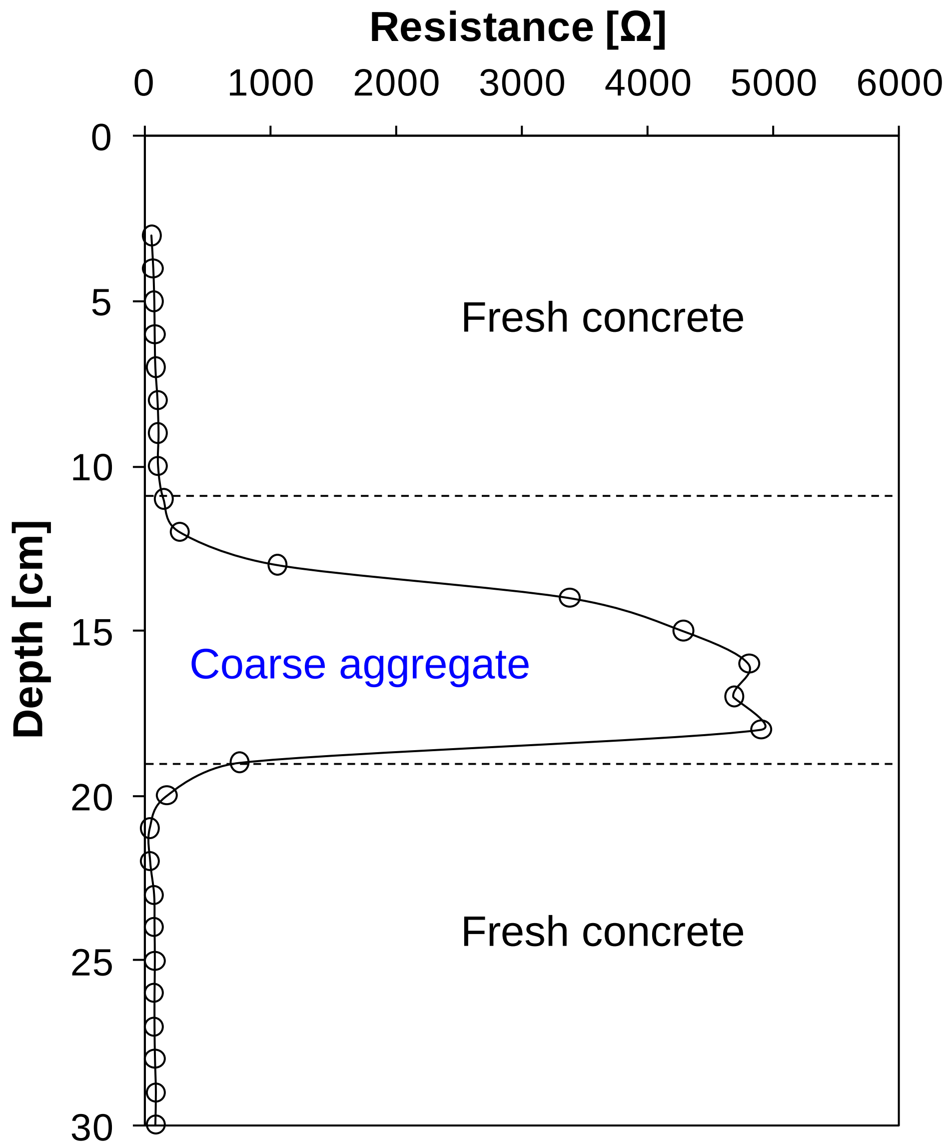
Exploratory tests - Electrical conductivity

Conductivity probe



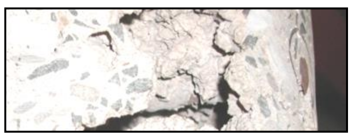
Other Projects

NDE capabilities for concrete

Corrosion

Corrosion of
embedded
steel

Single defect



Delamination

Voids

Vertical cracks

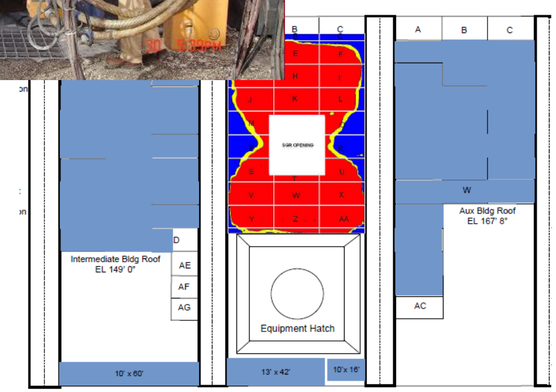
Pattern cracking

ASR

Freeze - thaw

High temperature

Independent resource for concrete NDE technical capability assessment and development



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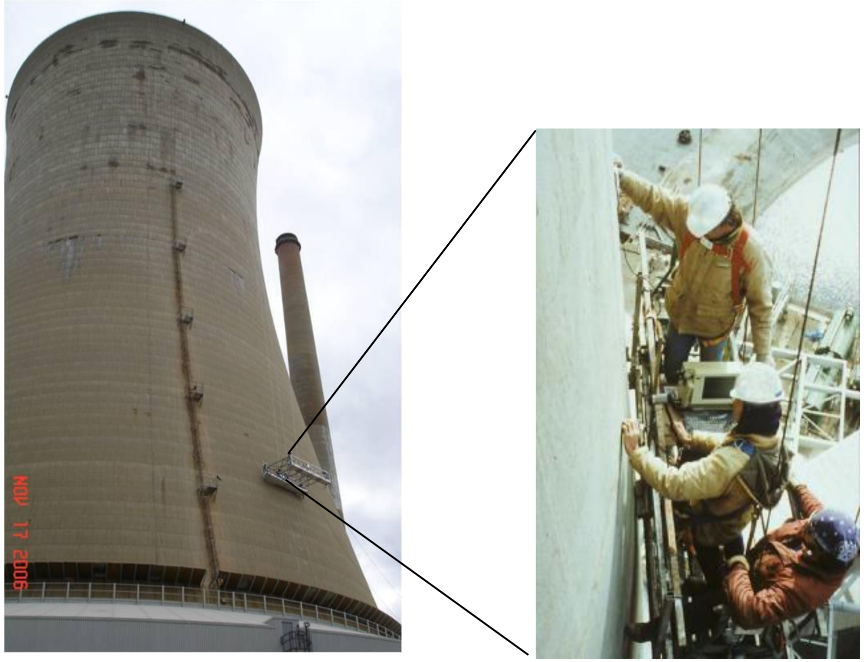
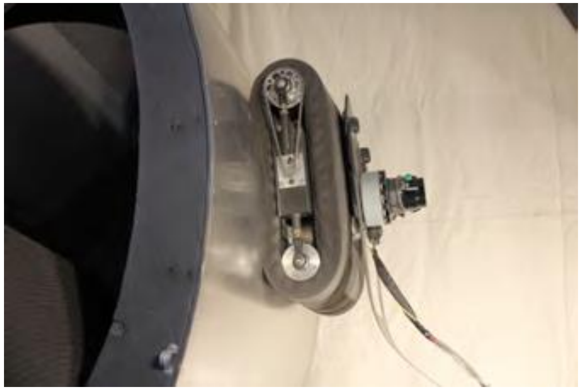
Automation of concrete inspection

The availability of automated concrete inspections will translate into faster and less costly inspections of vertical structures. This will allow for easier and more frequent inspections of the aging nuclear fleet.





http://www.youtube.com/EPRIvideos

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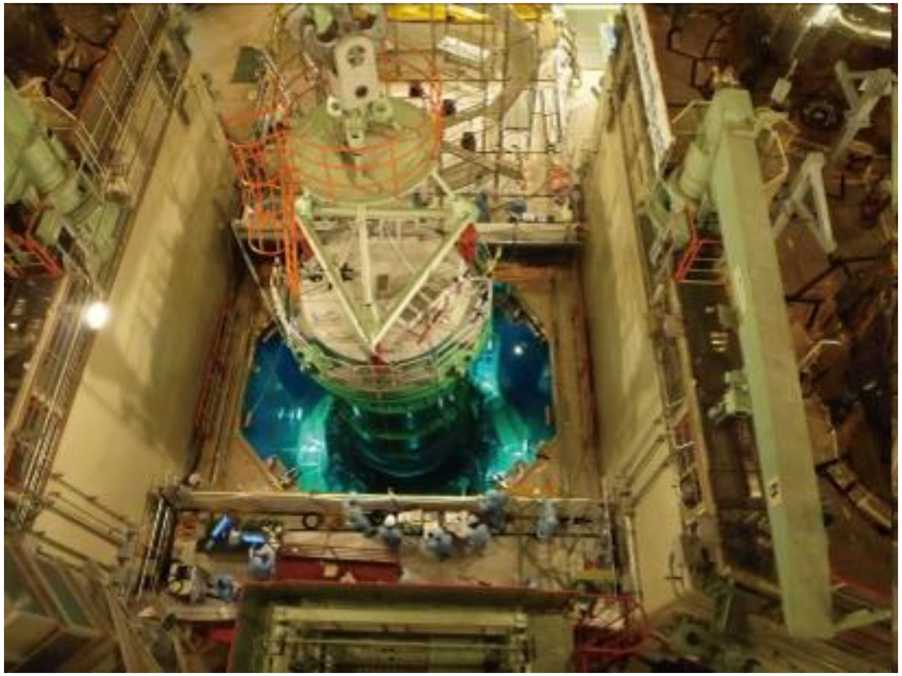
Radiation damage in concrete

Reactor cavity concrete may see > 10^{20} n/cm^2 during the period of Long Term Operation, which is beyond the design basis.

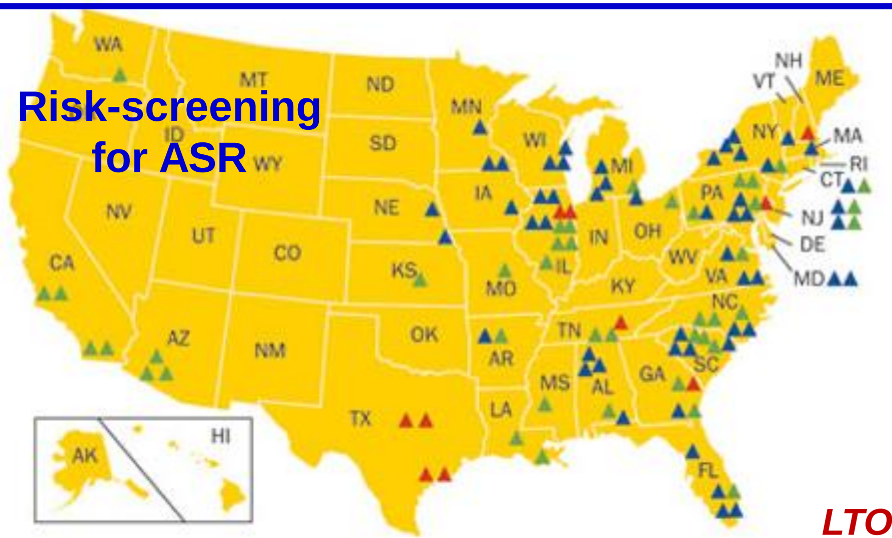


EPRI is working on a new report with updated data on irradiated concrete samples.

In parallel, research in fundamental understanding on radiation in concrete will be pursued

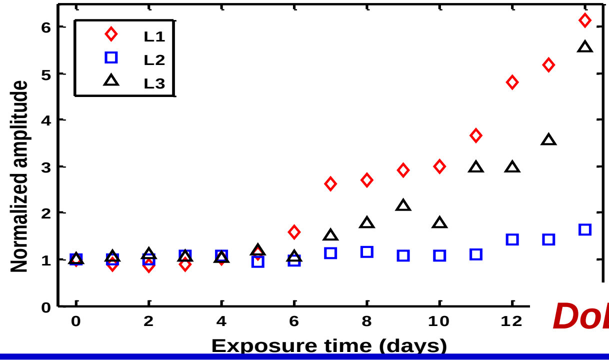
EPRI 's projects on ASR

Risk-screening for ASR



LTO

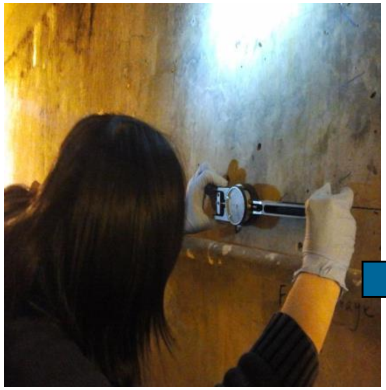
Non-linear UT to detect ASR

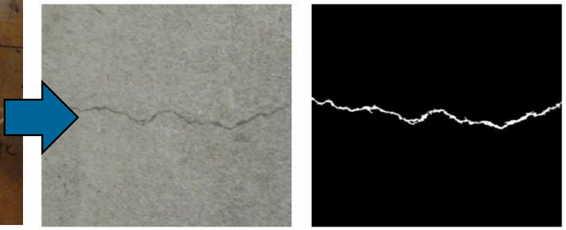


DoE

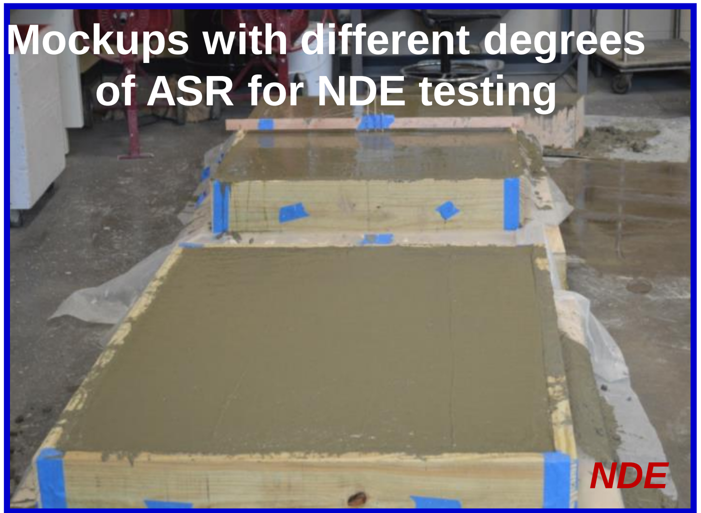
TI

Improving monitoring of ASR affected structures



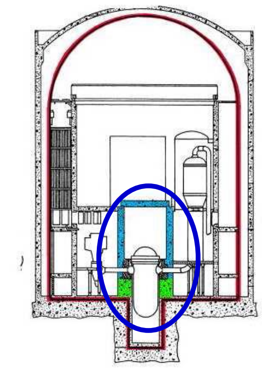


Mockups with different degrees of ASR for NDE testing



NDE

Expanding inspection techniques



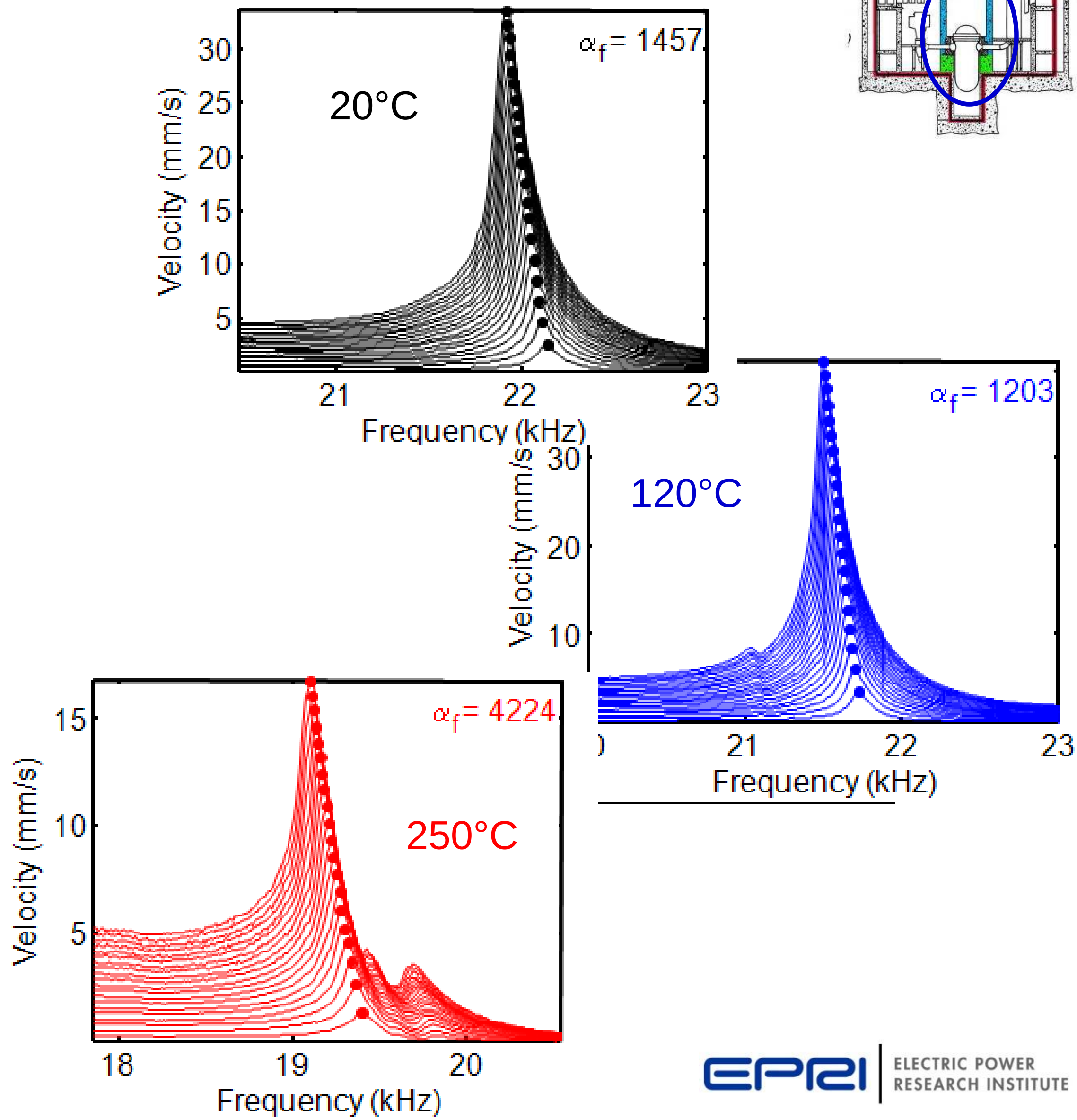
Non linear UT can give information on degree of damage with depth for concrete subjected to:

Radiation

Carbonation

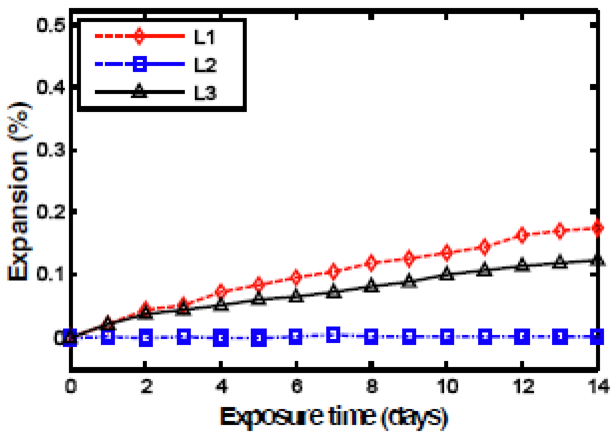
Alkali-silica reaction

Temperature damage

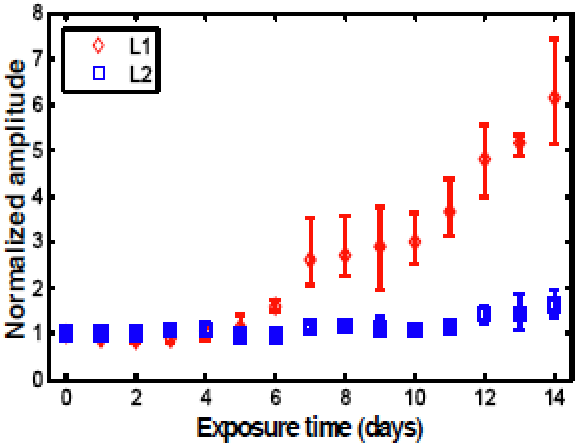


Non-linear Ultrasound

<u>Non linear UT</u> can give information on degree of damage with depth for concrete subjected to ASR.



% expansion of concrete bars with different degrees of ASR



Jacobs, 2010

Normalized amplitude (non linear parameter) in the same concrete bars with different degrees of ASR

Note the sensitivity of the acoustic non linear parameter in detecting the degree of damage caused by ASR

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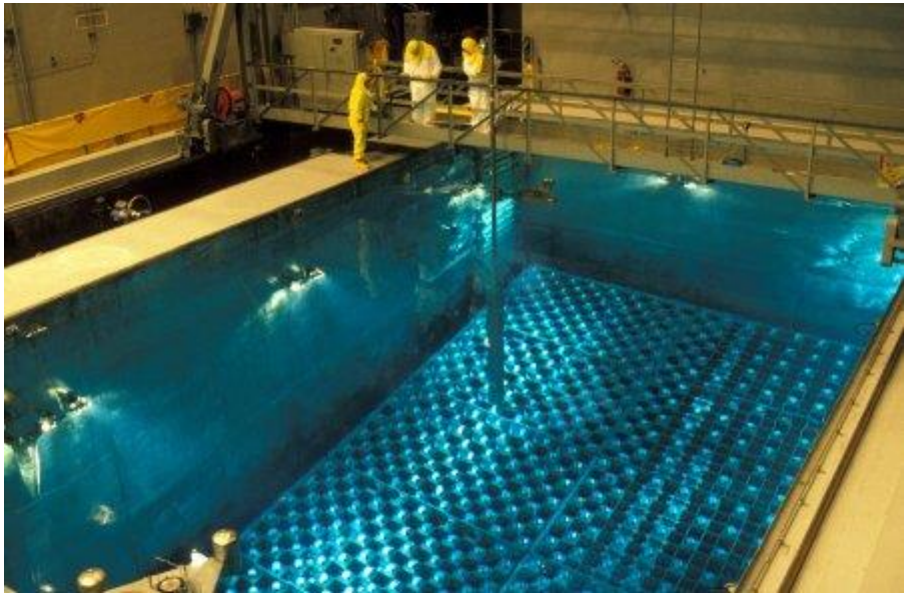
Concrete degradation in Spent Fuel Pool

Concrete in spent fuel pools is degrading due to leakage beneath the liner. The spent fuel pool water exits through welds in the liner and begins to attack the concrete substructure.



1 in. = 25.4 mm

EPRI is engaged in studying the effects of water containing boric acid on the structural integrity of spent fuel pools. A project on modeling the degradation rate due to boric acid being performed in 2013-2014.

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Chloride attack in concrete – cooling towers

Cooling towers and water intakes are subjected to corrosion related degradation due to aggressive water used in the cooling system.

A project on determining the extent of degradation and the structural bearing capacity margin in severely damaged cooling towers is being performed at EPRI.

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