Crystal River Unit #3
Containment Delamination Update

November 20th 2009

Progress Energy

Agenda

- Introduction
- Plant Overview
- CR3 Containment Design Features
- SGR Opening Sequence & Identification of Delamination
- Investigative Approach
- Condition Assessment
- Root Cause Analysis (RCA)
- Operational Experience (OE)
- Design Basis Analysis (DBA)
- Repair Approach
- Summary Comments / Questions

Crystal River 3 Overview

- Babcock and Wilcox Pressurized Water Reactor
- Location: Crystal River Florida
- 2609 MW_{th}
- 838 MW_e
- Commercial Operations began 1976

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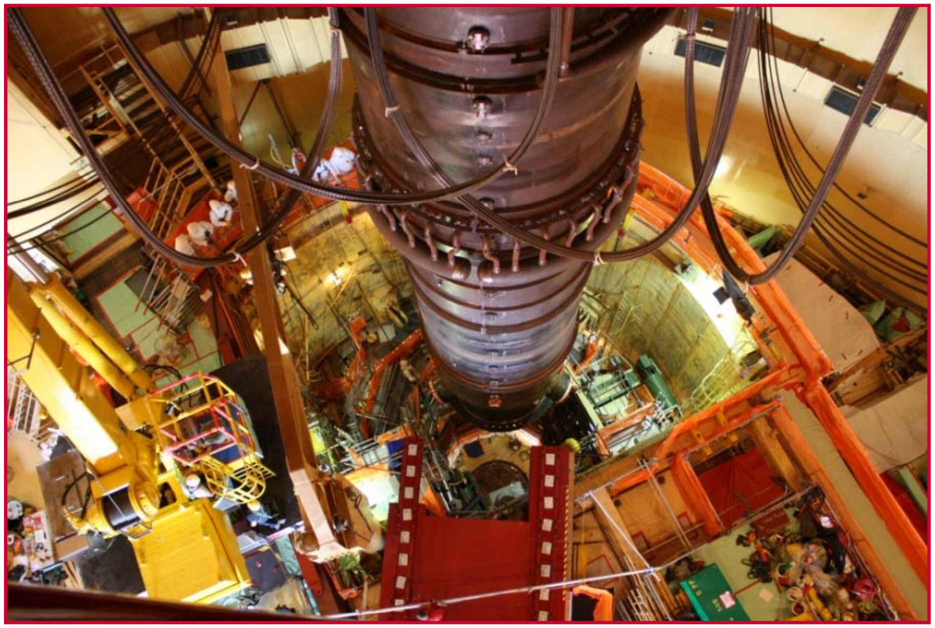
2009 Crystal River 3 Outage Overview
Building a nuclear future for Florida customers

- **Routine refueling scope**
  - Off line maintenance and fuel for 2 years
- **Steam Generator Replacement (SGR)**
- **Extended Power Uprate (EPU)** – Phase 2
  - Extensive steam plant work
  - Taking advantage of longer OTSGR duration
  - Steam plant efficiencies
  - Part of total ~15% Uprate

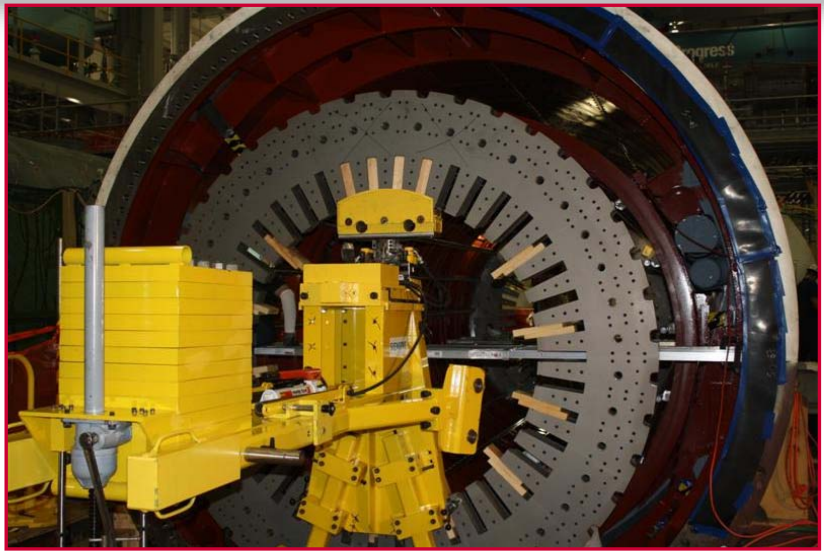
Steam Generator Replacement (SGR)
Work Breakdown

- Containment Opening
- Lifting and Rigging
- Cutting and welding



Extended Power Uprate (EPU)
Work Breakdown

- Generator Replacement
  - Stator, Rotor, Exciter
- Moisture Separators
- MSR Drain Coolers
- Lube Oil Coolers
- Feed Water Heaters
- Iso-Phase cooling



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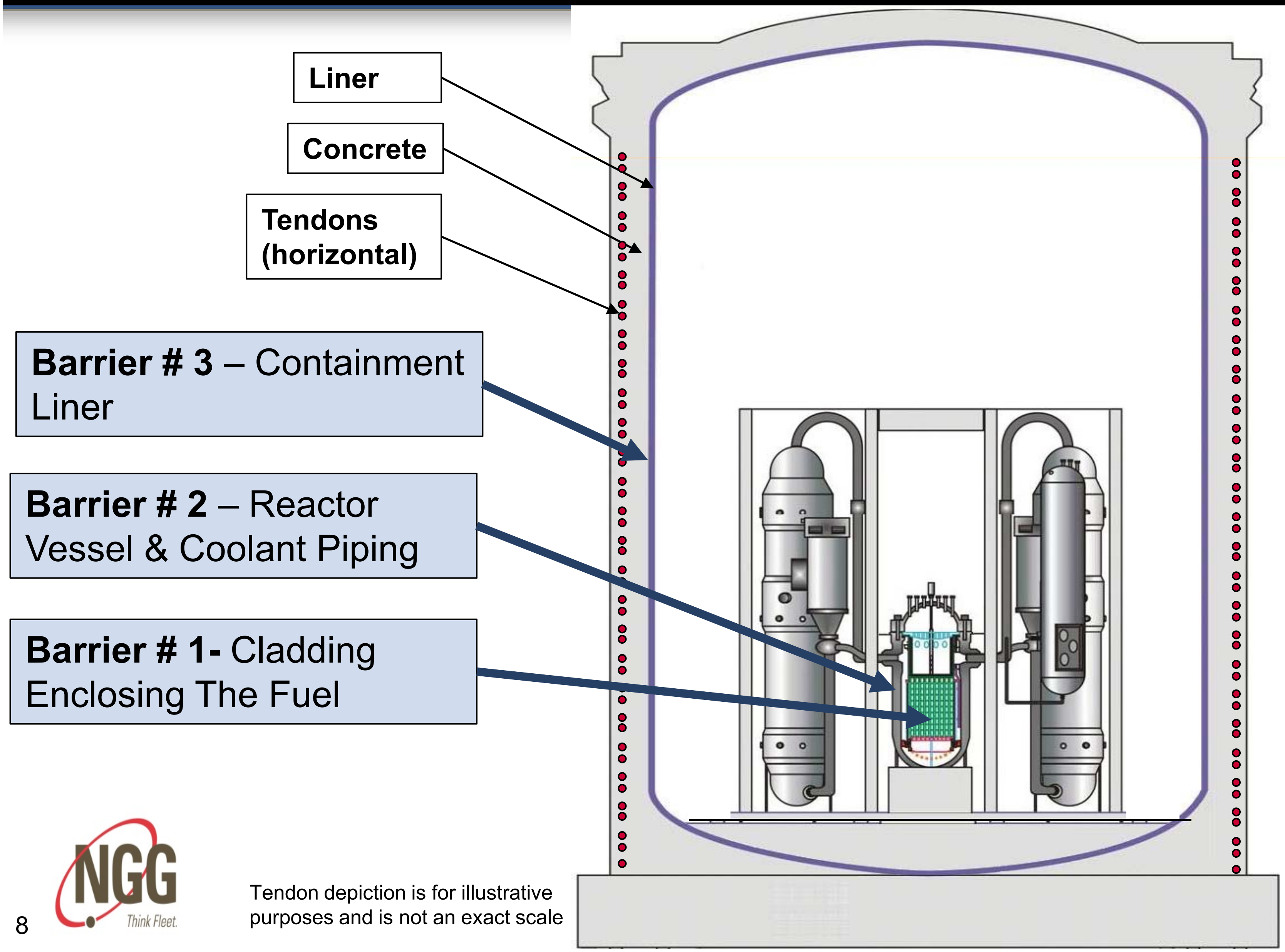
CRYSTAL RIVER #3
DESIGN FEATURES

Fission Product Barriers

Simplified Schematic



Tendon depiction is for illustrative purposes and is not an exact scale

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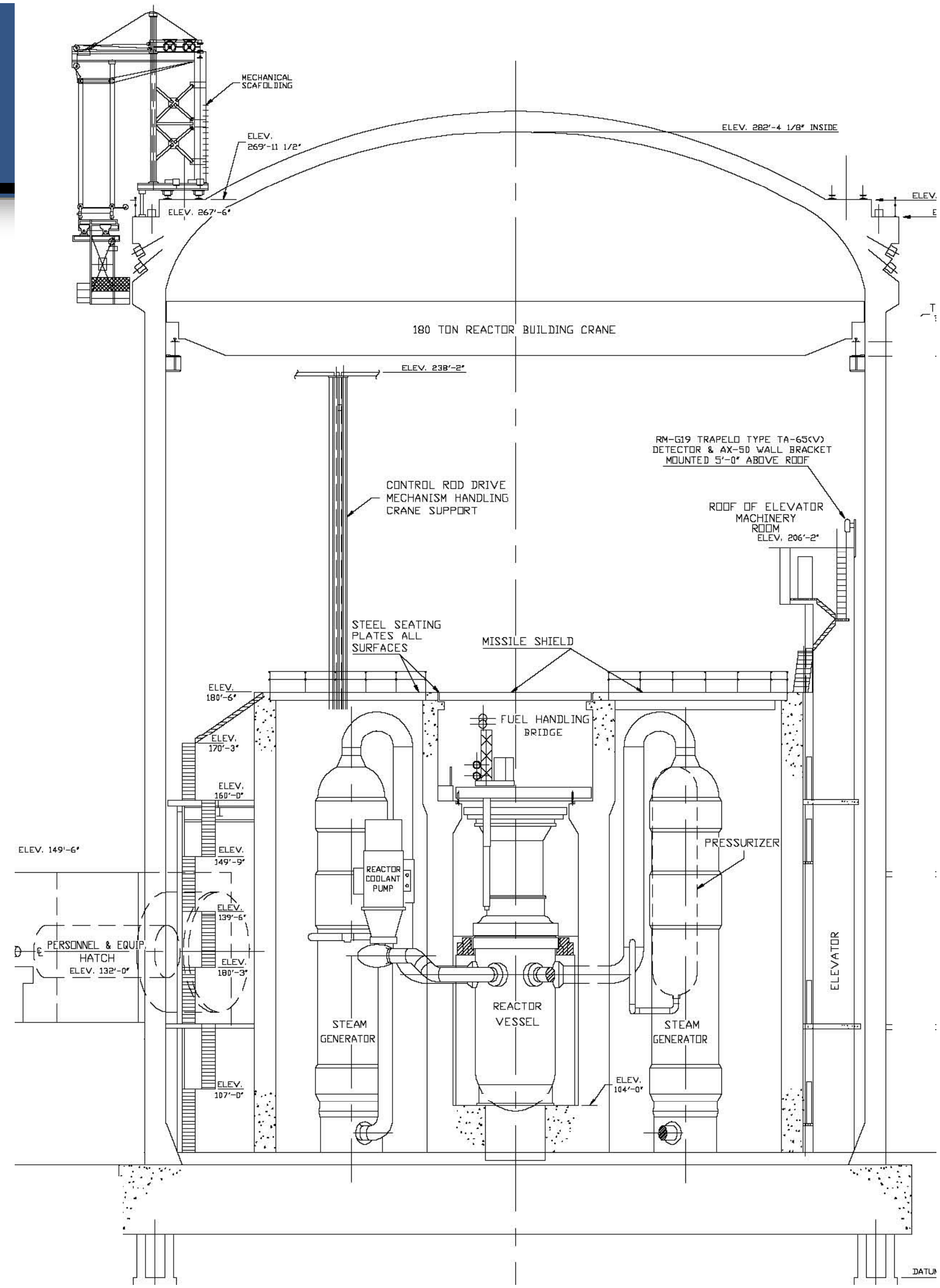
CR3 Containment Dimensions

Dimension	Value
Containment Outside Dimension (OD)	137 ft 0.75 in
Dome Thickness	36 in
Basemat Thickness	12 ft 6 in
Liner Thickness	0.375 in
Wall Thickness	42 in
Buttress Wall Thickness	5 ft 10 in
Vertical & Hoop Conduit OD	5.25 in
# of Vertical Tendons	144
# of Tendon Hoops	94
# of Tendons per Hoop	3
# of Prestressed Dome Tendons	123



SGR OPENING SEQUENCE & IDENTIFICATION OF DELAMINATION

Steam Generator Replacement (SGR) Opening
(between Buttresses 3 and 4)

SGR Opening Dimensions

@ Liner
23’ 6” x 24’ 9”

@ Concrete Opening
25’ 0” x 27” 0”

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Concrete Removal

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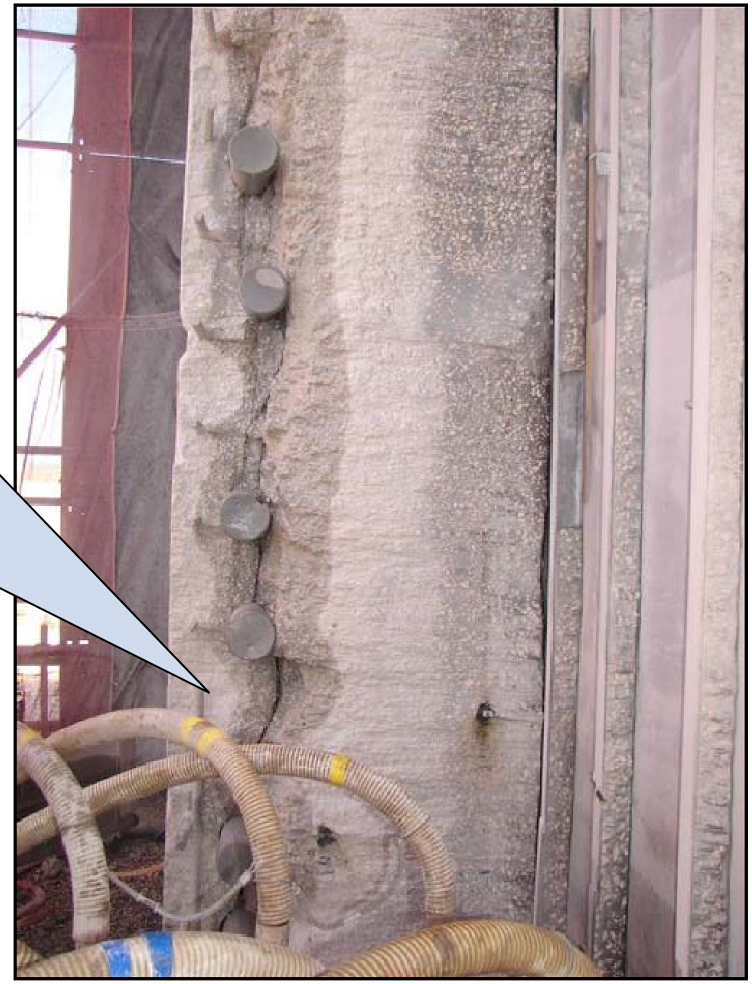
Concrete & Liner Removal Sequence

Delamination Close-up



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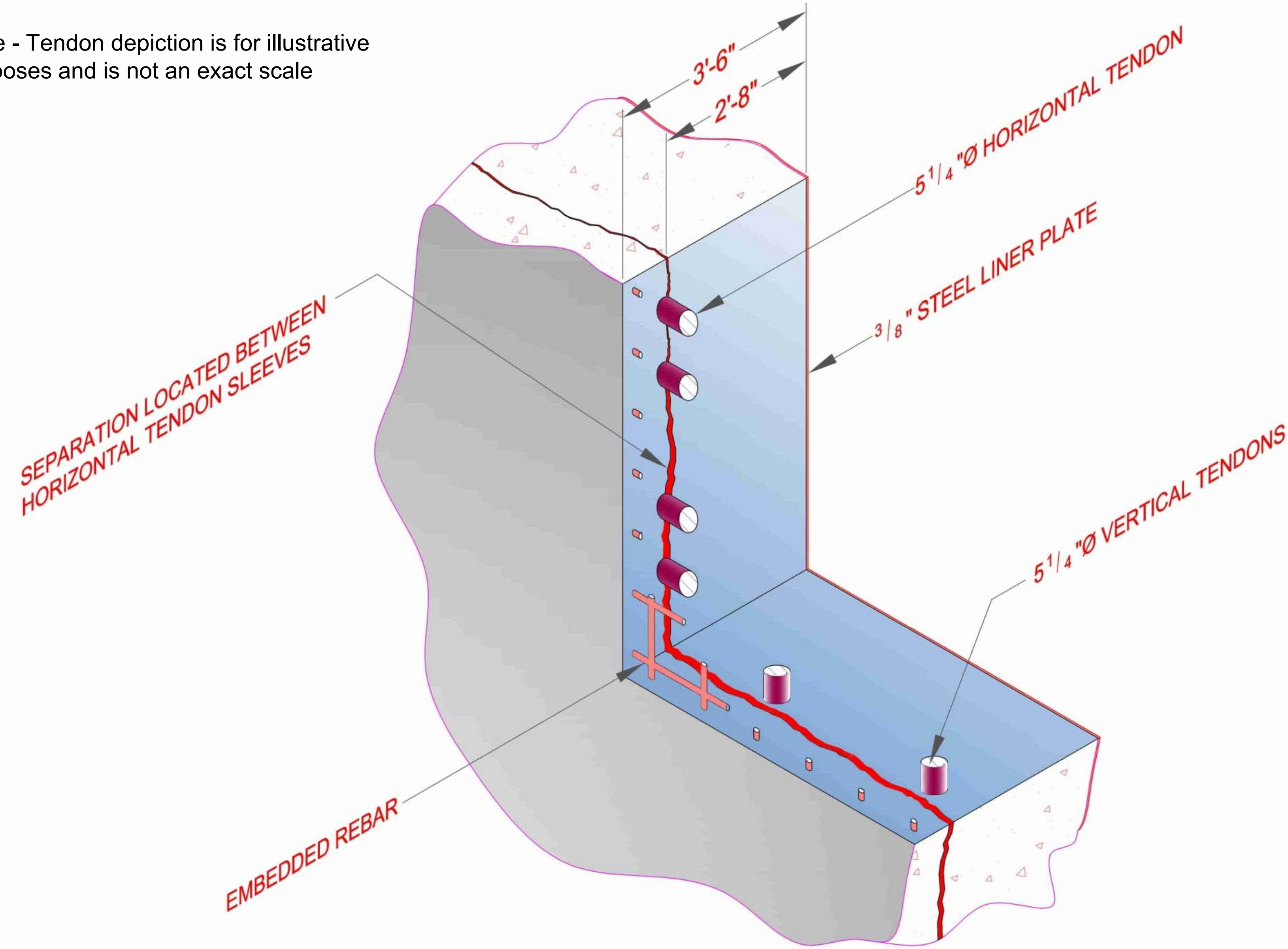
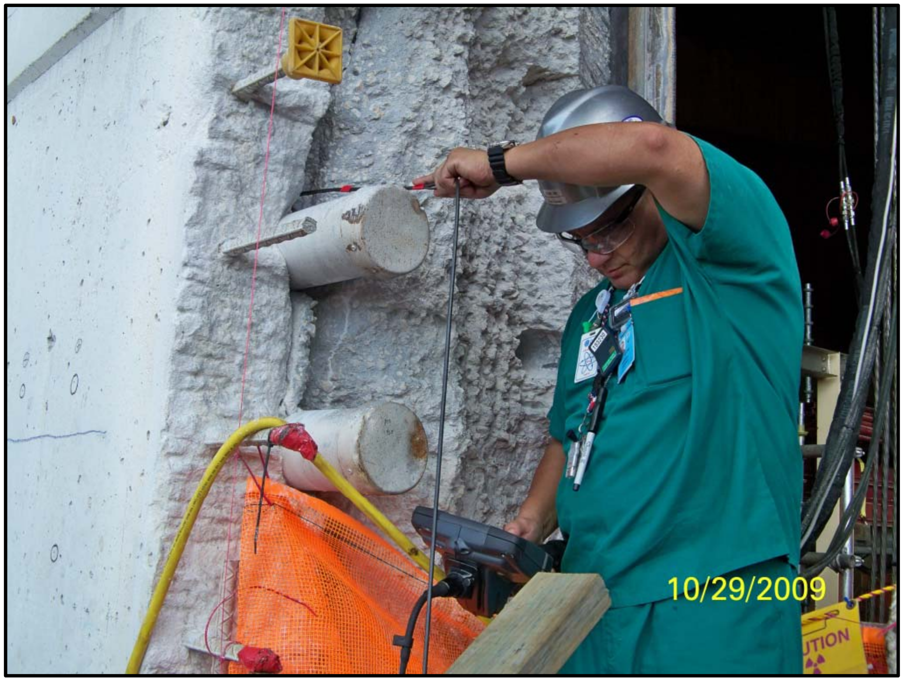
Location of the Delamination

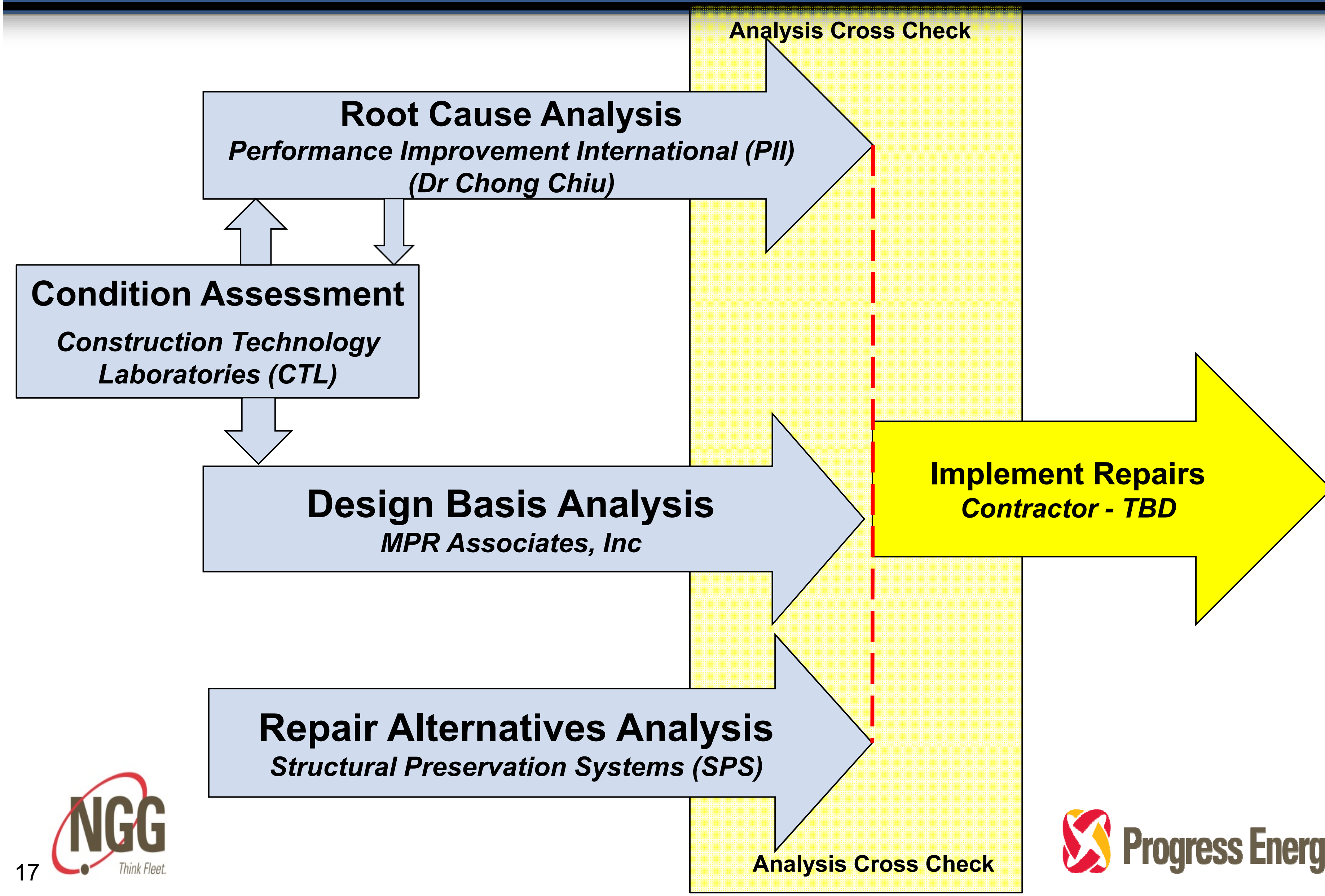
Note - Tendon depiction is for illustrative purposes and is not an exact scale



INVESTIGATION APPROACH



Work Flow Summary



External Support

- **Condition Assessment & Laboratory Testing**
  - NDT - ***Construction Technology Laboratories (CTL)***
  - Labs - *MacTec, Soil& Materials Engineers (S&ME)*
  - Other Field Data - *Sensing Systems, Inc; Core Visual Inspection Services (Core VIS), Nuclear Inspection & Consulting, Inc; Precision Surveillance; Gulf West Surveying Inc; AREVA*

- **Root Cause Analysis**
  - Lead - ***Performance Improvement International (PII)***
  - Owner's Support - *Worley Parsons, Bechtel*

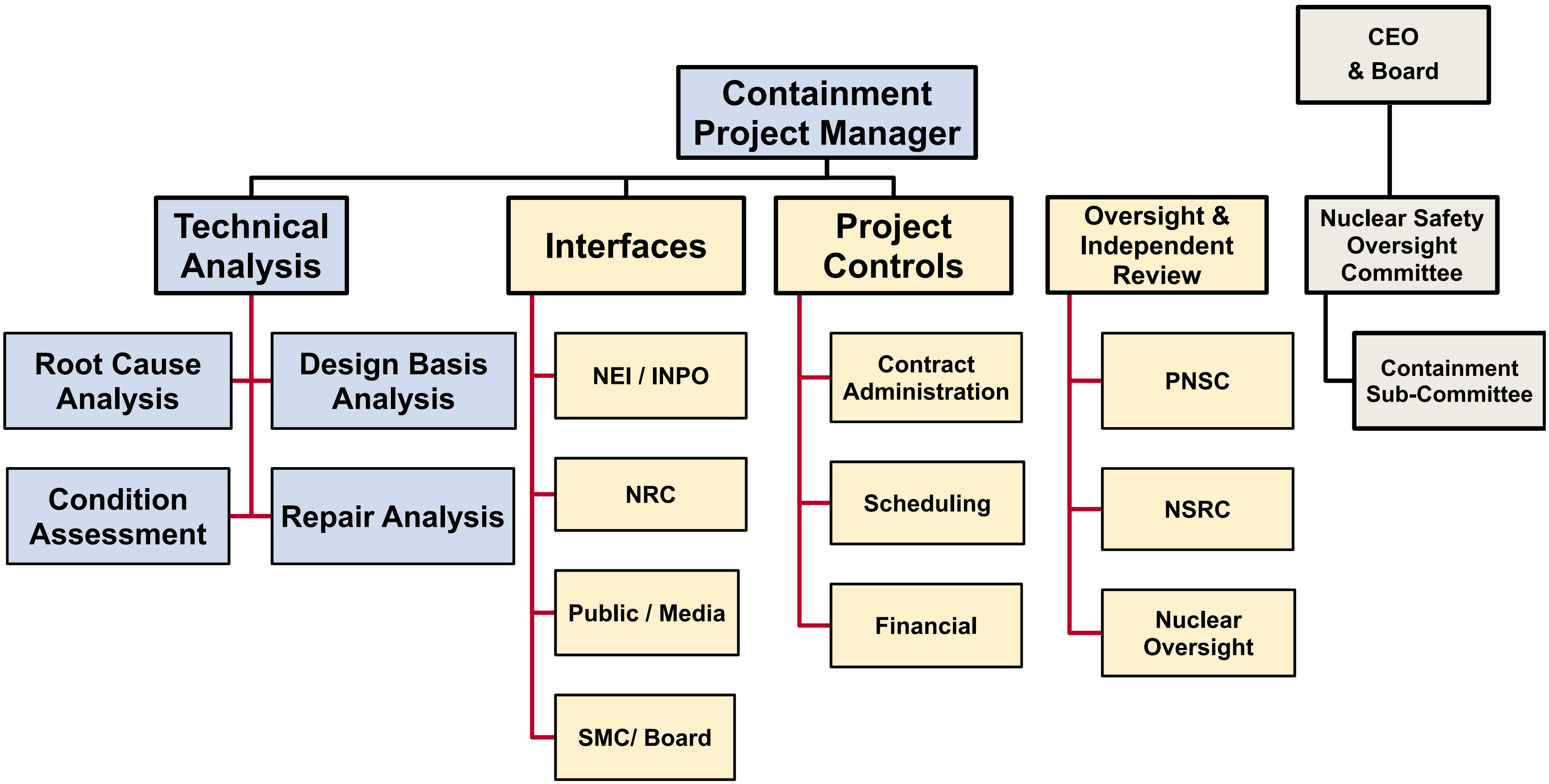
External Support (continued)

- **Design Basis Analysis**
  - Lead - ***MPR Associates, Inc.***
  - Owner's Support - *Worley Parsons*

- **Repair Analysis**
  - Lead - ***Structural Preservation Systems (SPS)***
  - Owner's Support - *Wiss, Janney, Elstner, Inc (WJE)*

- **Industry Support**
  - *Exelon, SCANA, and Southern Company*

Organization – Functional View



Nuclear Safety Oversight Committee (NSOC)

Containment Sub-Committee Membership

Member	Title
Bob Bazemore (PGN)	VP-Audit **(Chairman)**
Joe Donahue (PGN)	VP- Nuclear Oversight
Chris Burton (PGN)	VP – Harris
Greg Selby	Technical Director - EPRI
Dr. Shawn Hughes	VP - Shaw Stone and Webster
Dr. Paul Zia	Civil Engineering Professor, NCSU
Hub Miller	33 years industry oversight experience
Darrell Eisenhut	41 years industry operation and oversight experience

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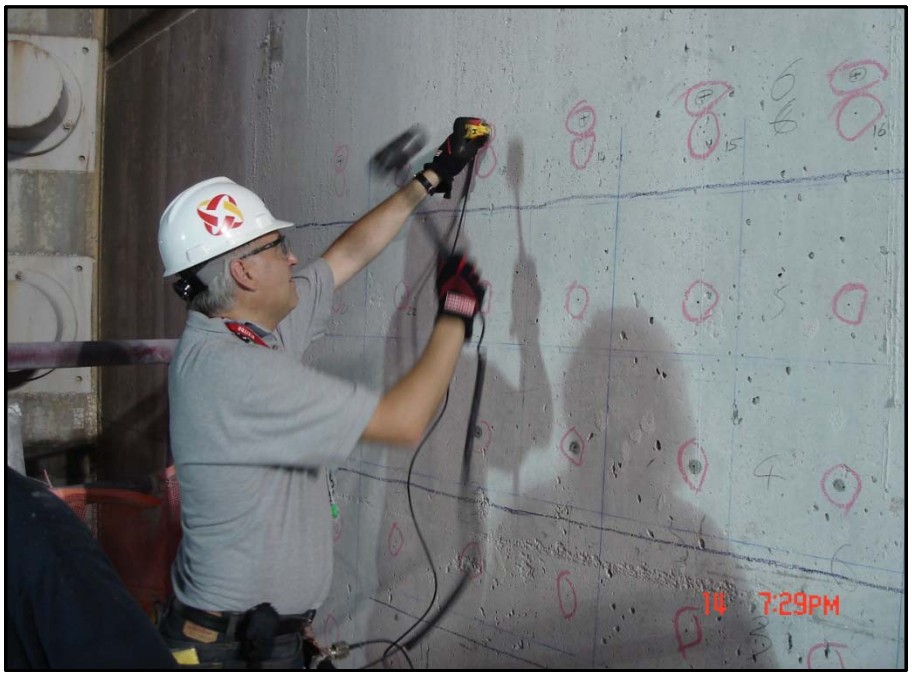
CONDITION ASSESSMENT



Condition Assessment Activities
Completed or Planned

- **Determine Extent of Condition**
  - Characterize the extent of delamination at the SGR opening
  - Determine condition of other portions of structure

- **Non Destructive Testing (NDT) of Containment Wall Surfaces**
  - Use of Impulse Response (IR) Method
  - Comprehensive on external exposed surfaces
  - Accessible areas in adjacent buildings

Condition Assessment Activities

Completed or Planned

- **Concrete Cores**
  - Used to confirm IR results (over 80 cores)
  - Visual examination of core bore holes with boroscope to identify if delamination present

- **ASME Section XI IWL visual inspection** (affected areas)

- **Containment Dome Inspections**
  - NDT IR scans in segment above the SGR opening
  - Concrete cores with boroscope examination of bore holes
  - Physical survey with established benchmarks

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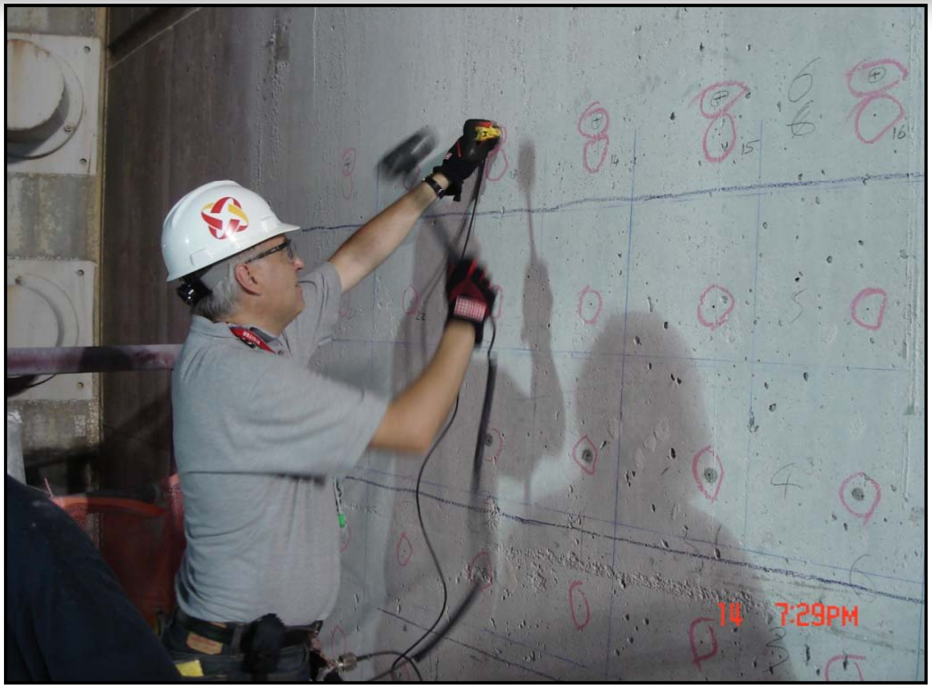
Condition Assessment Techniques
Impulse Response (IR)



- IR Equipment
  - Primary test method used in this evaluation
- IR Performed in the Field

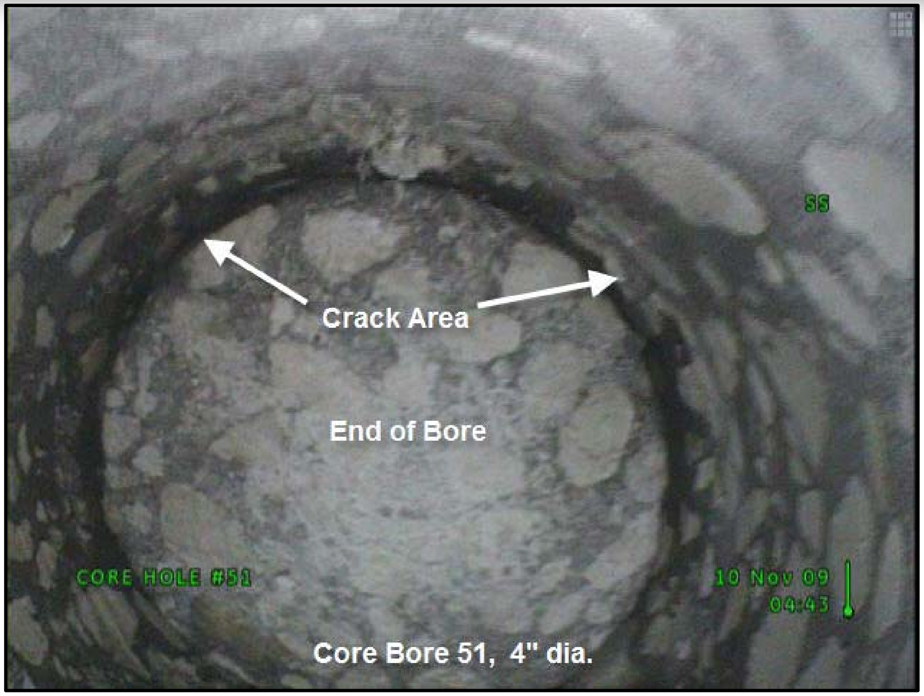
Condition Assessment Techniques

Ground Penetrating Radar (GPR)

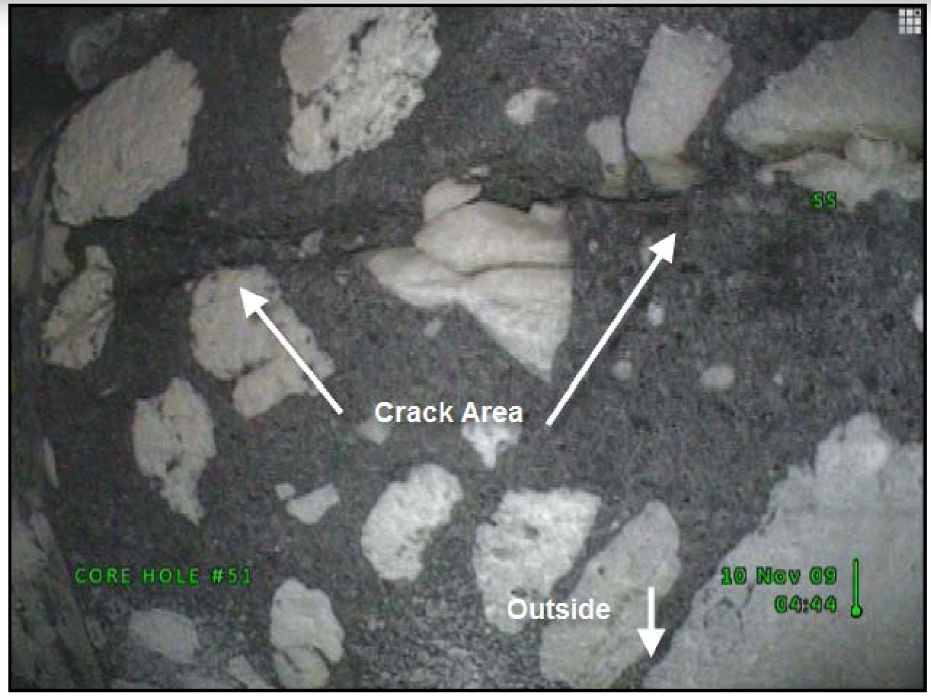
- Ground Penetrating Radar (GPR) Equipment
  - Locates internal features (rebar, tendon conduits, etc.)
- GPR Performed in the Field

Condition Assessment Techniques

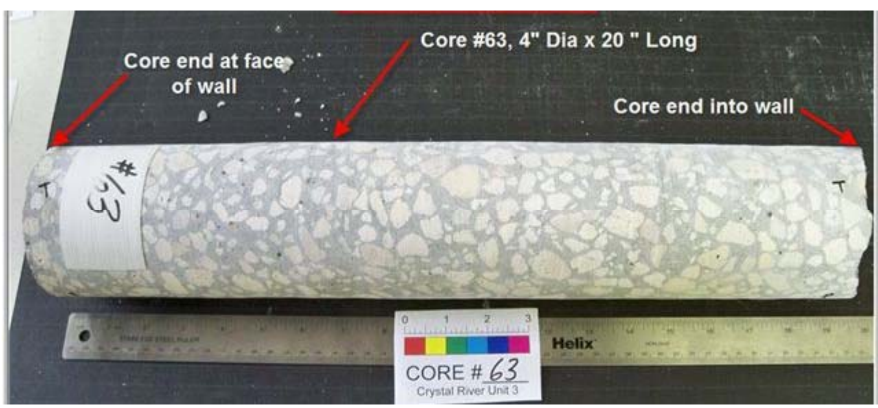
Core Bores & Boroscopic Examination



Examination – Inward View



Examination – Side View



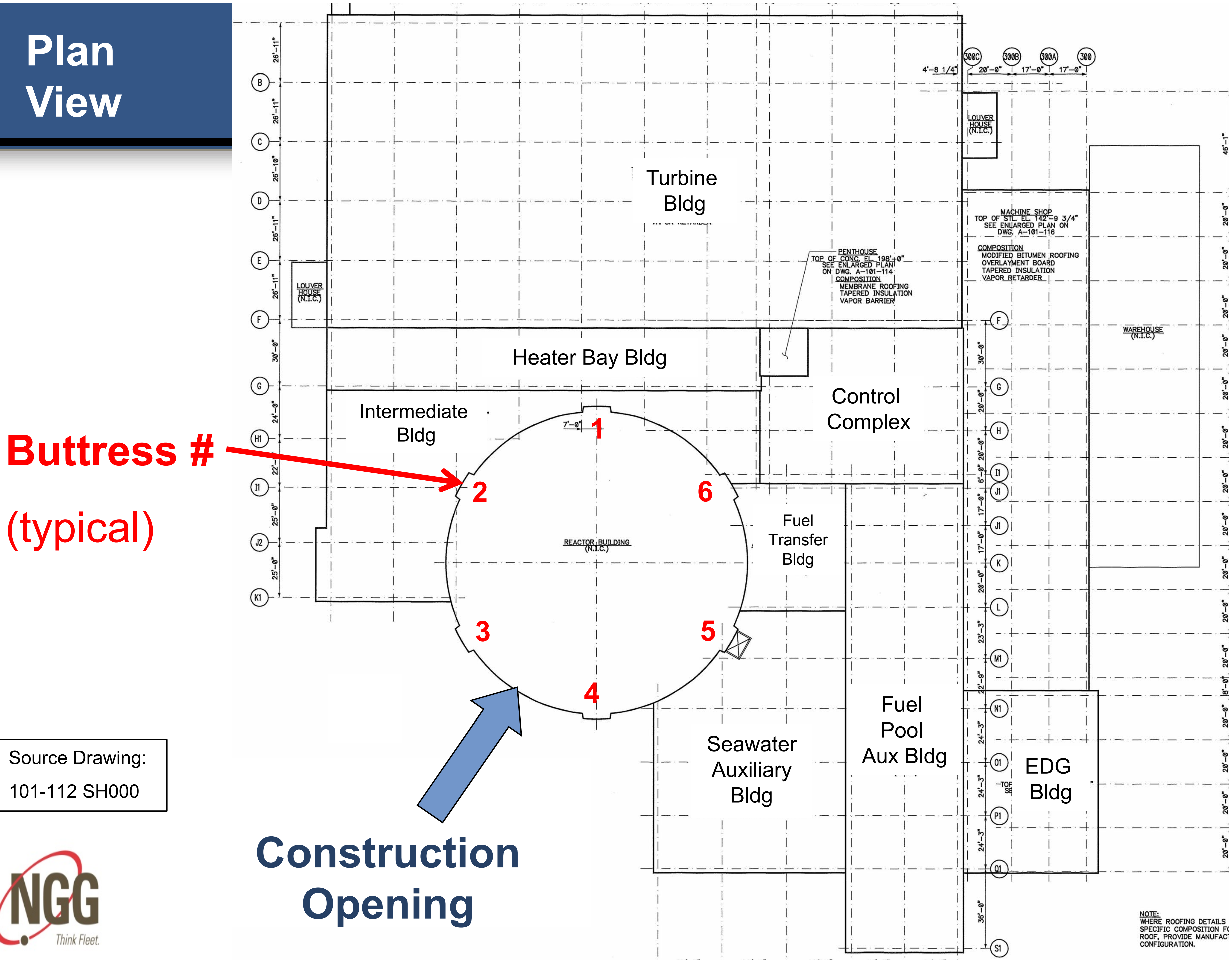
Core 51, Gap 1 Depth 5-1/4"

Gap 1 Width Less than 1/8"

Condition Assessment Techniques
Impact Echo (IE)

- IE Equipment
  - Ability to determine depth of delamination
- IE Performed in the Field

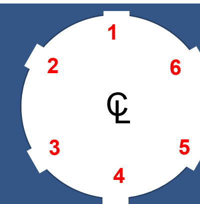
Plan View



Source Drawing:
101-112 SH000

Containment "Unfolded" – Buttress 2 to 5

Updated Nov 18th , Mosaic IR Overlay scale is approximate



IR scans completed per PT-407T:

Blue = no delamination

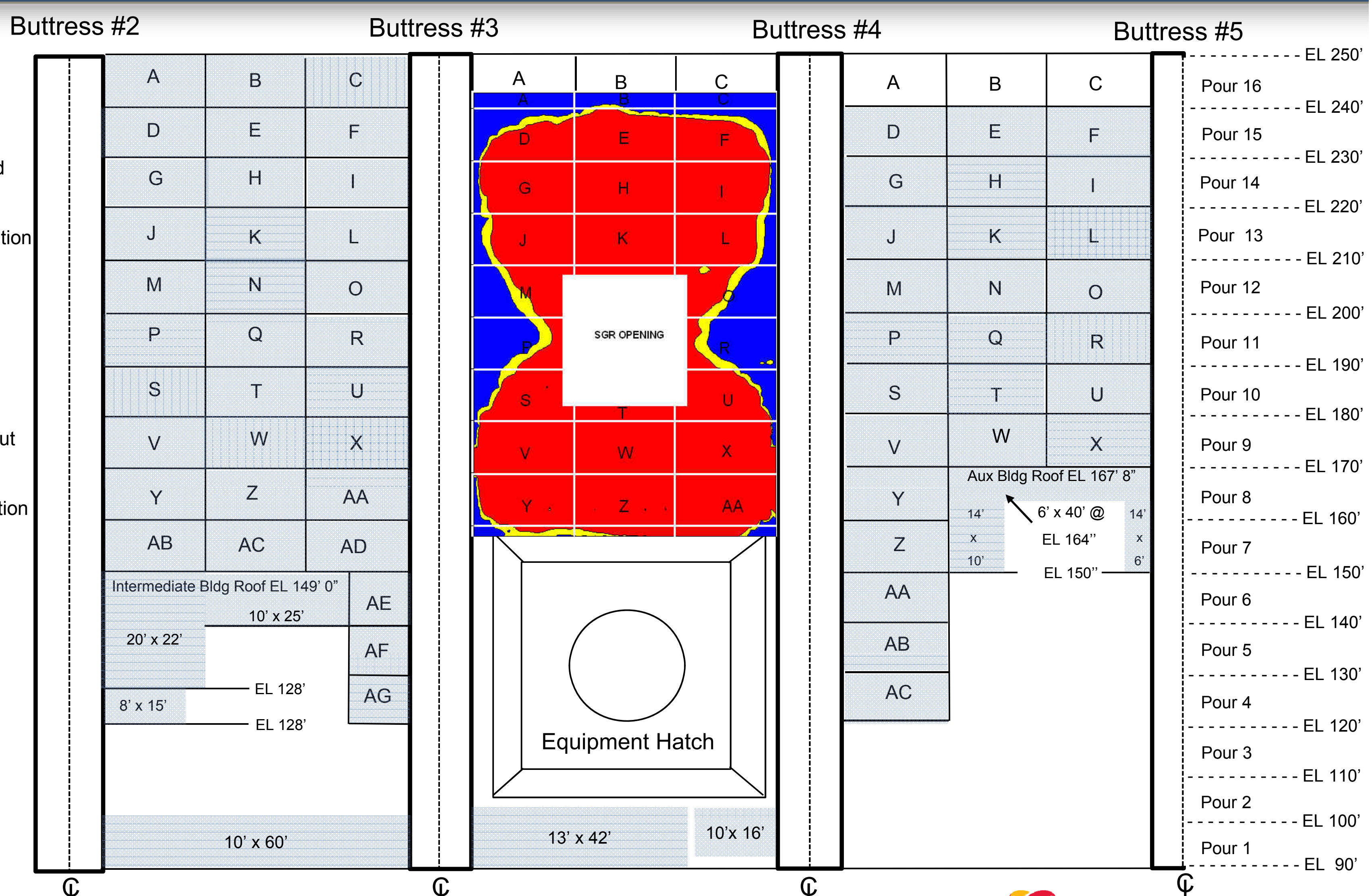
Actual IR scan output data:

Blue = no delamination

Yellow= transition

Red = delaminated

Drawing scale is not exact



Conclusion – IR scans with confirmation core bores identified delamination only in the Buttress 3-4 span above the Equipment Hatch, as shown in red above

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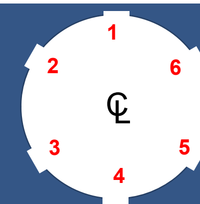
Containment "Unfolded" – Buttress 5 to 2

Updated Nov 18th 2009



IR scans completed per PT 407T:

Blue = no delamination

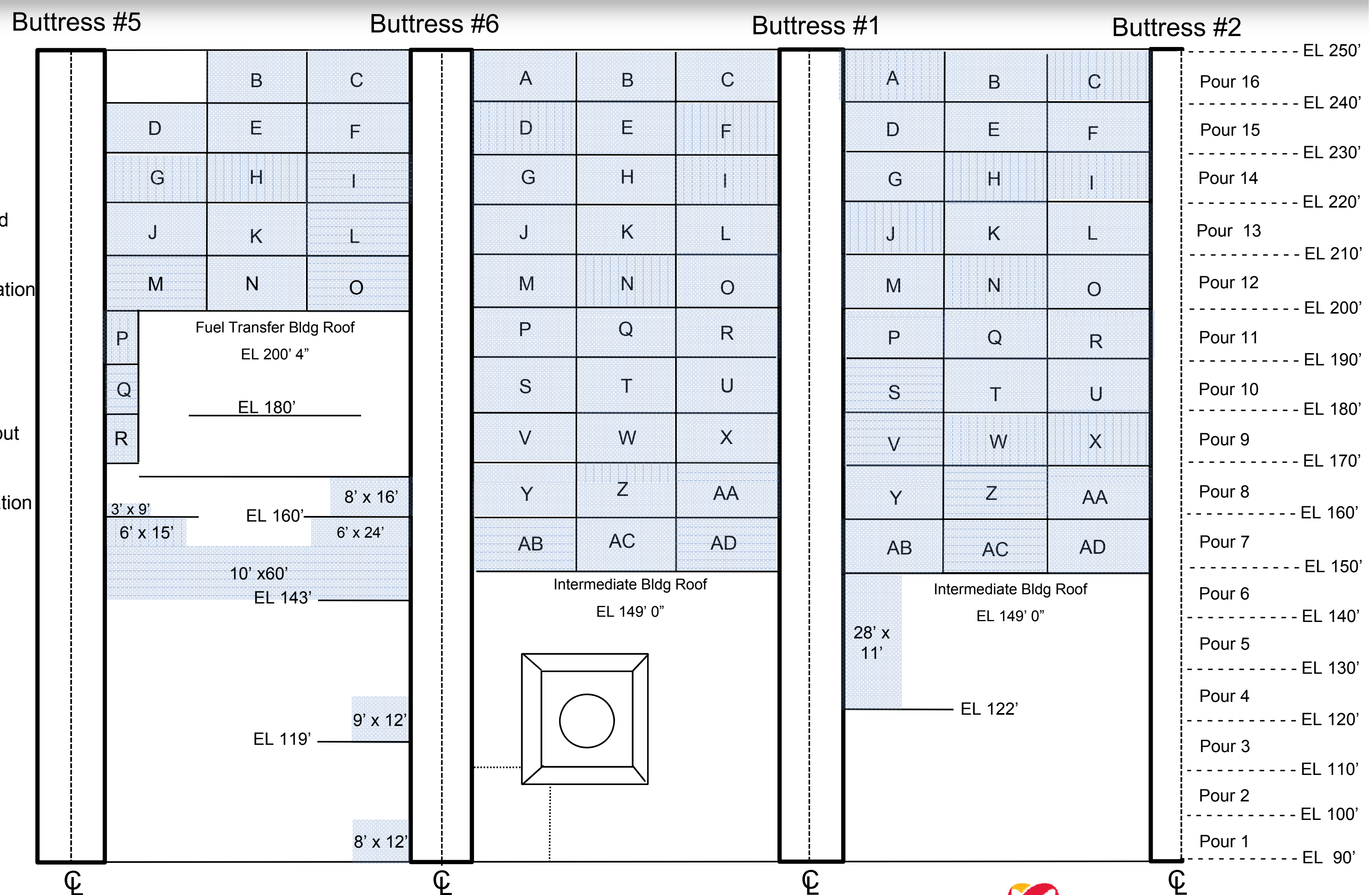
Actual IR scan output data:

Blue = no delamination

Yellow= transition

Red = delaminated

Drawing scale is not exact



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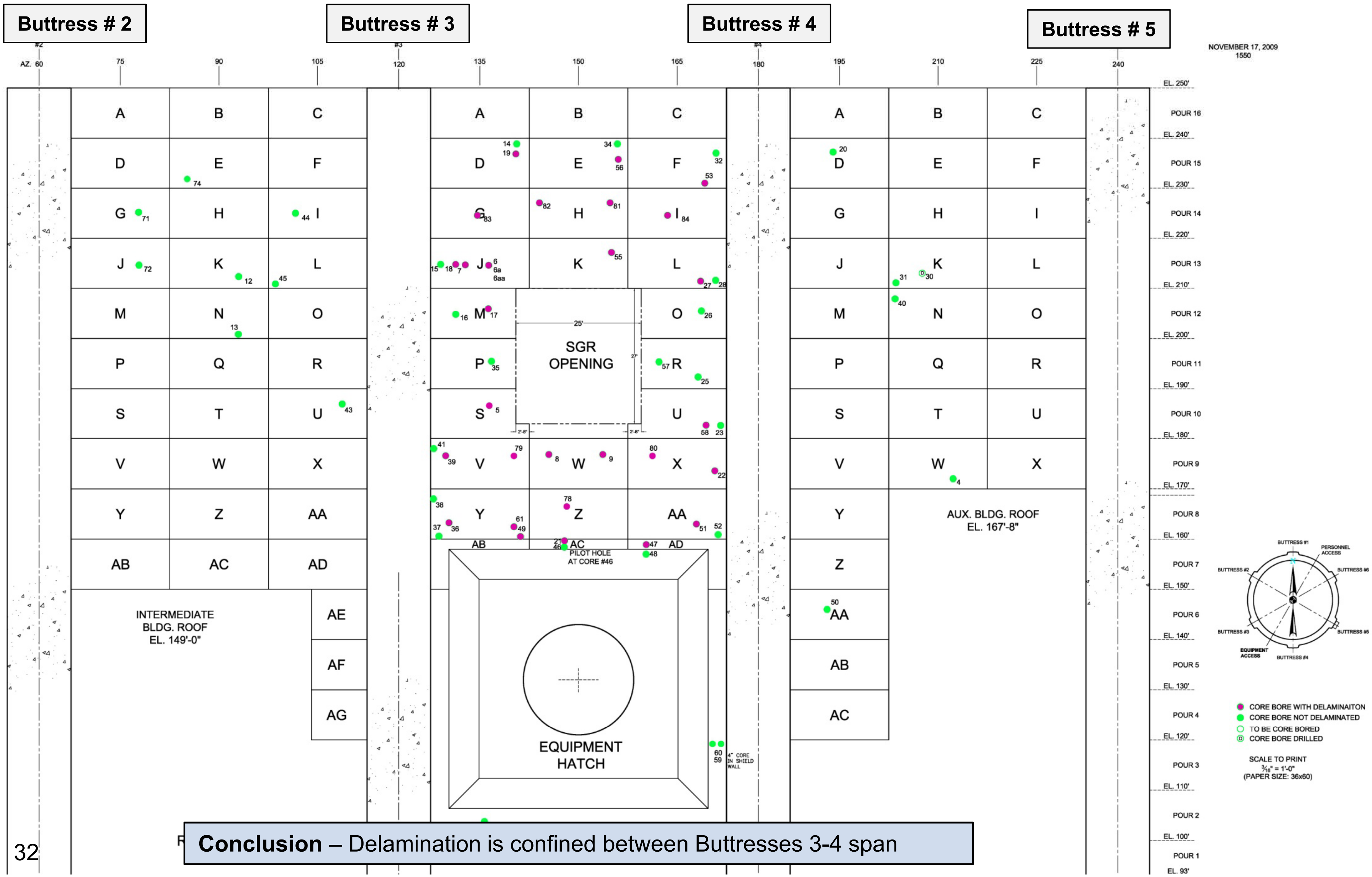
Conclusion – No delamination identified in these Buttress spans

Core Bores

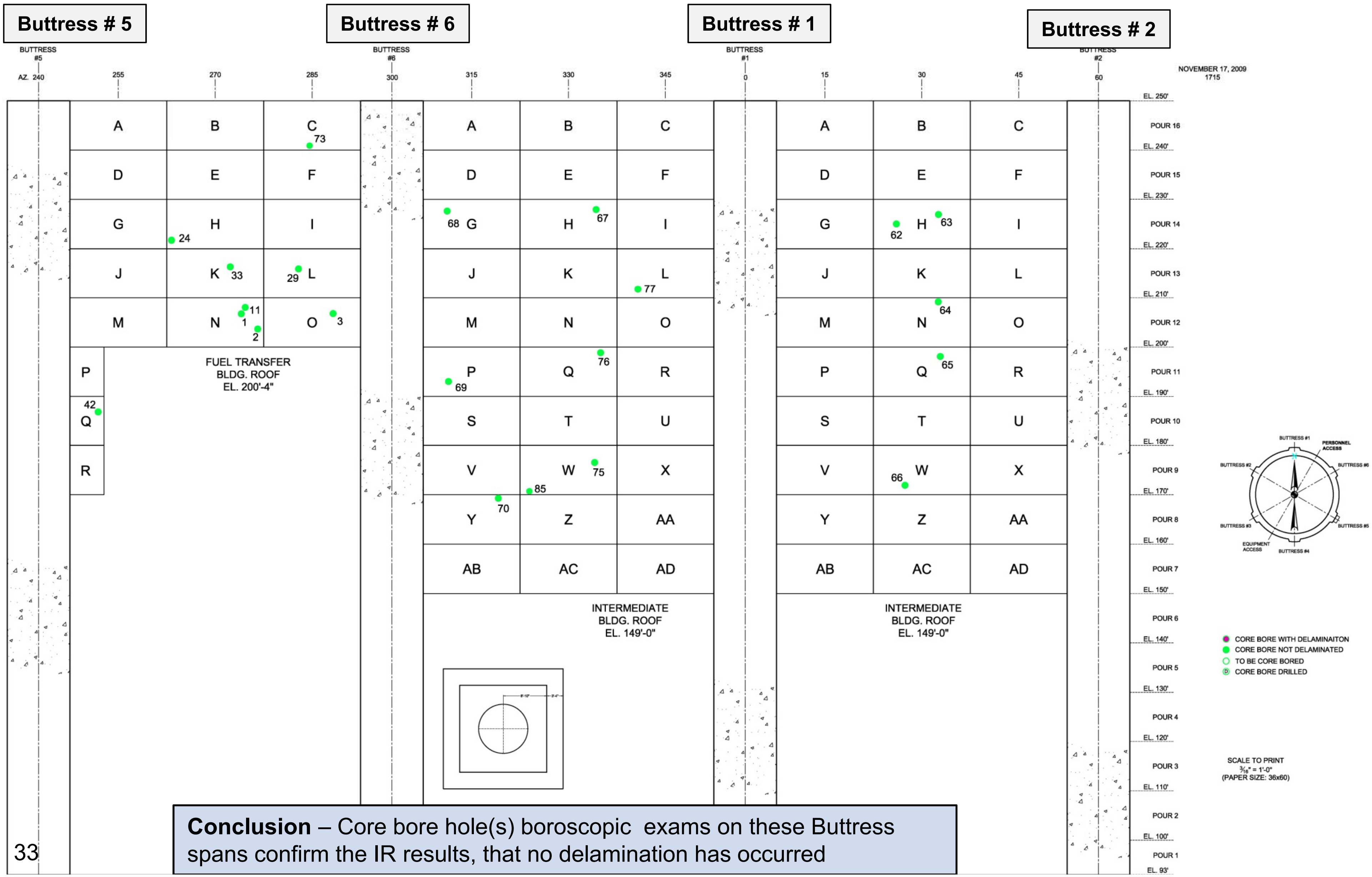
Buttress Spans 2 - 3 - 4 - 5 (as of Nov 17th 2009)



Conclusion – Delamination is confined between Buttresses 3-4 span

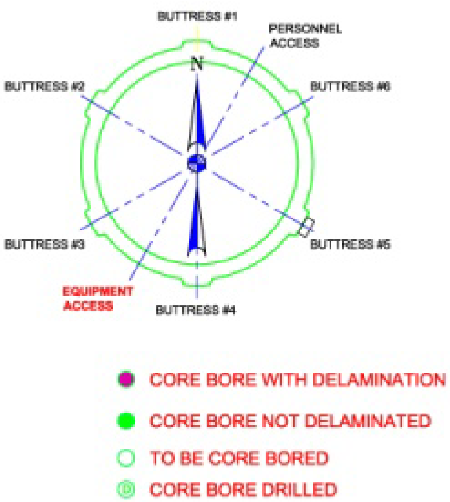
Core Bores

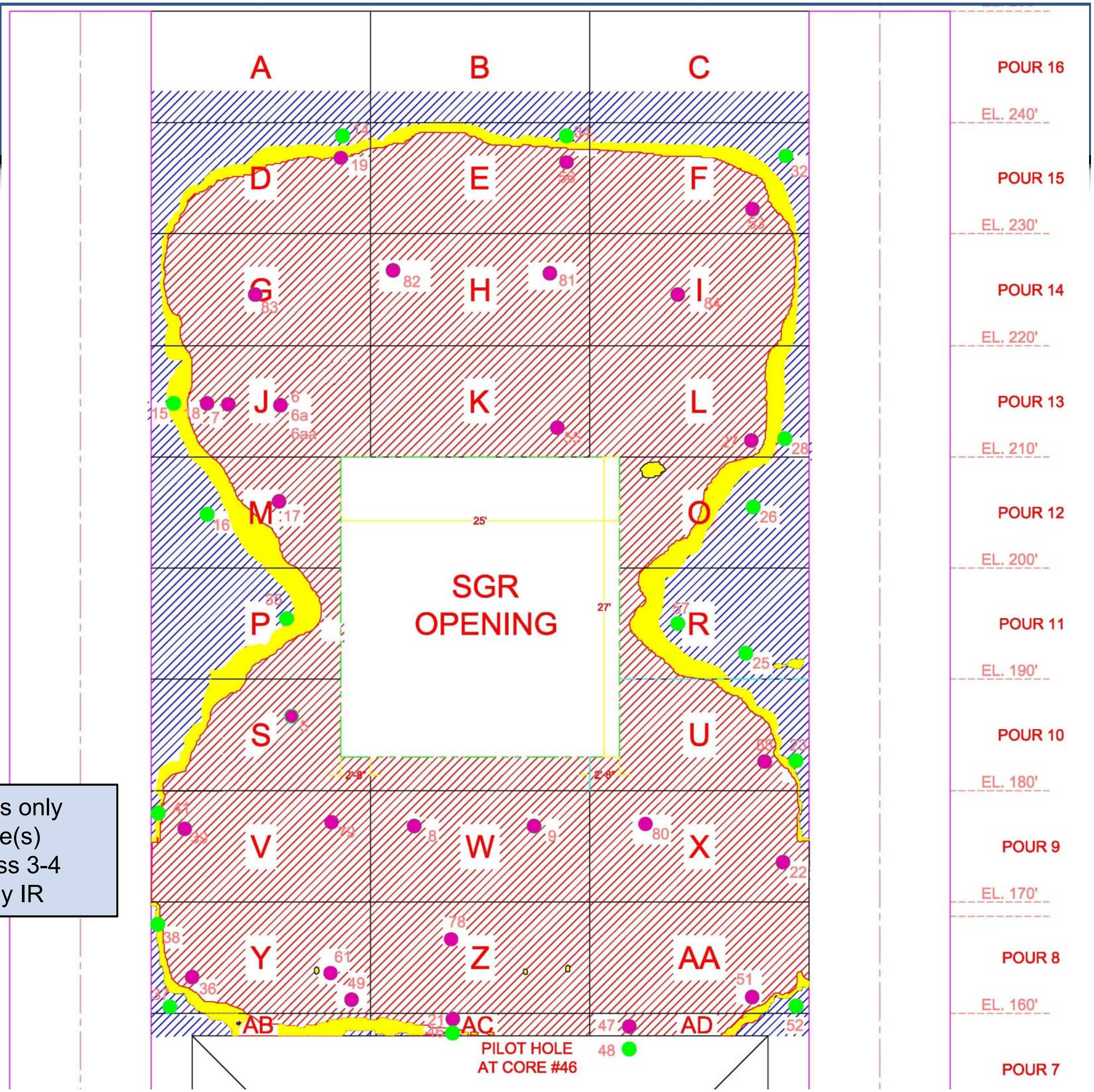
Buttress Spans 5 - 6 - 1 - 2 (as of Nov 17th 2009)



Conclusion – Core bore hole(s) boroscopic exams on these Buttress spans confirm the IR results, that no delamination has occurred

Core Borings





Conclusion – Delamination has only been observed in core bore hole(s) boroscopic exams in the buttress 3-4 span, as accurately predicted by IR

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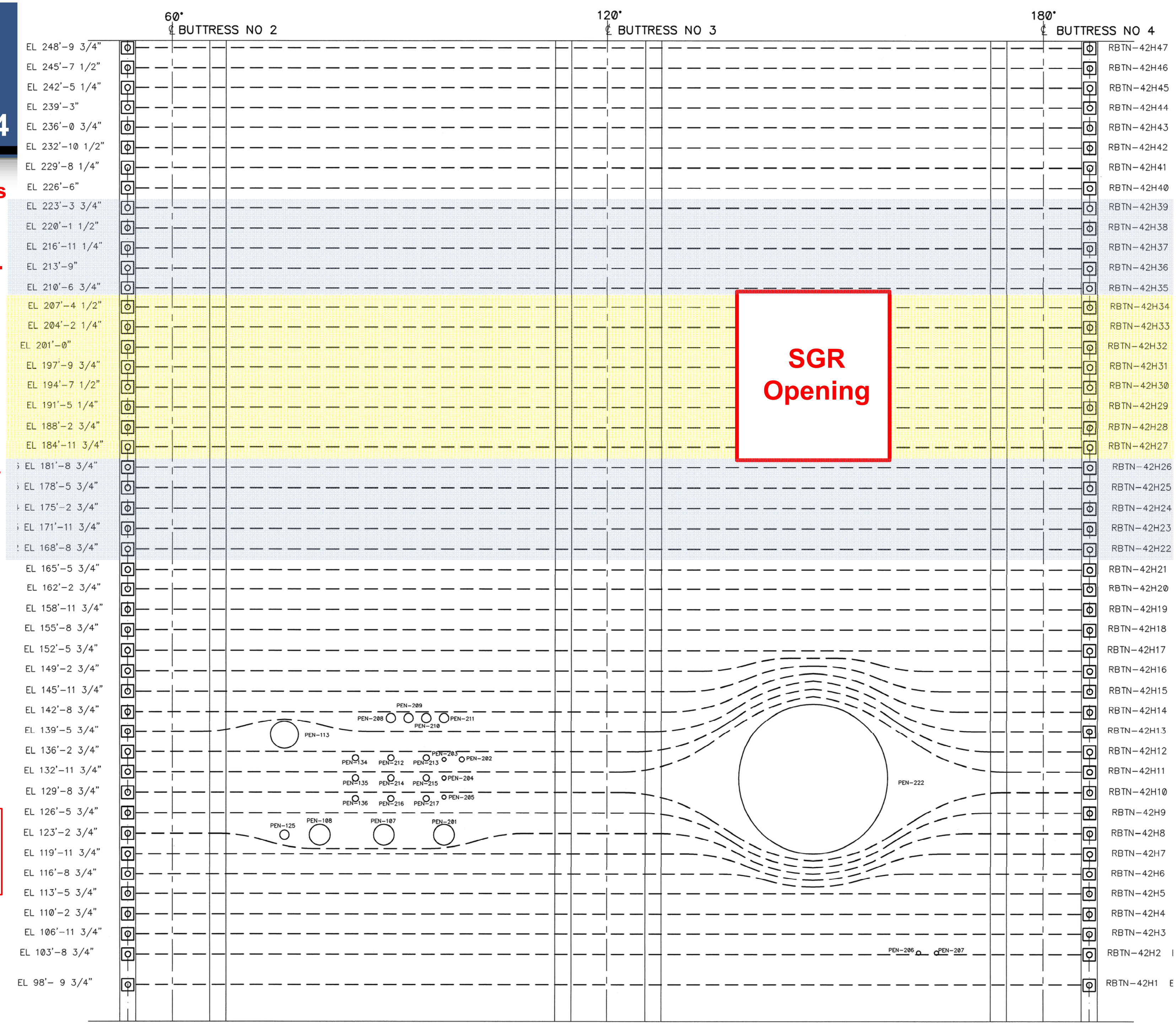
Horizontal Tendons Buttress 2 - 4

Additional tendons to be detensioned prior to closing SGR opening (pre-outage plan)

Tendons Removed

Additional tendons to be detensioned prior to closing SGR opening (pre-outage plan)



Source Drawing: 0425-006 SH001 - SH 000

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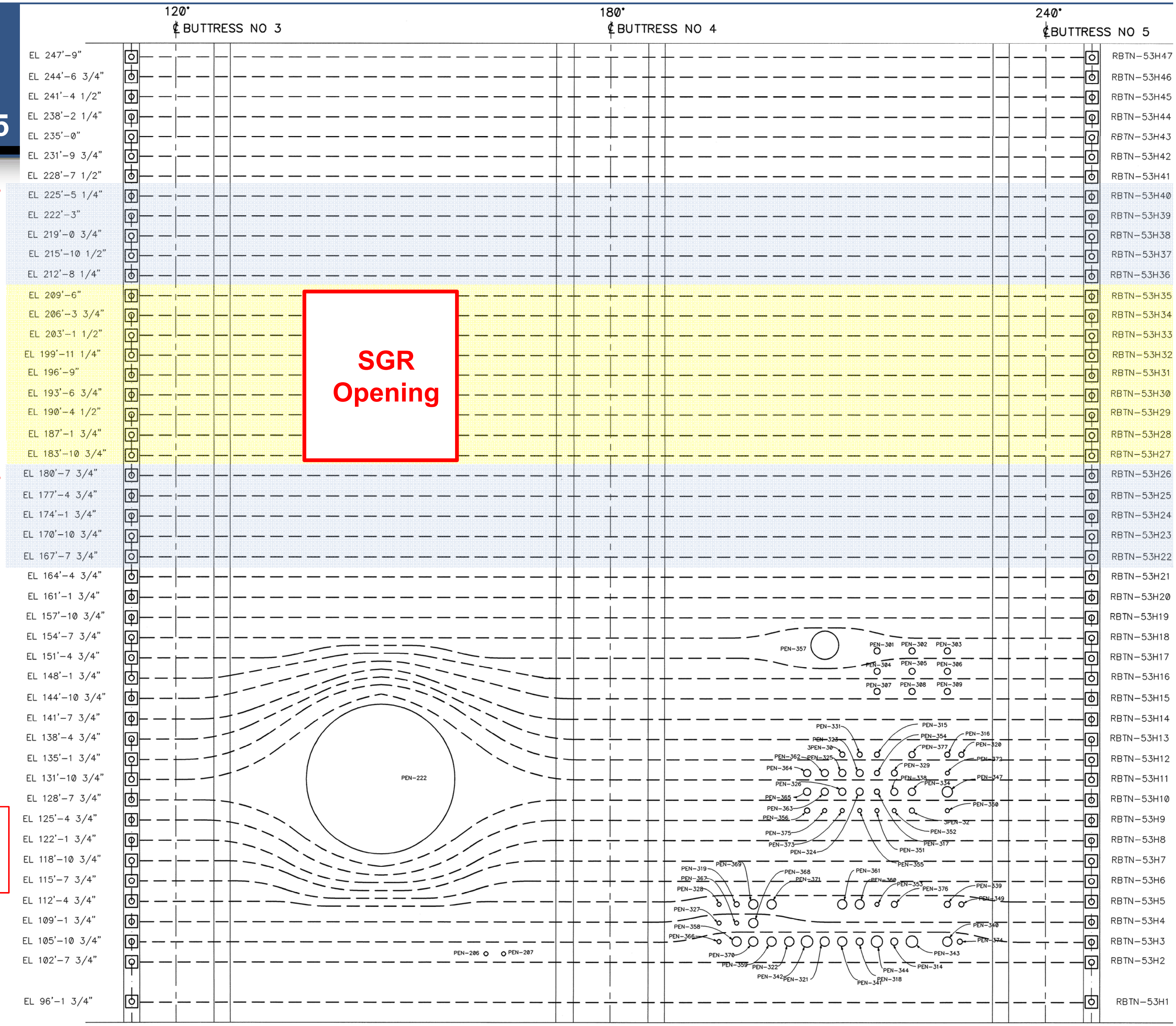
Horizontal Tendons Buttress 3 - 5

Additional tendons to be detensioned prior to closing SGR opening (pre-outage plan)

Tendons Removed

Additional tendons to be detensioned prior to closing SGR opening (pre-outage plan)



Source Drawing: 0425-007 SH001 - SH 000

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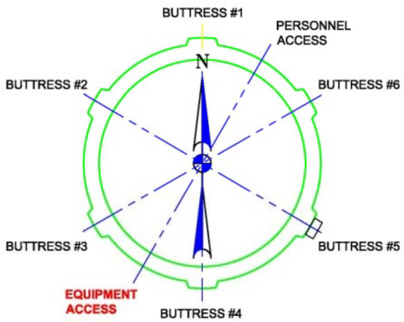
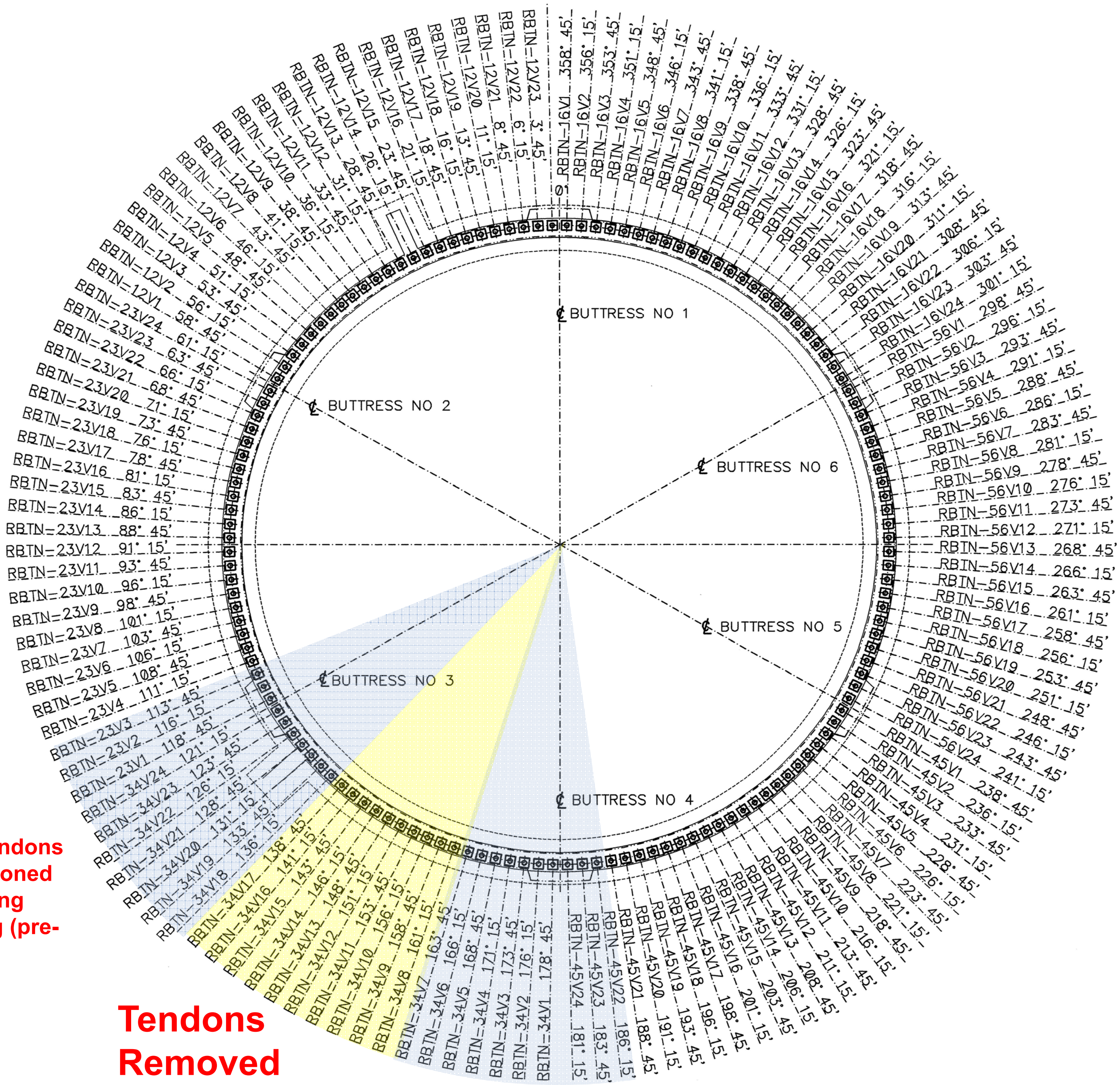
Vertical Tendons

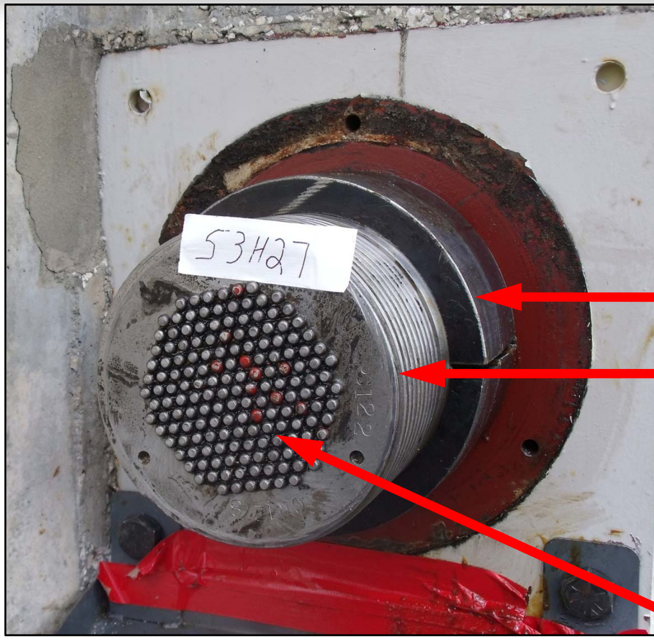


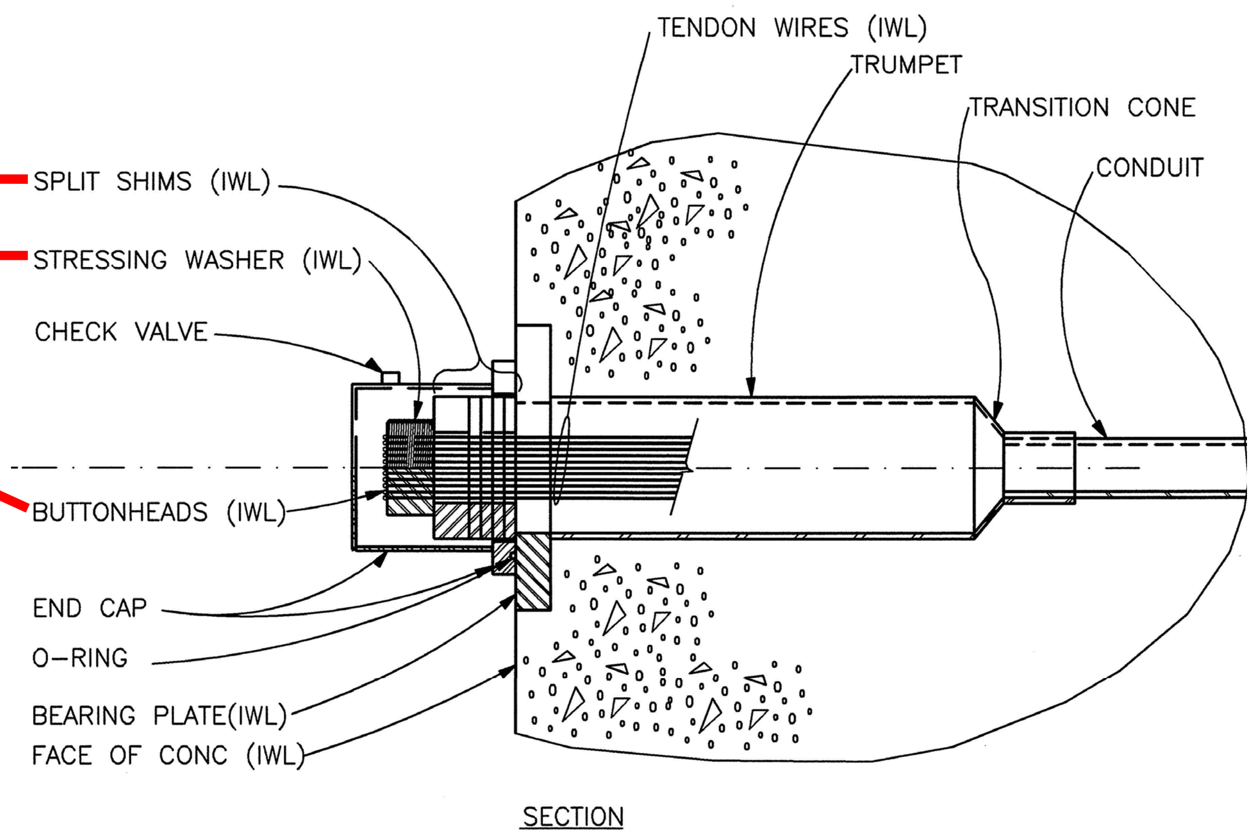


Additional tendons to be detensioned prior to closing SGR opening (pre-outage plan)

Tendons Removed

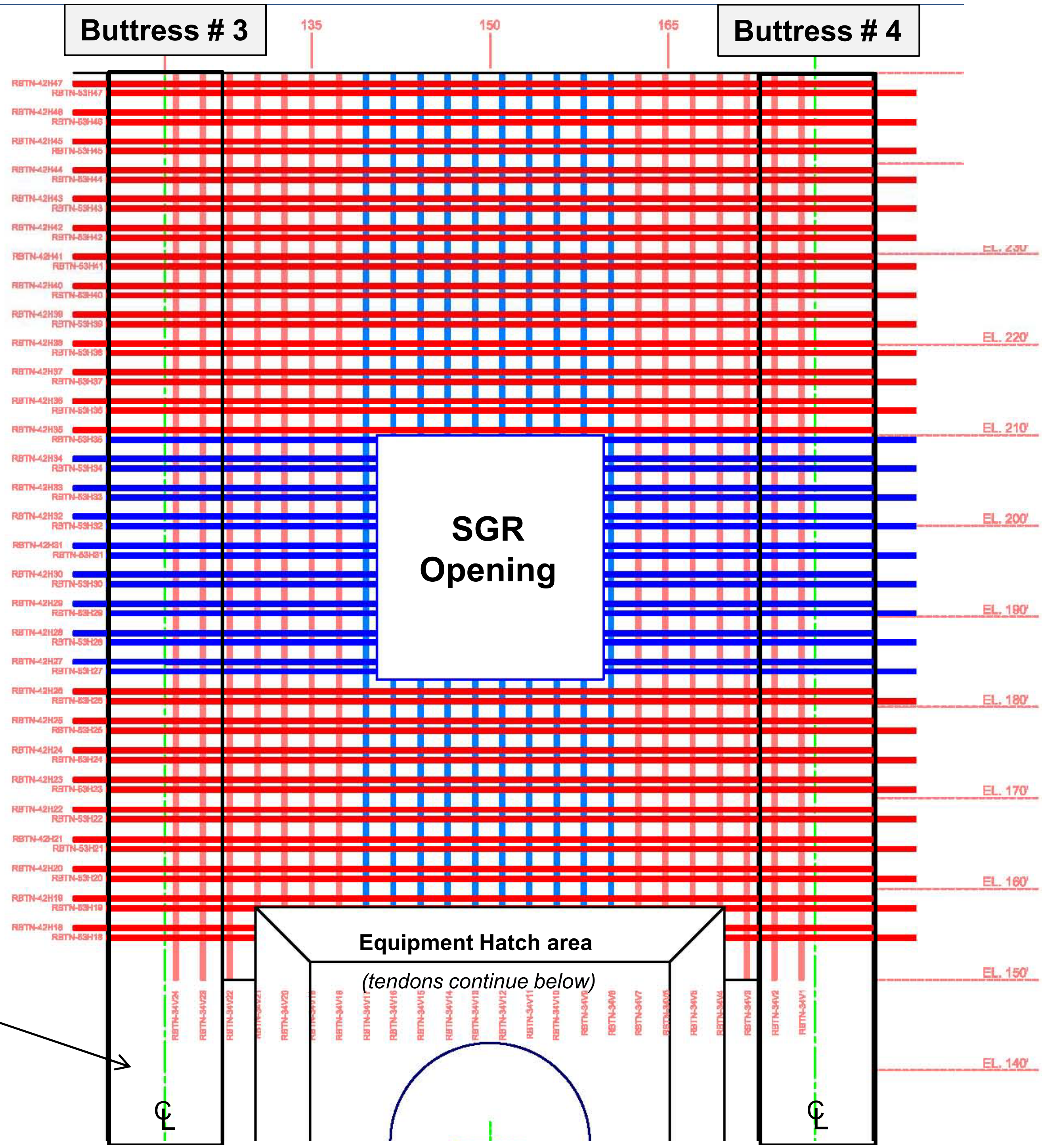
CR3 Typical Tendon
Schematic and Photo (for horizontal tendon # 53H27)





Source Drawing:
425-020-SH-001-SH000

Tendon Pattern



Tendon Pattern at time of cutting SGR Opening

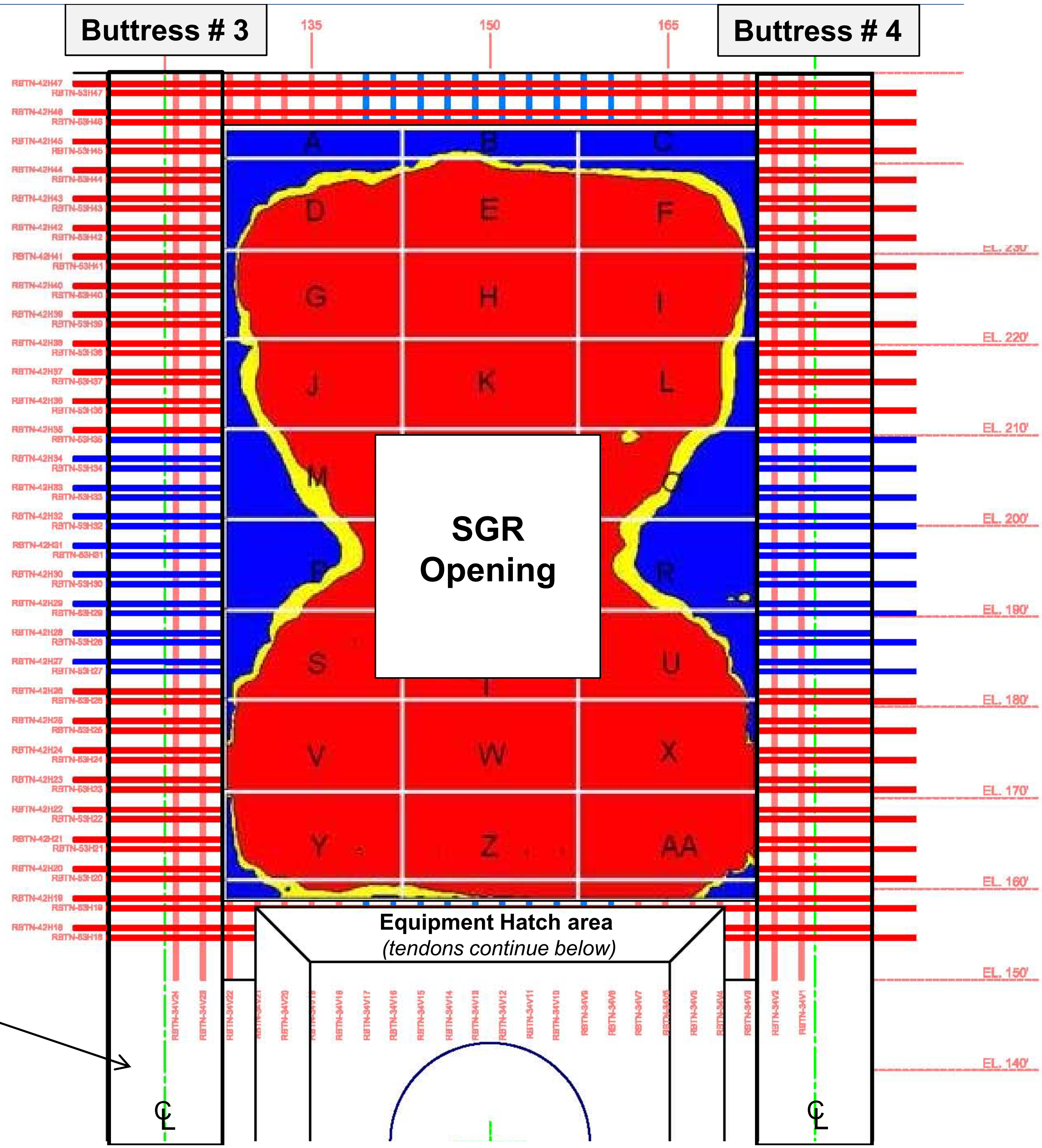
- Energized Tendon
- Removed Tendon

Buttress (typical)

Tendon Pattern

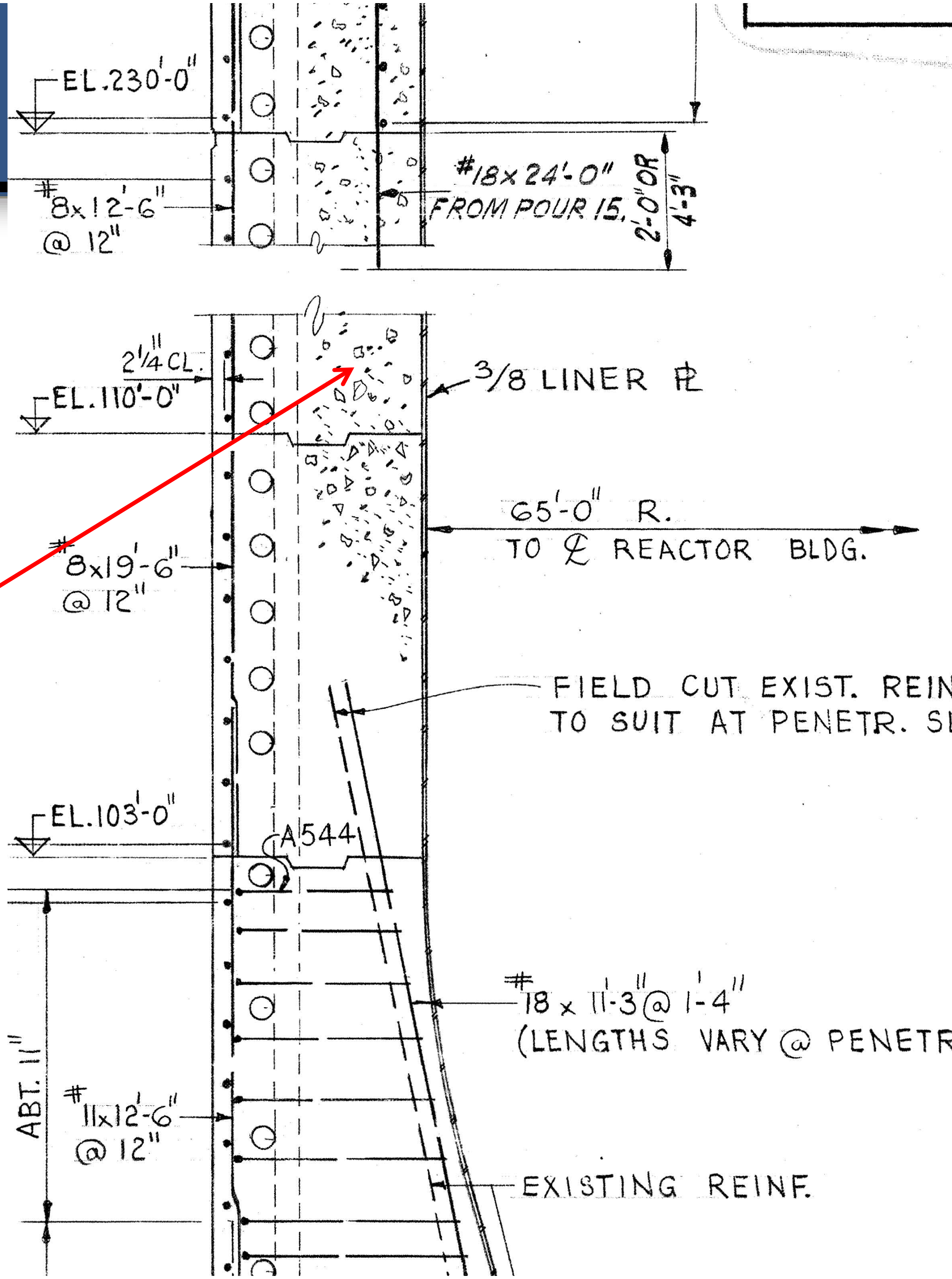
Tendon Pattern at time of cutting SGR Opening

- Energized Tendon
- Removed Tendon



Buttress (typical)

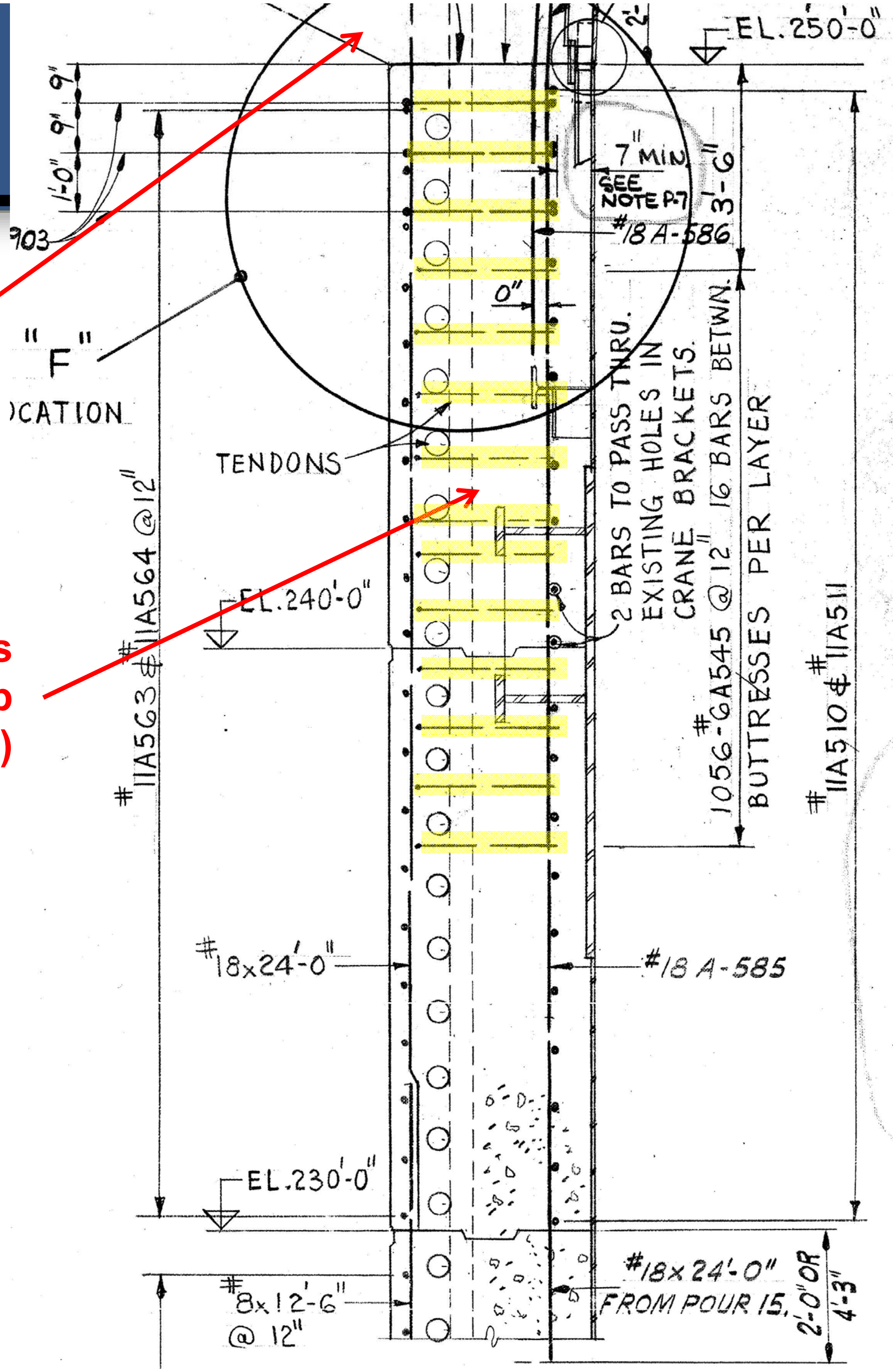
Wall Section Cutaway



Wall Section at SGR Opening (elevation view)

Source Drawing:
425-033 SH000

Wall Section Cutaway (cont)

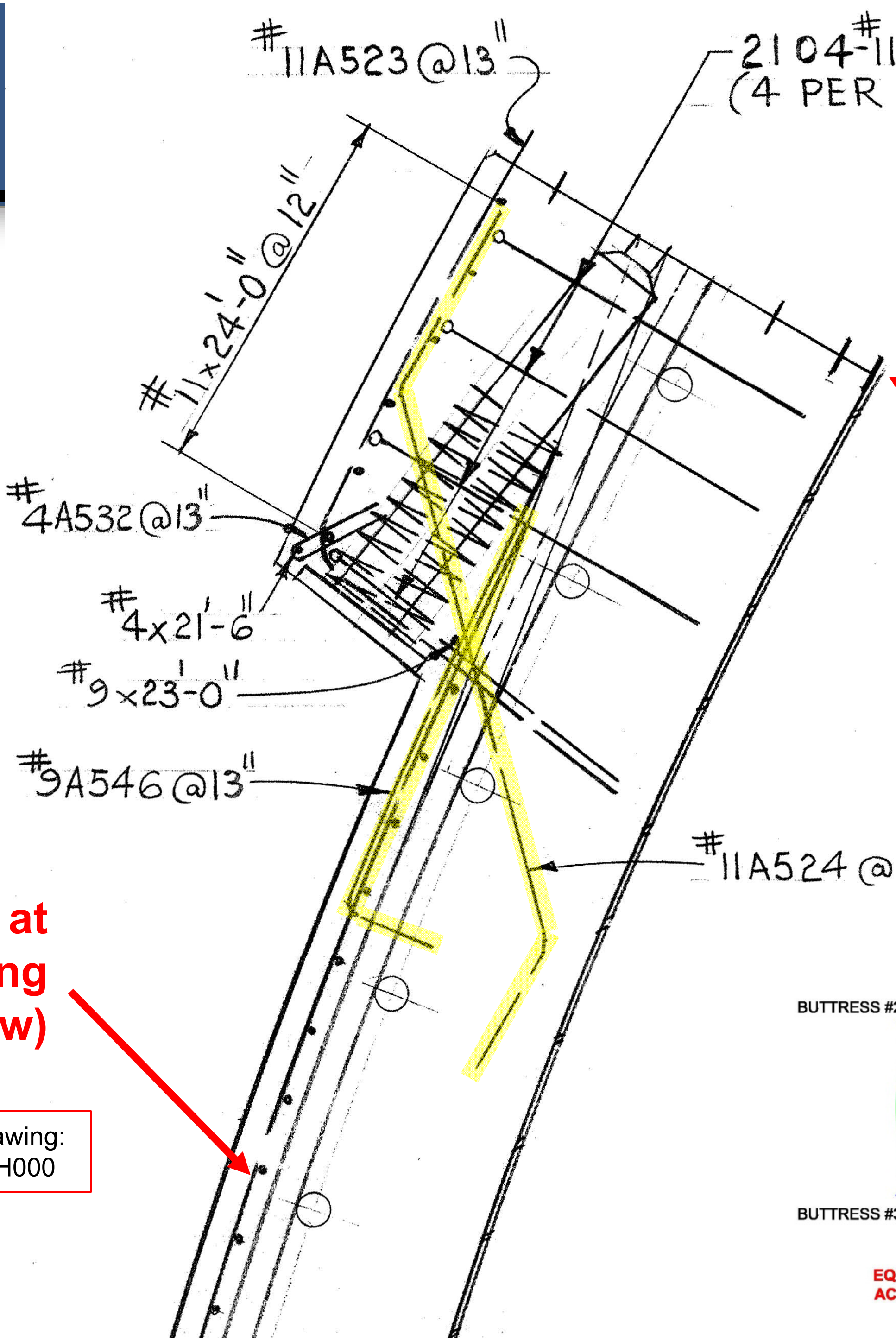


Bottom of Ring Girder

Wall section at higher elevations showing additional stirrup reinforcement (elevation view)

Source Drawing:
425-033 SH000

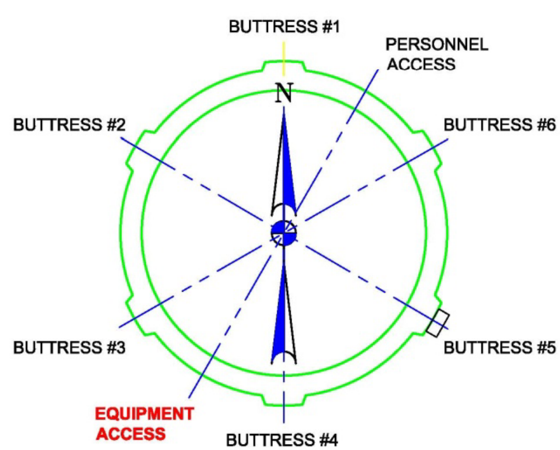
Buttress Cutaway



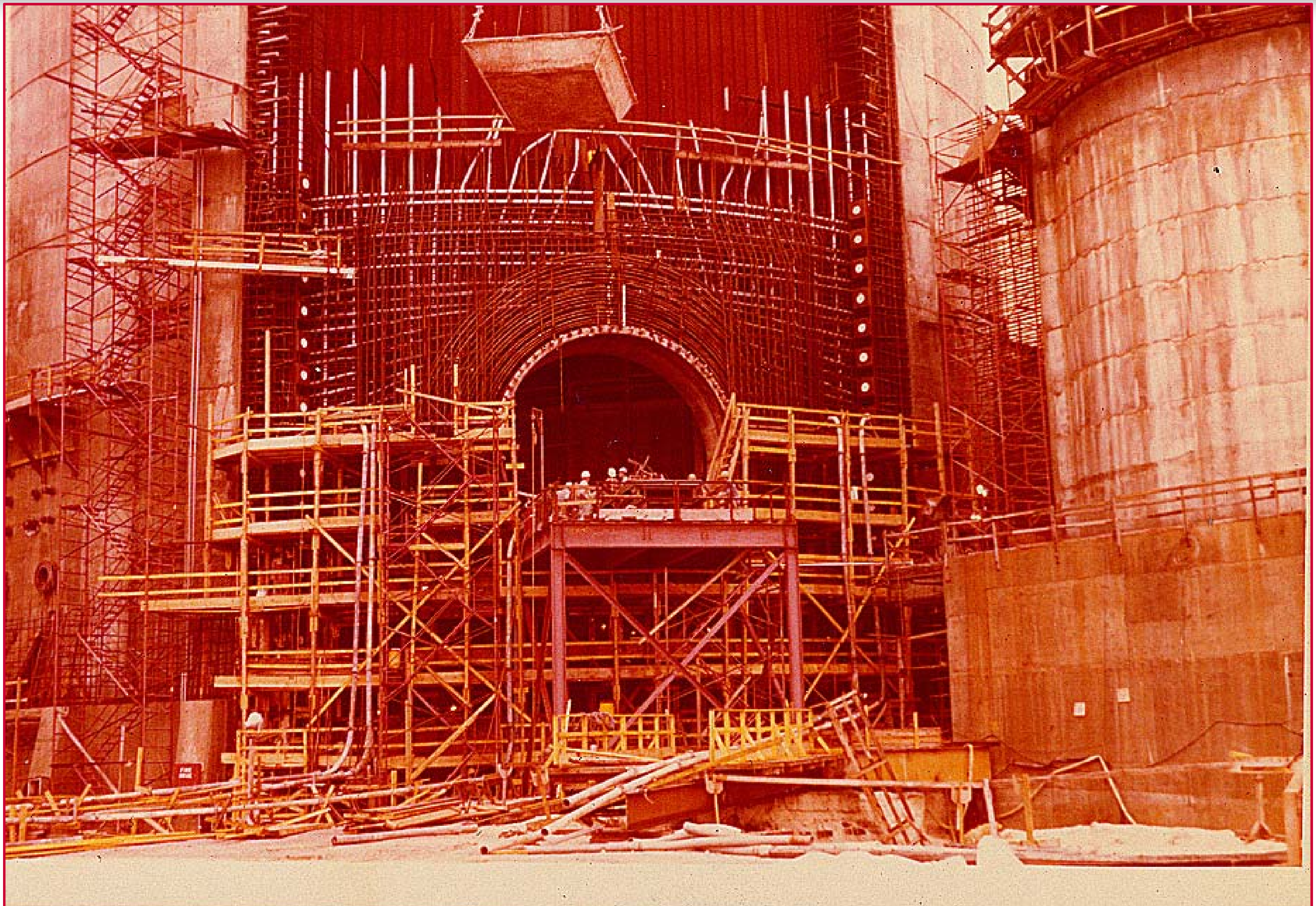
Buttress match-line

Wall Section at SGR Opening (Plan View)

Source Drawing:
425-033 SH000



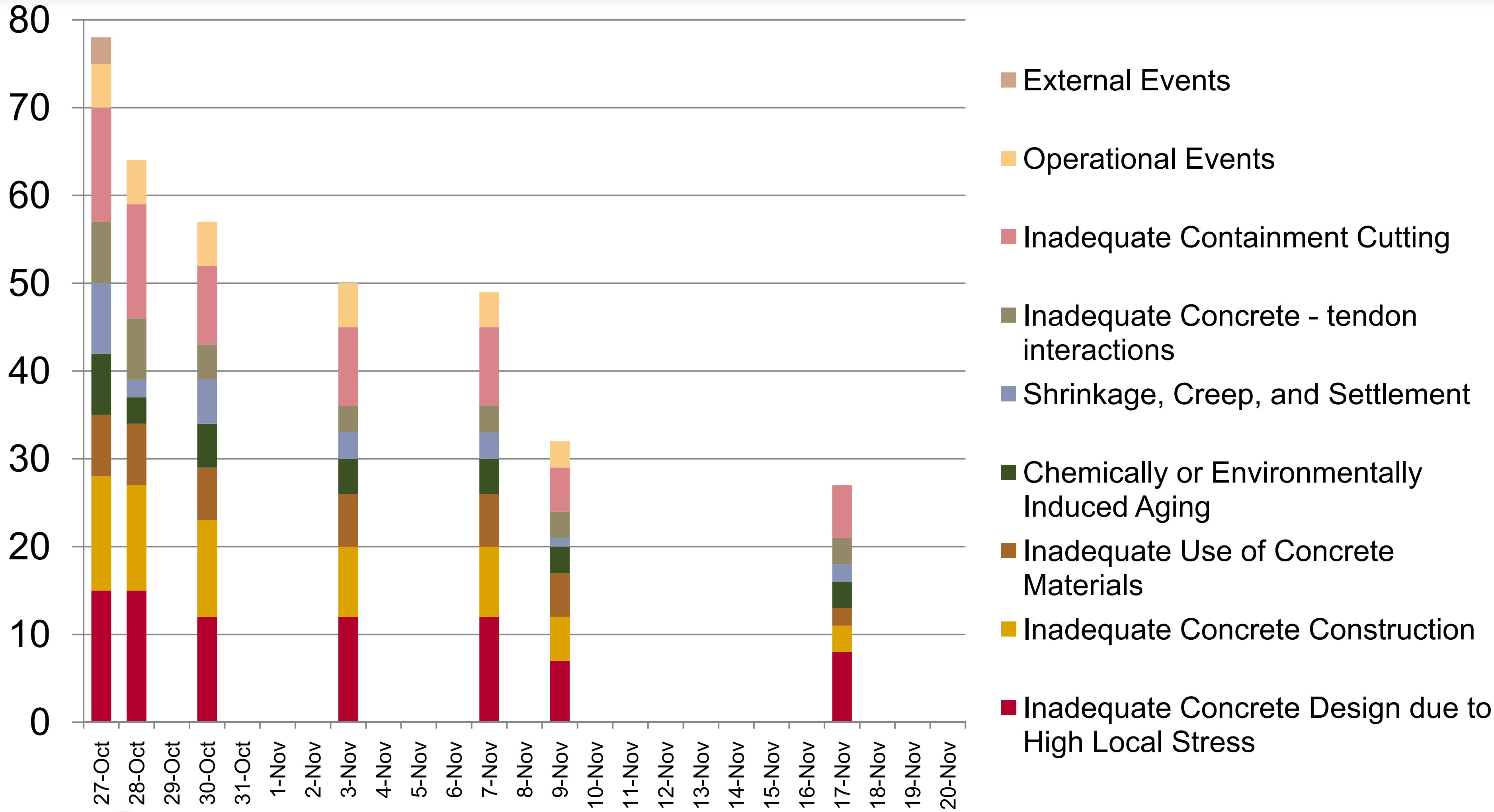
Equipment Hatch Opening Reinforcement
Photo - 30 Nov 1972



ROOT CAUSE ANALYSIS

Root Cause Analysis – PII Metrics

Un-refuted Failure Modes as of Nov 17th 2009



Root Cause Analysis
Field Data Acquisition

- Impulse Response (IR) Scans
- Boroscopic Inspections
  - Core bore holes
  - Inside the delaminated gap
- Visual inspections
  - Delamination cracks at SGR Opening
  - Larger fragments from concrete removal process
  - Containment external surface

Root Cause Analysis
Field Data Acquisition (continued)

- Nearby energized tendons lift-off (vertical and horizontal)
- Containment dimension measurements
- Strain gauge measurements
- Linear variable displacement transducer (LVDT) gap monitoring
- Building natural frequency

Root Cause Analysis
Field Data Acquisition (continued)

- Core bores laboratory analysis
  - Petrographic Examination
  - Modulus of Elasticity and Poisson's Ratio
  - Density, Absorption, and Voids
  - Compressive Strength, Splitting Tensile Strength, and Direct Tensile Strength
  - Accelerated Creep test
  - Accelerated Alkali Silica Reaction (ASR) test
  - Chemistry and contamination test
  - Scanning Electron Microscope (SEM) examination of micro-cracking

OPERATIONAL EXPERIENCE (OE)

Steam Generator Replacement (SGR) OE
Type of Information Collected from the Industry

- Architect Engineer and Constructor
- Type of Containment and design pressure
- # of Buttresses
- Concrete design strength requirement
- Dimensions
  - Internal containment diameter and wall height
  - Containment cylinder wall and dome thickness
  - Tendons details (# vertical, # horizontal, # dome, strand diameter)
  - Liner thickness

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Steam Generator Replacement (SGR) OE
Type of Information Collected from the Industry (cont)

- Reinforcement details
- Whether concrete opening was made
  - Was hydro-excavation used
  - And if so, equipment operating parameters
- Detensioning details
  - # by cutting
  - # by relaxation
  - # of tendons removed/detensioned beyond the SGR opening

Concrete OE

- **Worley Parsons**
  - 1976 dome delamination investigation and repair (as Gilbert / Commonwealth)

- **Structural Preservation Systems (SPS)**
  - Largest Concrete Repair Contractor in the US, 2nd largest Concrete Contractor (of any type) in the US
    - Defects, Damage, and Deterioration
  - Performs > 4,000 repair projects per year
  - 3,000 employees in 27 offices Nationwide, and London, Dubai & Singapore

- **Wiss, Janney, Elstner, Inc (WJE)**
  - Structural engineering and materials science firm specializing in failure investigations and problem solving
  - Specialist in structural condition assessments and design of repairs and retro-fits for reinforced and post tension concrete structures
  - Conducted original CR3 Structural Integrity Test (SIT)
  - 450 employees in 20 offices nationwide

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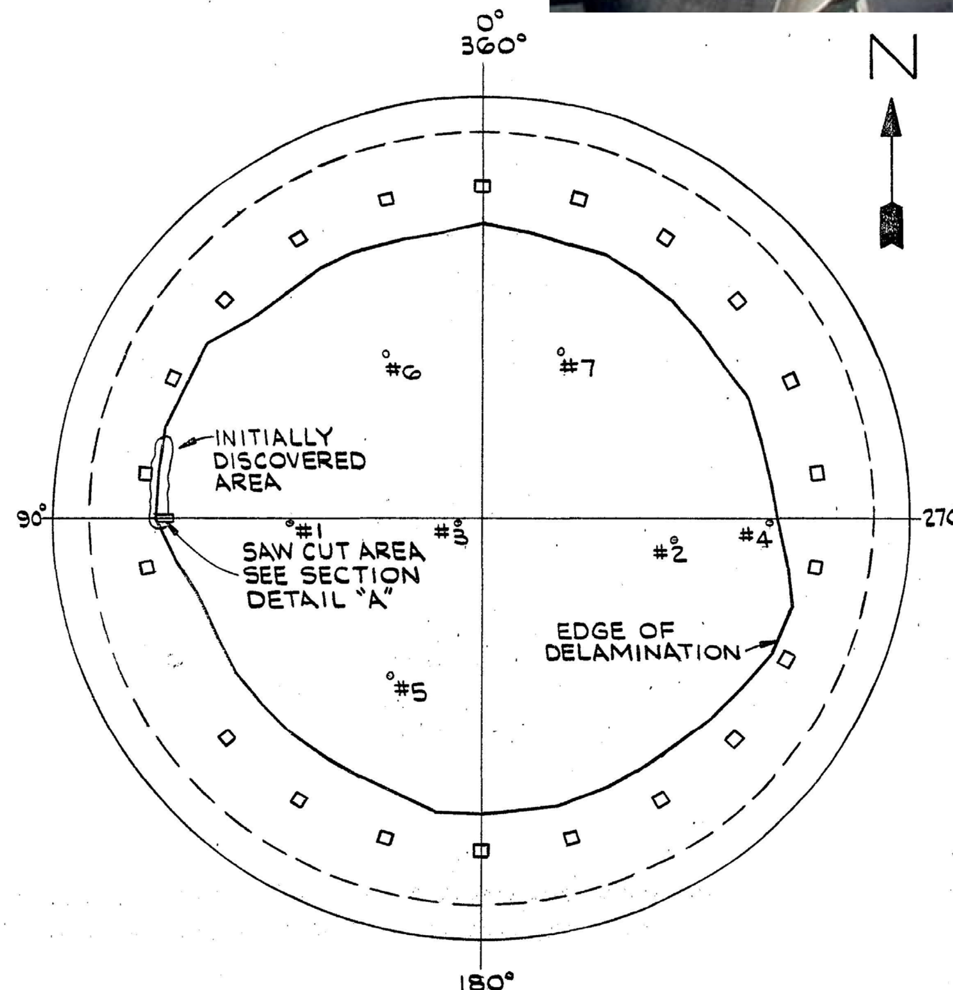
1976 Dome Delamination
Cause[(1)]

- Compression - tension interaction failure occurred
- Contributing Effects
  - Radial tension due to pre-stressing
  - Thermal effects
  - Tendon alignment
  - Stress concentrations
  - Shrinkage
- Combined with biaxial compressive stresses and lower than normal[(2)] direct tensile strength of concrete

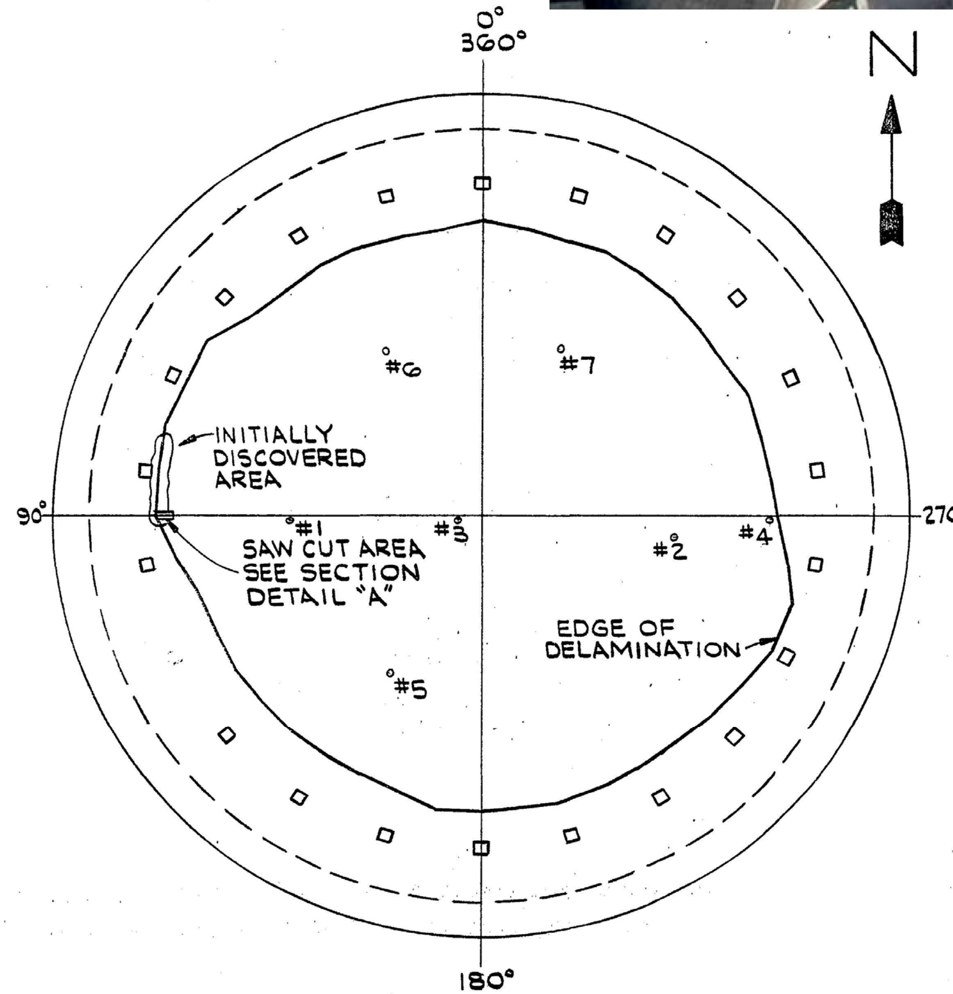


[(1)]Cause information taken from 1976 Final Report prepared by Gilbert / Commonwealth

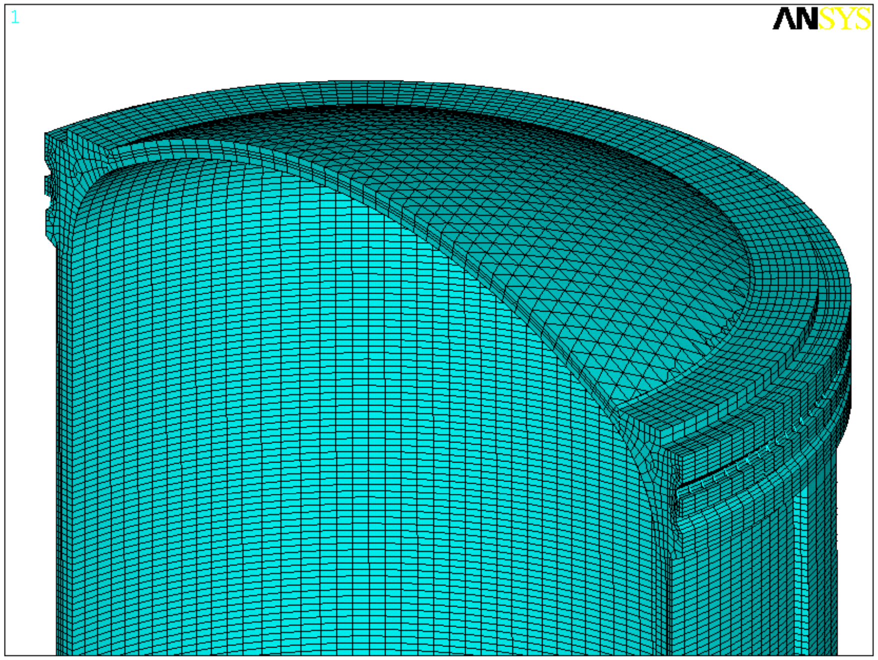
[(2)]Lower than normal (or typical), but above design requirements

1976 Dome Delamination
Repair Approach

- Tendons detensioned (18)
- Delaminated surface was removed
- Lower level cracks grouted with epoxy
- New reinforcement placed
- New cap poured and cured
- Tendons partially re-tensioned (18)



DESIGN BASIS ANALYSIS



Design Basis

- Reinforced Post-Tensioned Concrete Structure
- Live and Dead Loads
- Wind (110mph @ 30' increasing to 179 mph @ 166'10")
- Tornado Wind (300 mph)
- Tornado pressure (external pressure of 3 psig)
- Tornado Missiles (35' utility pole or 1 ton car @ 150 mph)
- Seismic (OBE – 0.05 and SSE - 0.10)
- Temperature Loads
- Accident Pressure (55 psig)
- Accidental Containment Spray Actuation Press (- 6.0 psig)

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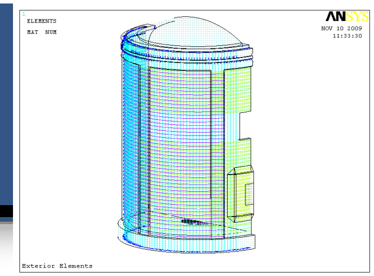
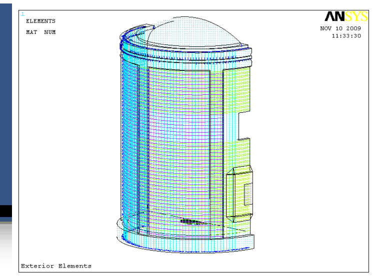
CR3 FEA Model



- **180 degree Symmetric model**
  - Symmetry plane @ 150 degrees midway Between Buttress 3 & 4 / 1 & 6
  - ½ Opening, ½ Damage & ½ Hatch Modeled Explicitly

- **Concrete Model**
  - Brick elements for all components
  - Dome and Base modeled independently
  - Simplified ring beam and buttress geometry
  - Constraint equations used to join dome and ring girder for meshing efficiency
  - Constraint equation used to model sloped surfaces of the hatch

CR3 FEA Model (continued)



- **Liner Model**
  - Shell mesh with variable thickness
  - Shared nodes with containment inner surface
- **Tendon Modeling**
  - Hoop tendons modeled explicitly for release and re-tensioning
  - Vertical Tendons modeled explicitly for release and re-tensioning
  - Dome tendons modeled independently with forces ported to global model

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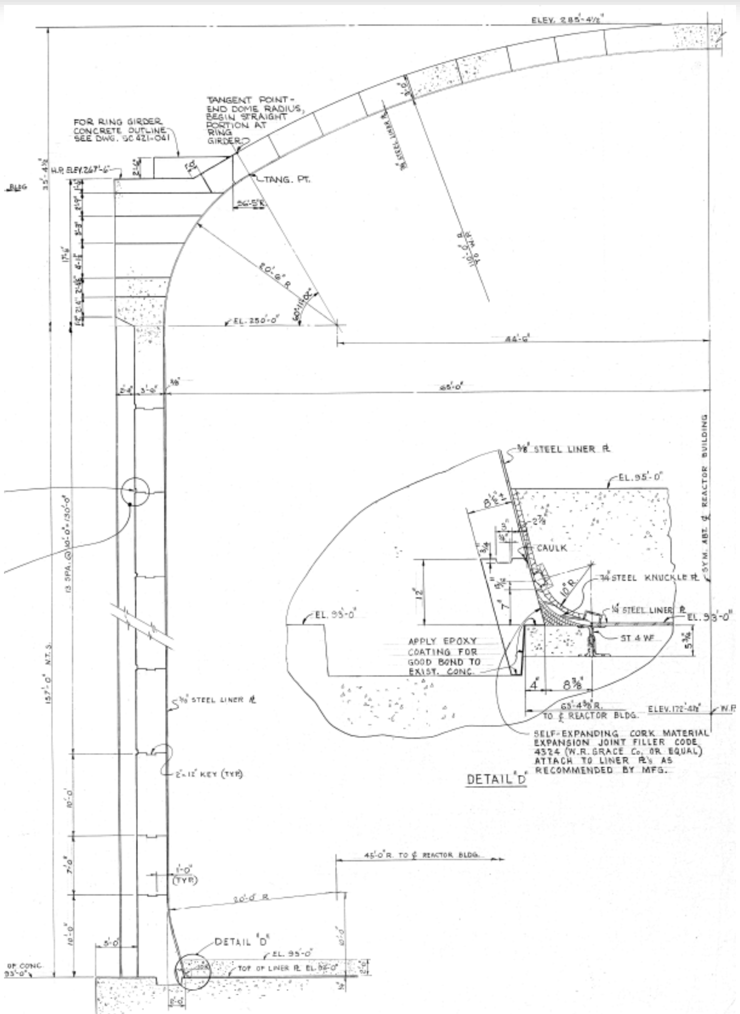
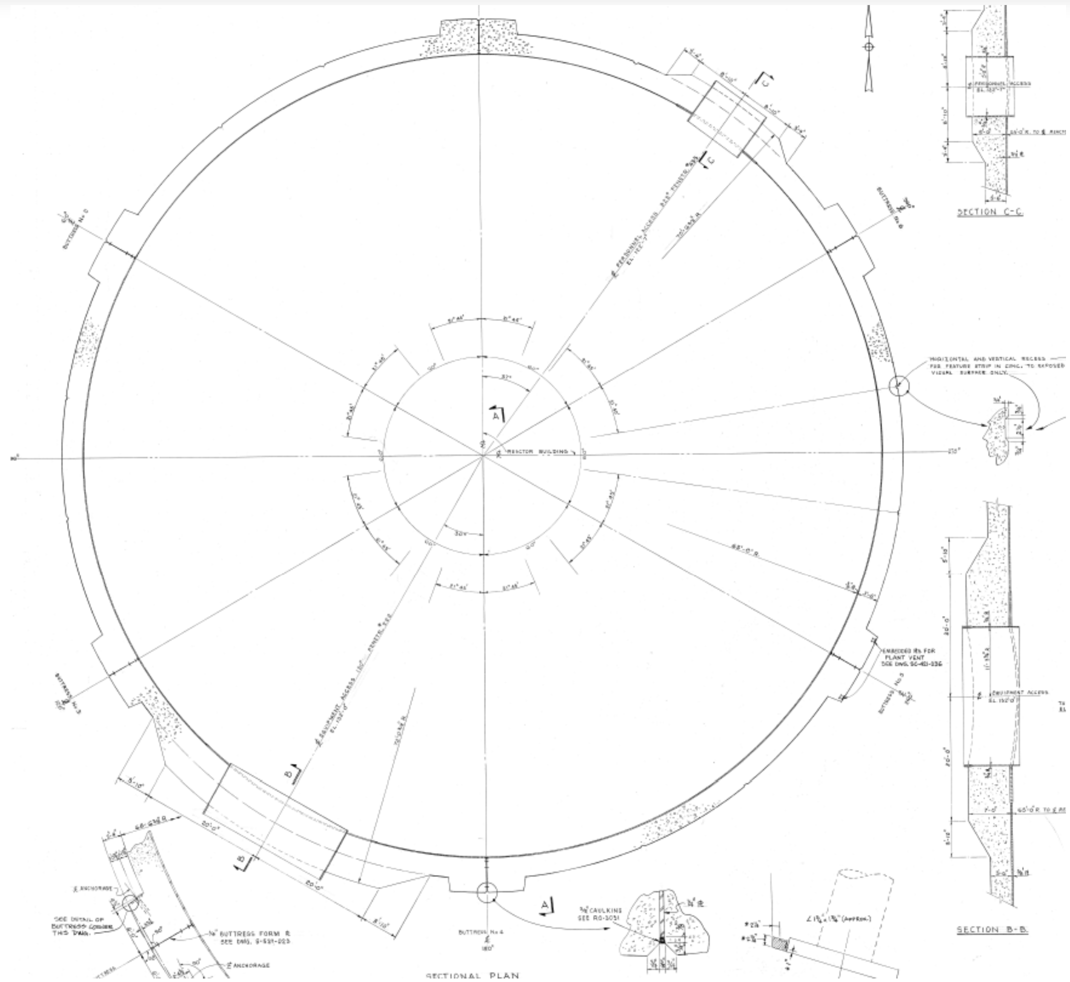
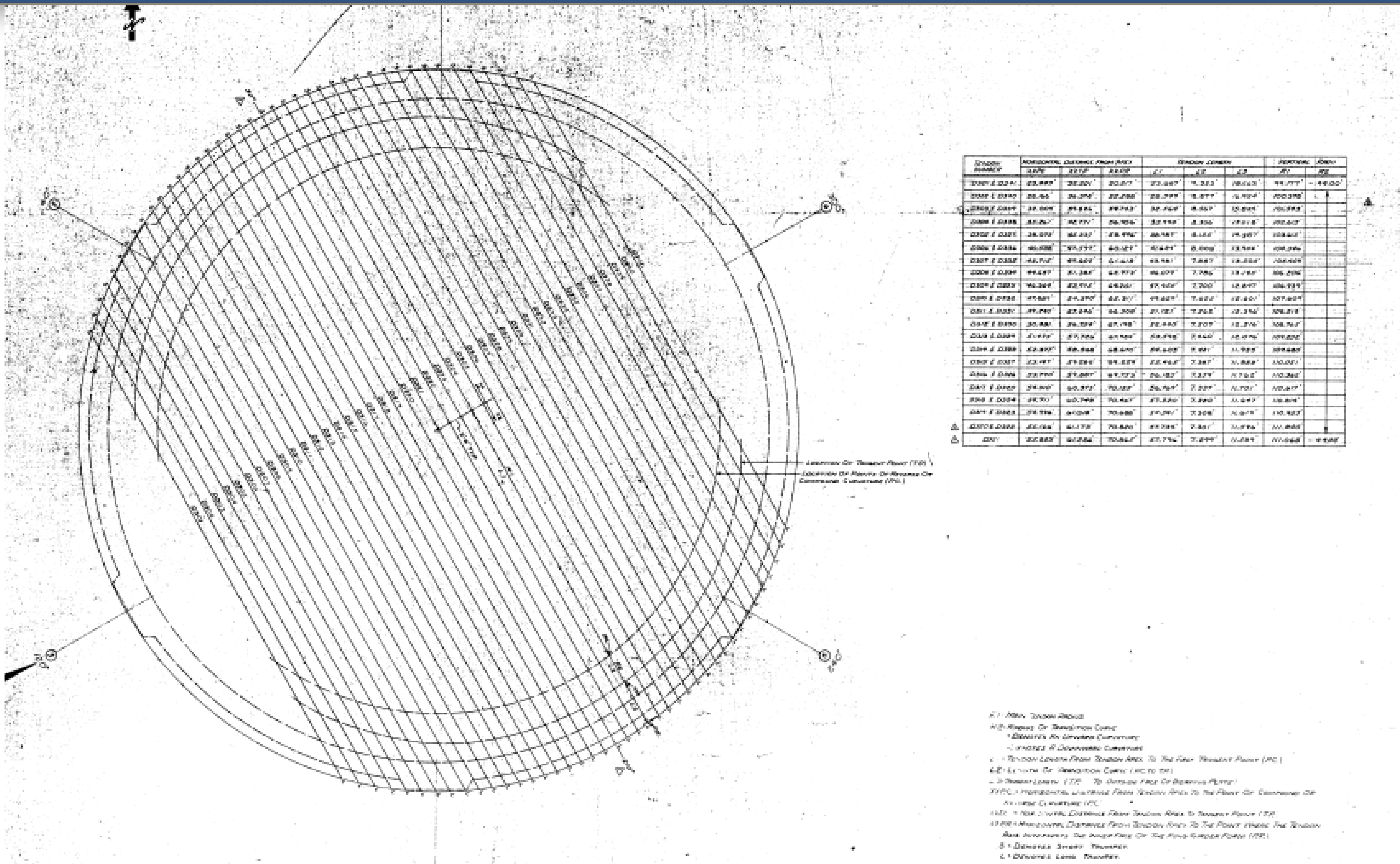
Concrete Geometry Based on Gilbert Associates Drawings

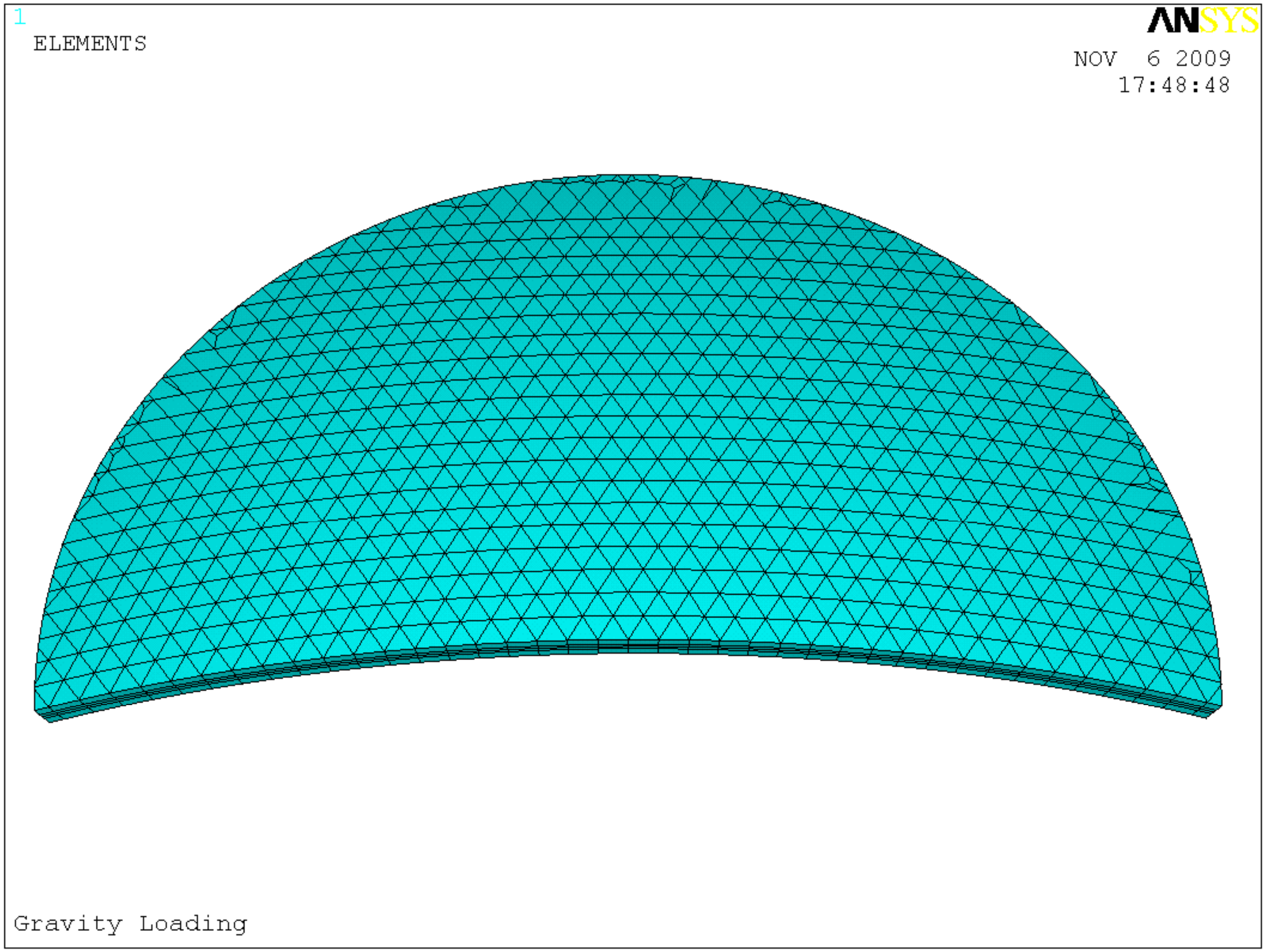




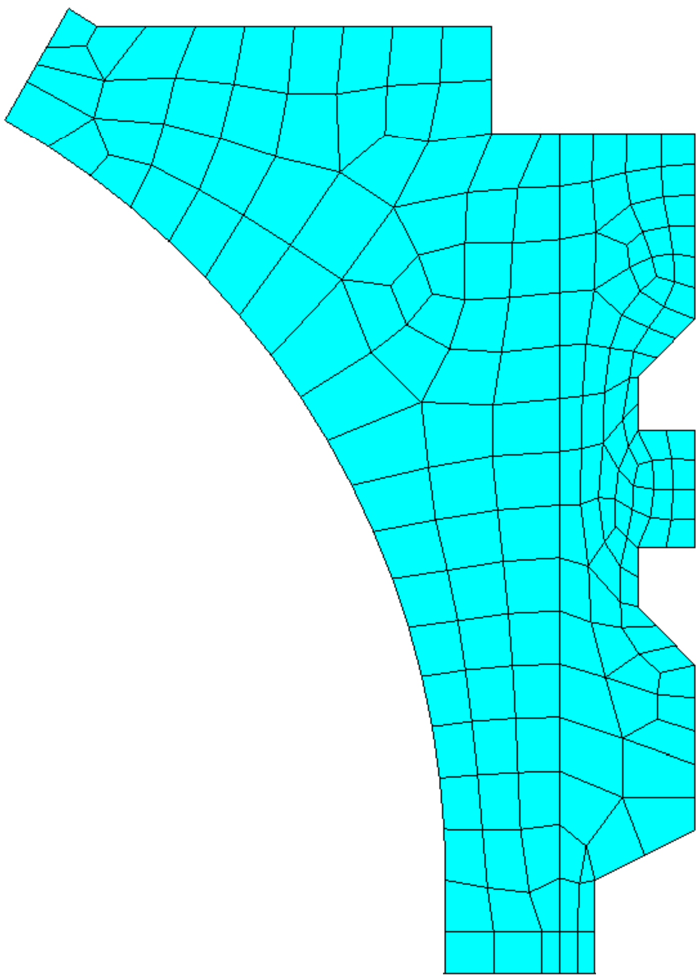
Tendon Geometry Based on Prescon Drawings

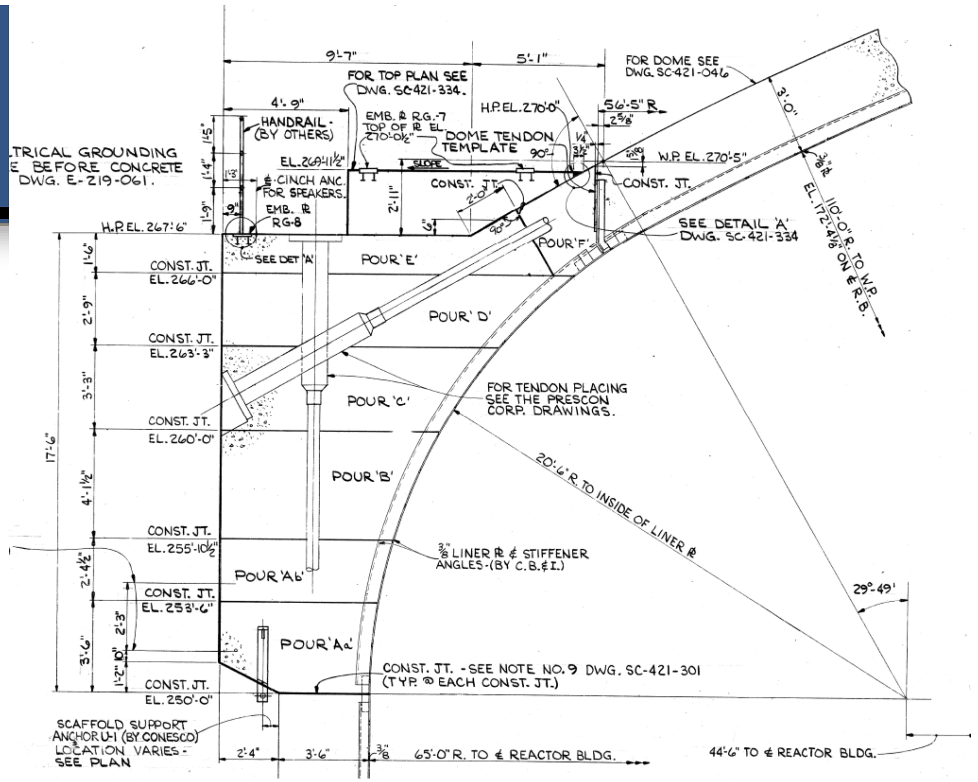


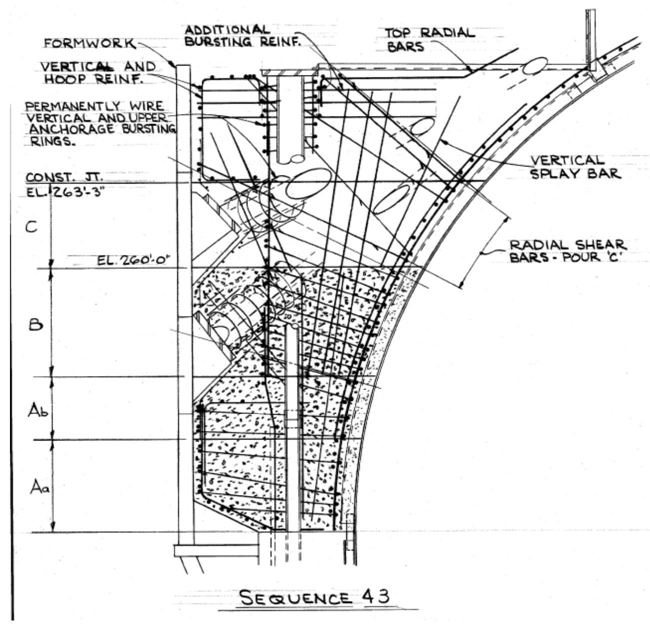
Dome FEA Model



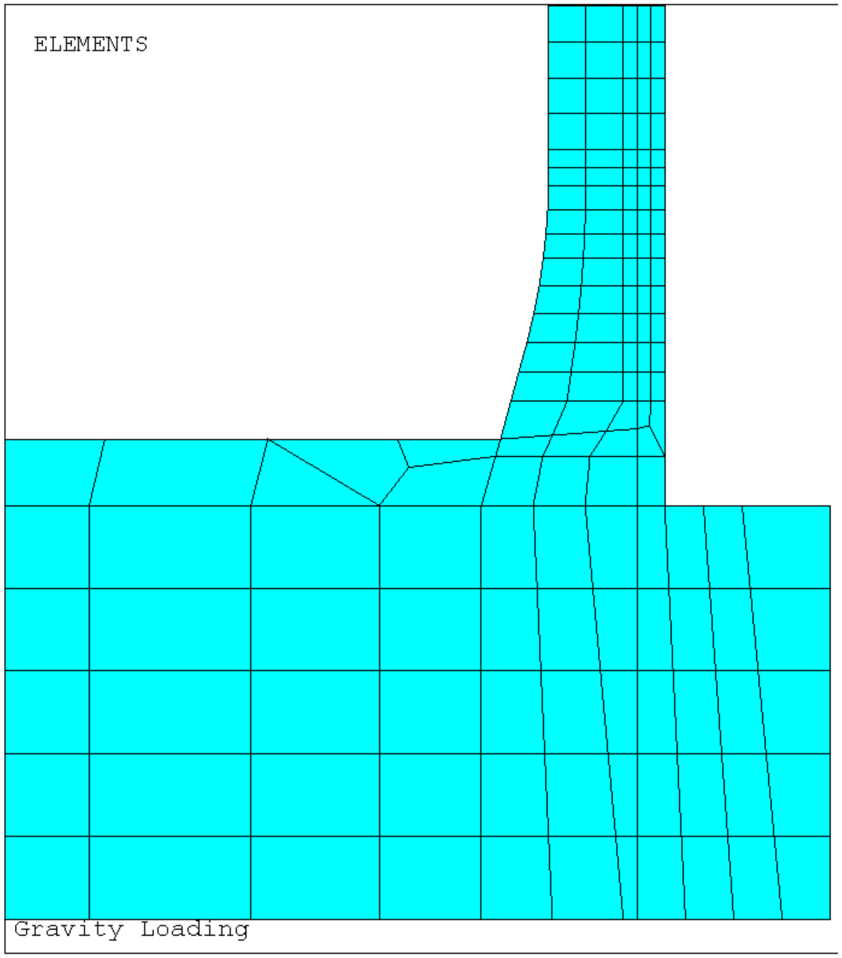
Ring Girder Model

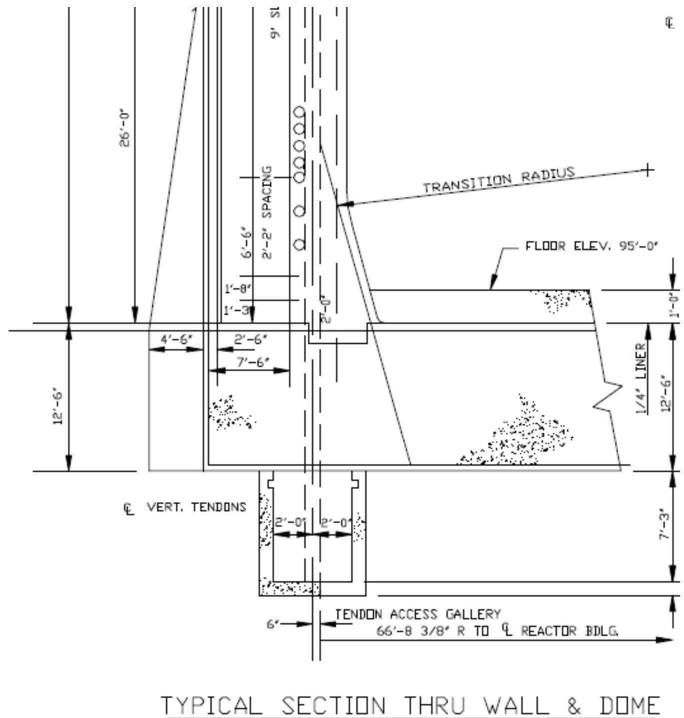


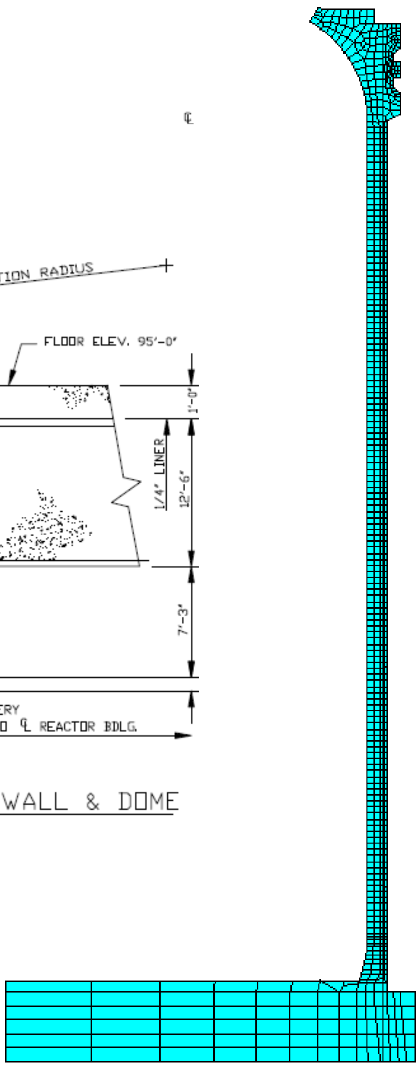




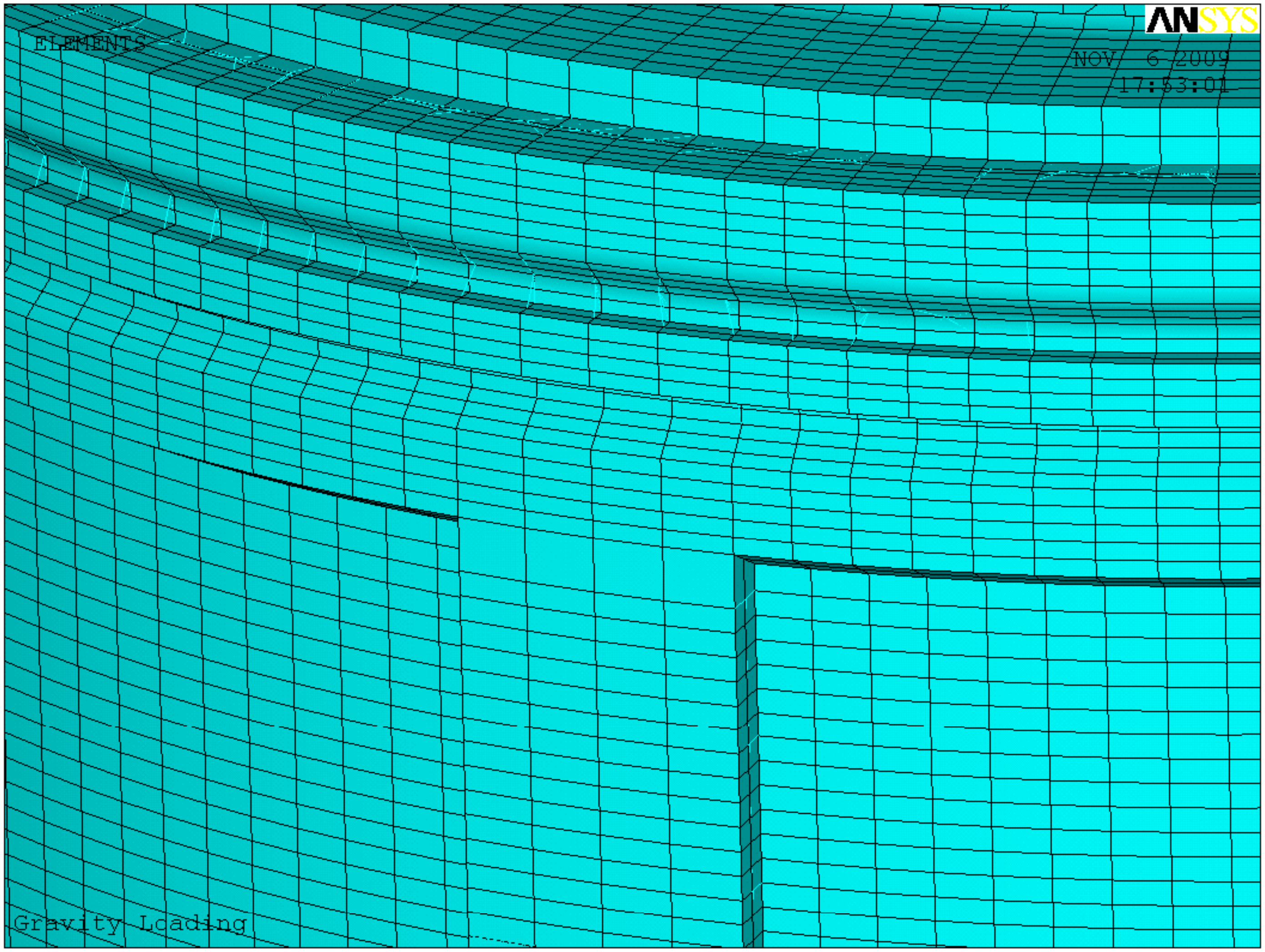
Core Building Geometry – FEA Mesh
Hoop Tendon Locations Defined



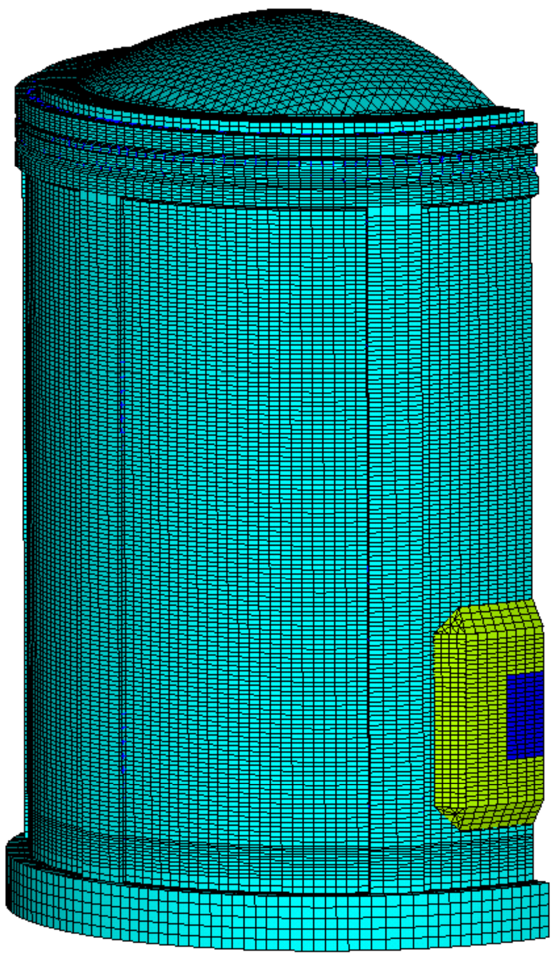


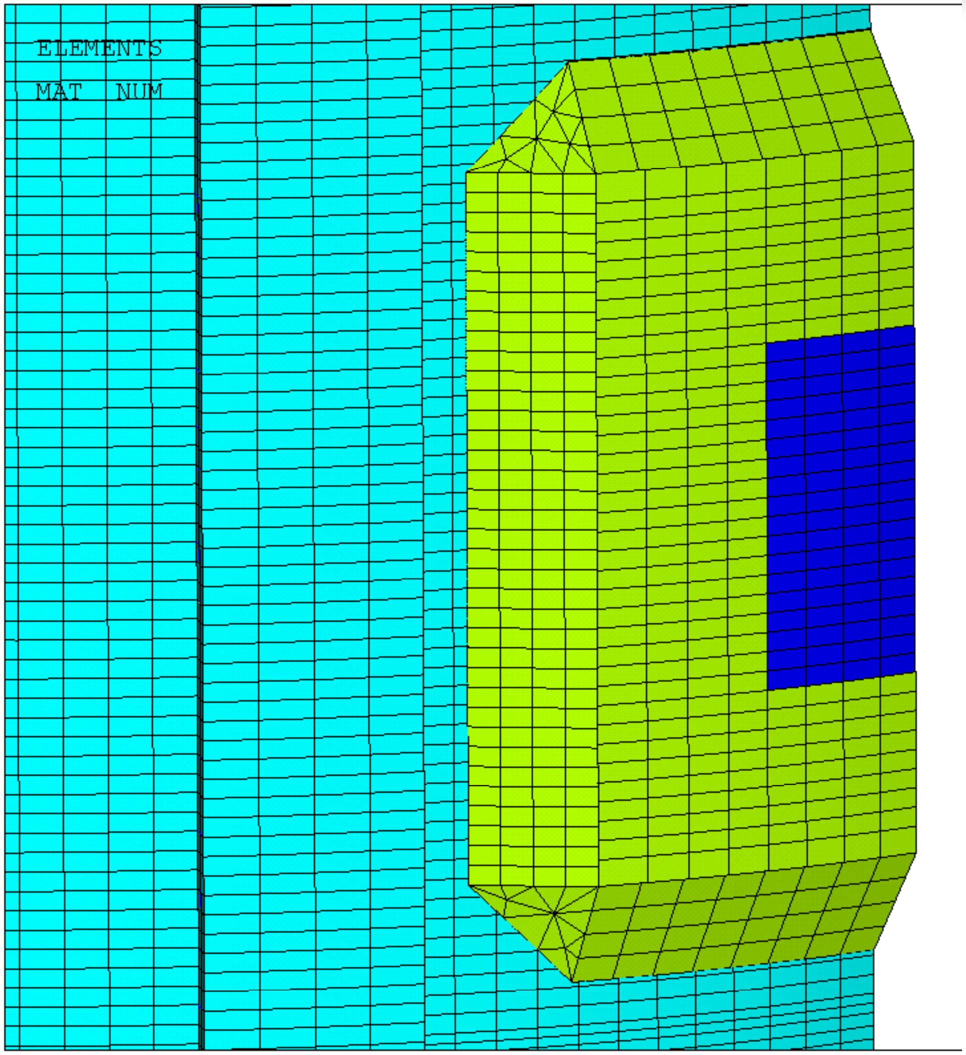


Core Building Geometry - Buttresses



Equipment Hatch Model





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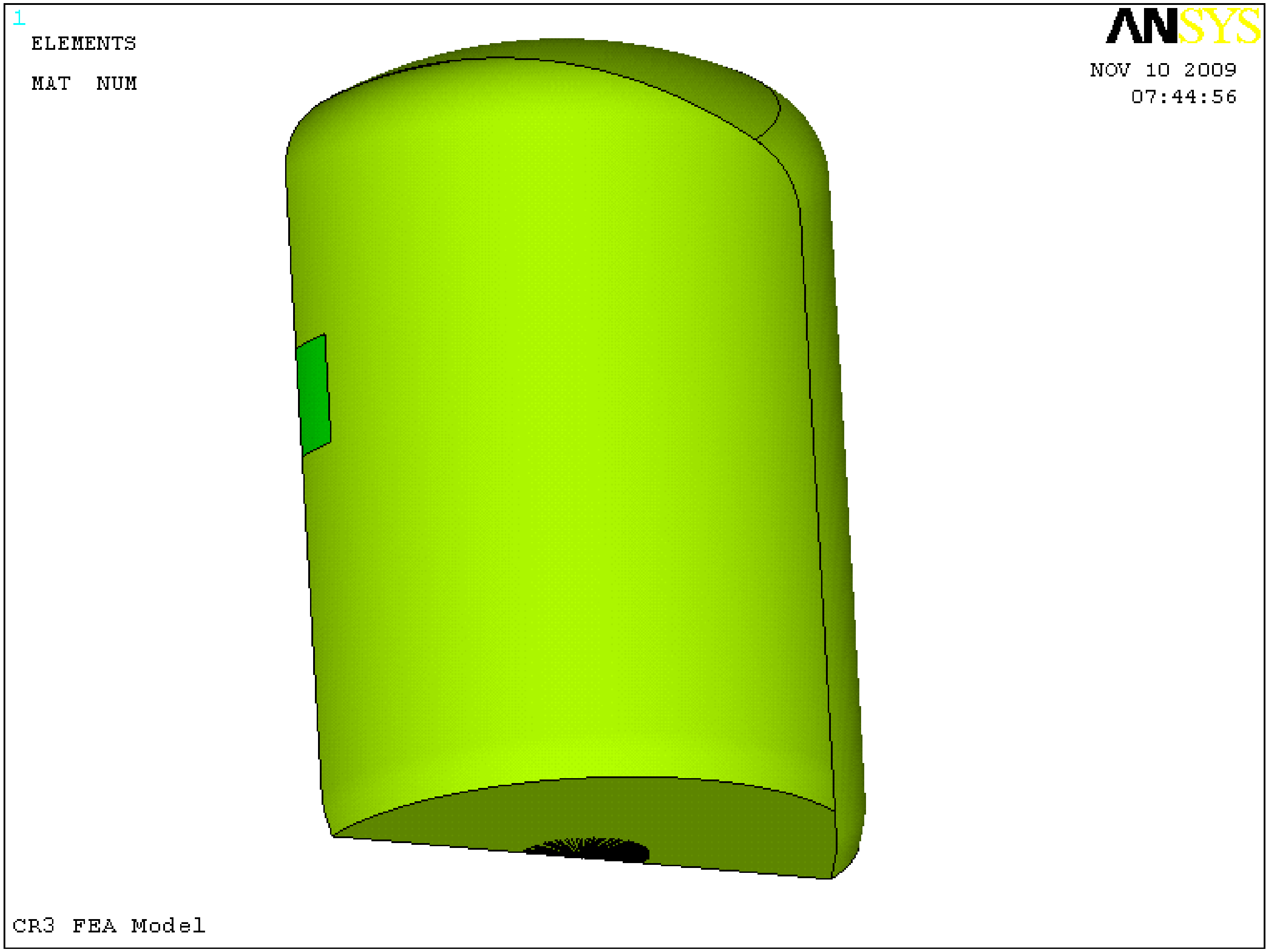
Liner



Tendon Loading

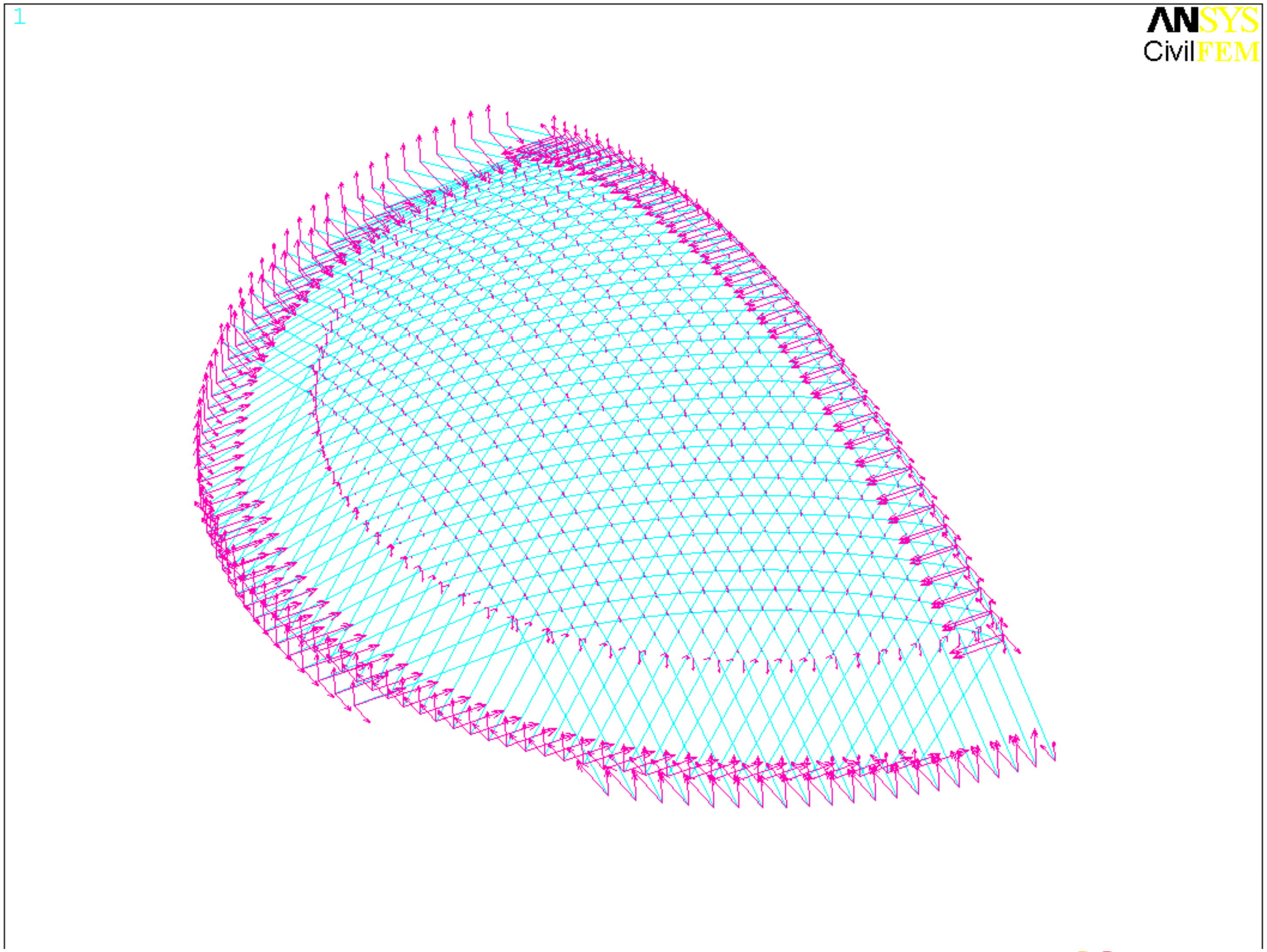
- The tendons are preloaded to a prescribed load magnitude.
- The application of the tendon loads is achieved in the analysis using initial strain input
- An empirical formula has been developed to account for the loss of load as the distance from the anchor point increases:

$$P = P_0 \, e^{-(ma + ks)}$$

- Where:
  - P_o = preload magnitude
  - m = friction coefficient
  - a = inflection angle (0.16)
  - k = wobble coefficient (0.0003)
  - s = distance from anchor point

- Tendon preloads used in analysis:
  - $P_{0\text{-dome}}$ = 1635 Kips (1,215,000 lb. 40 years)
  - $P_{0\text{-horizontal}}$ = 1635 Kips (1,252,000 lb. 40 years)
  - $P_{0\text{-vertical}}$ = 1635 Kips (1,149,000 lb. 40 years)

Dome Force Vectors Ported to Global Model



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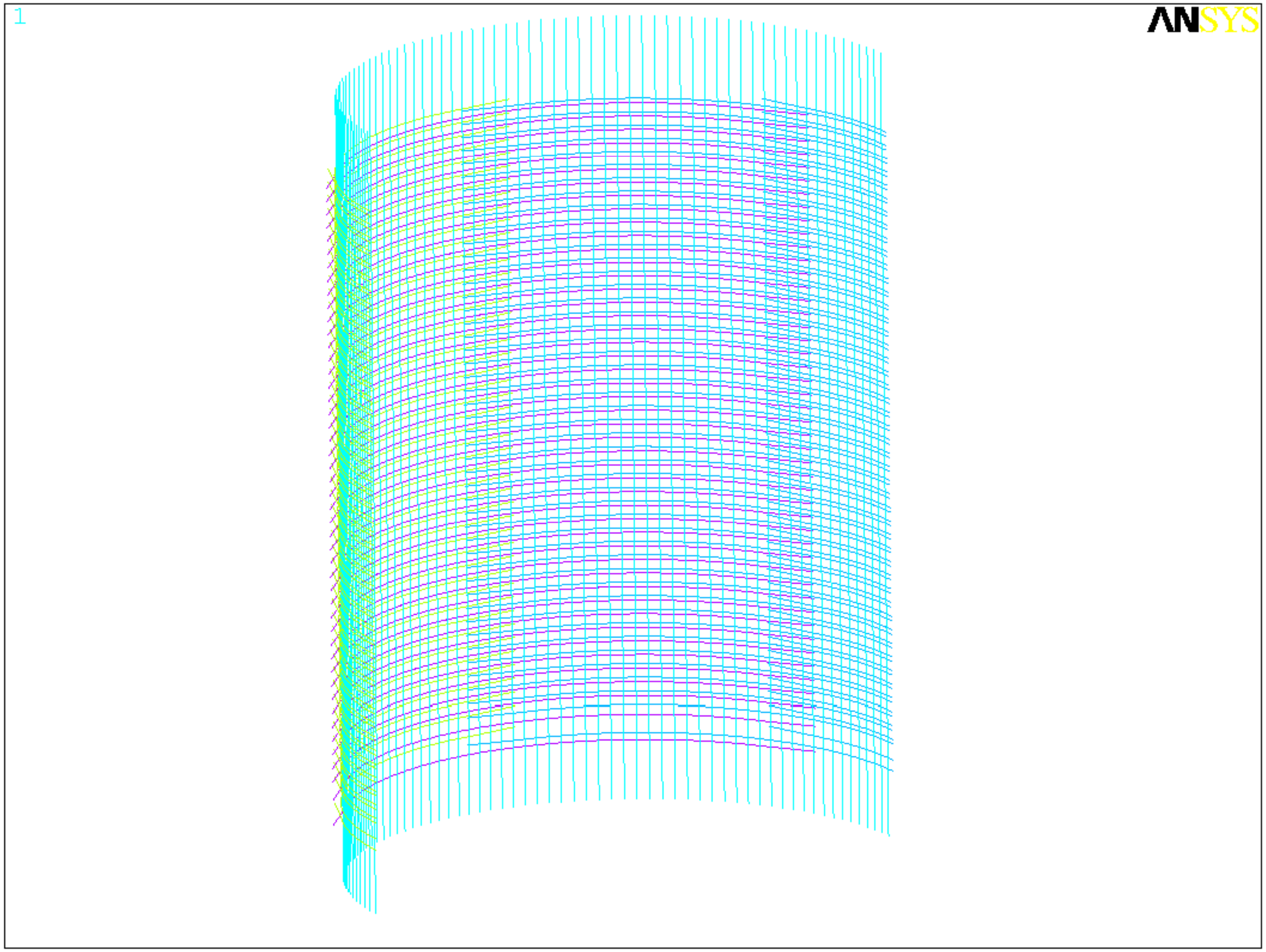
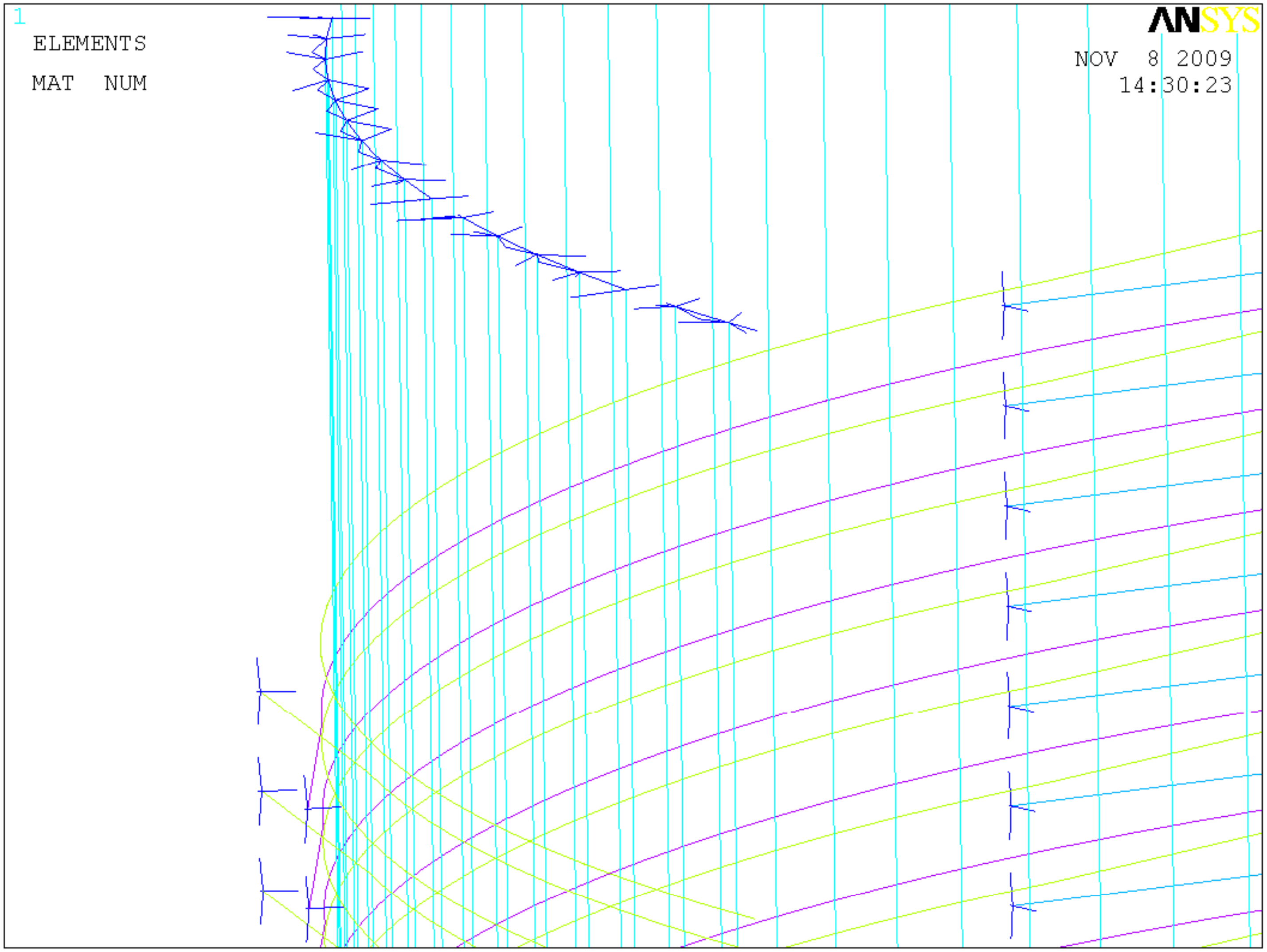
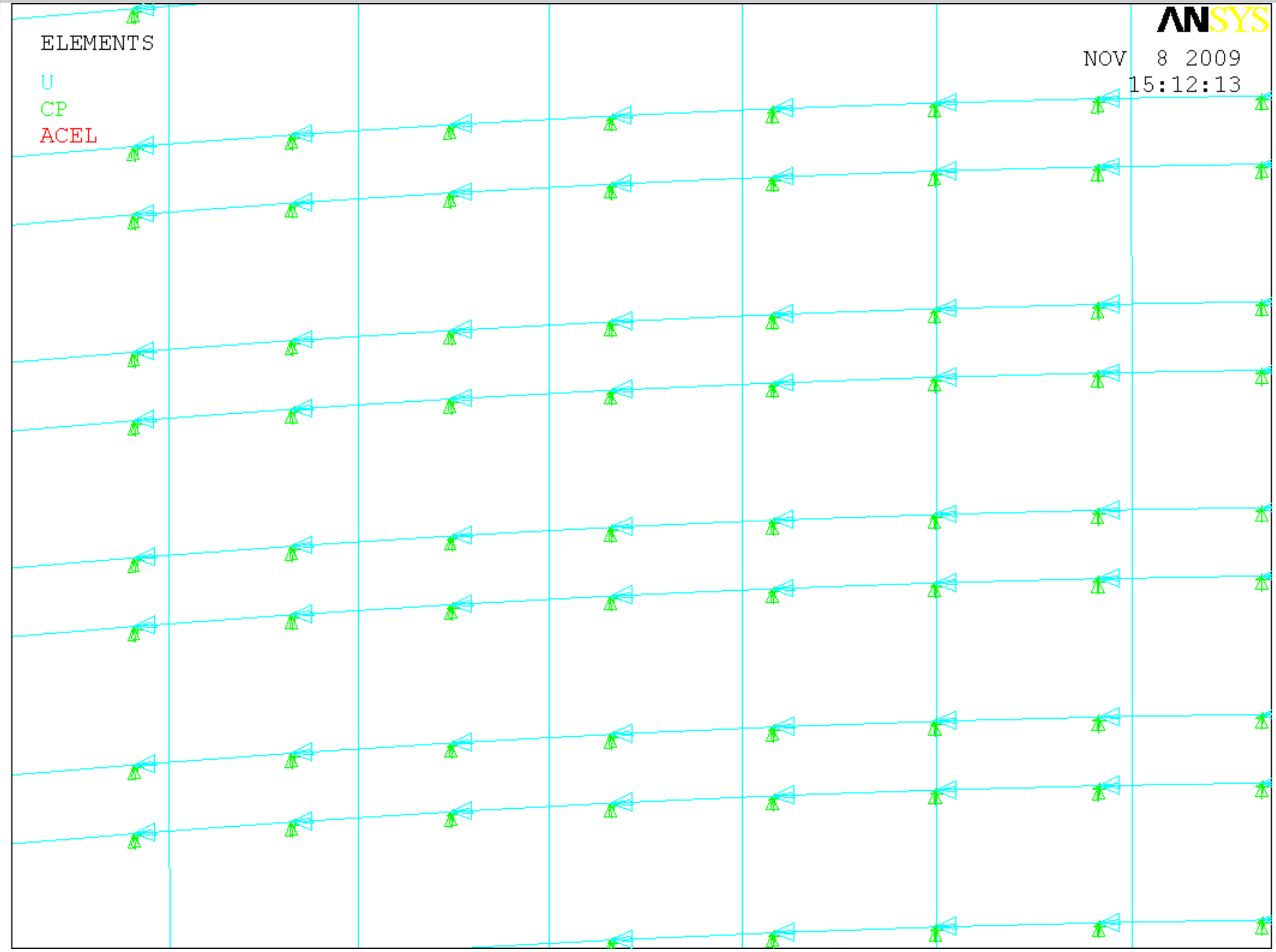
FEA Model – Vertical and Hoop Tendons



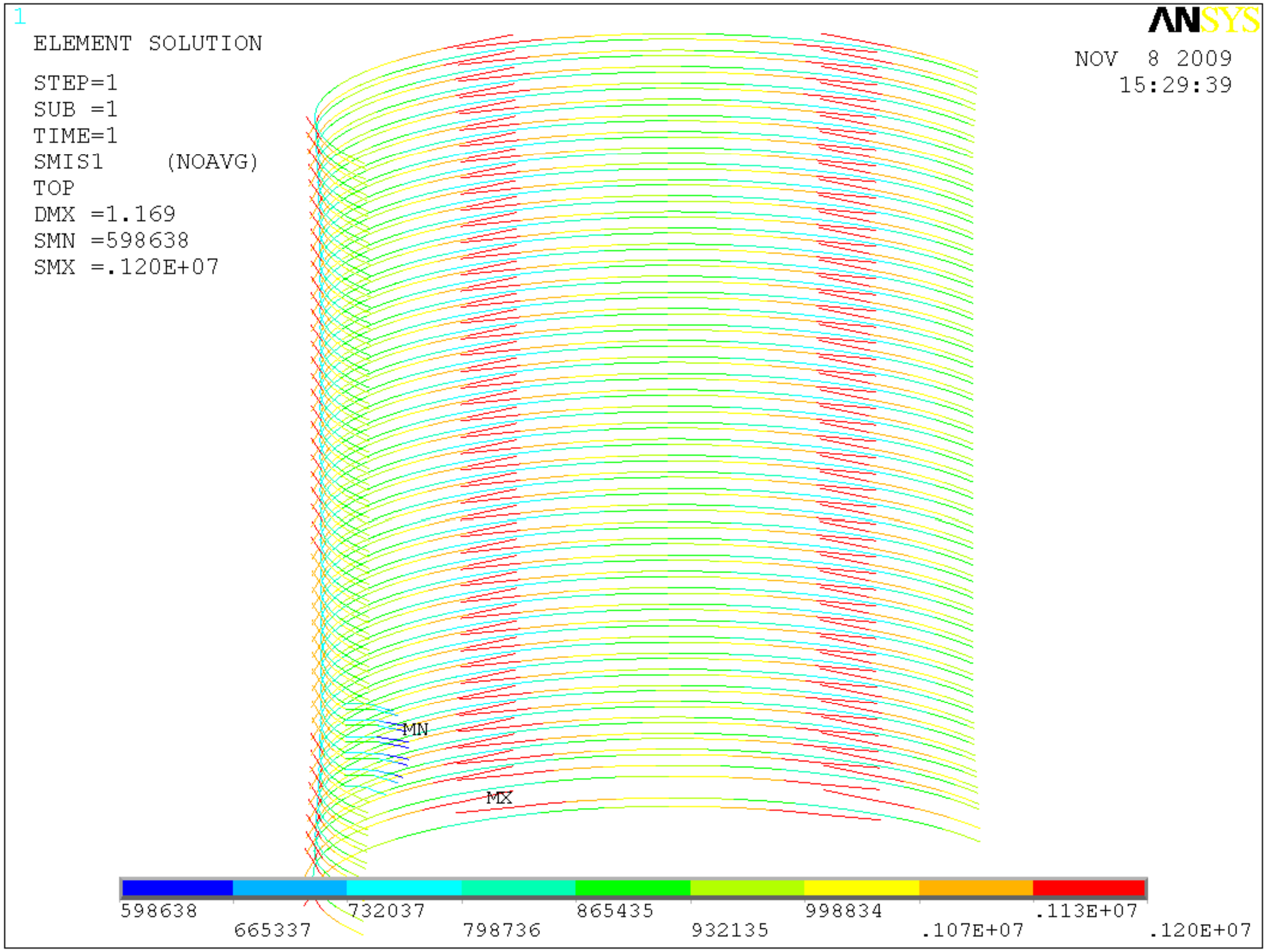
FEA Model – Vertical and Hoop Tendon Supports



FEA Model – Hoop Tendons Couples and Supports



Hoop Tendon Forces



Planned Analysis

- **Existing Design Cases for Comparison**
  - Gravity (.95 G)
  - Internal Dead Load (200 psf)
  - Tendons (1635 kips / tendon)
    - Include losses
  - Internal Pressure (55.0 psi)
  - Wind Pressure (0.568 psi)
  - Seismic
  - Accident Thermal

- **Planned Analysis Steps**
  - Dead Load + Tendons
  - Remove Hoop + Vertical Tendons in SGR Opening
  - Remove SGR Opening
  - Delamination[(1)]
  - Remove Additional Hoop & Vertical Tendons
  - Replace the SGR Plug[(2)]
  - Repair[(2)]
  - Re-tension Tendons
  - SAVE Path Dependent Model for Starting point to Run 5 Controlling Design cases

(1) Analysis will consider timing of delamination and specific concrete properties
(2) Sequence of replacing SGR concrete plug and repair may be adjusted

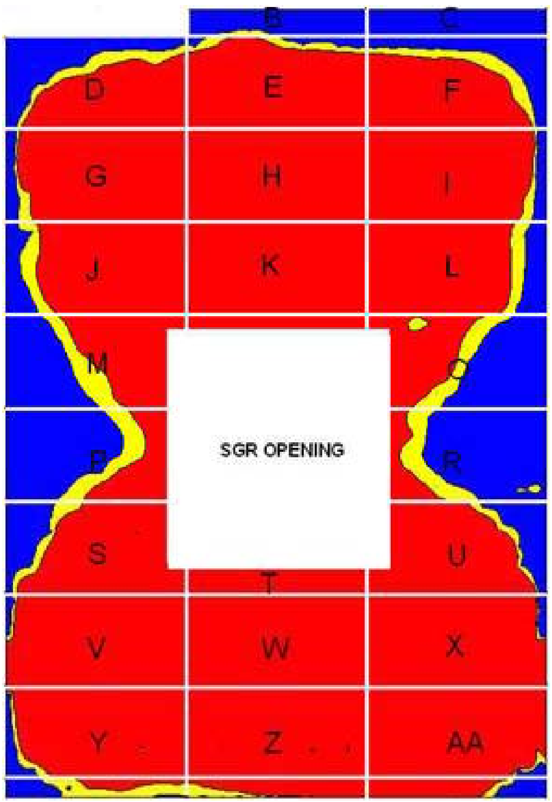
Design Basis Controlling Load Steps

- Restart the Re-tensioned Model and solve the following Controlling Load Steps
  - 1.5 Internal Pressure + Accident Thermal
  - 1.25 Wind + 1.25 Pressure + Accident Thermal
  - 1.25 Earthquake + 1.25 Pressure + Accident Thermal
  - 2.0 Wind + Pressure + Accident Thermal
  - SSE Earthquake + Pressure + Accident Thermal

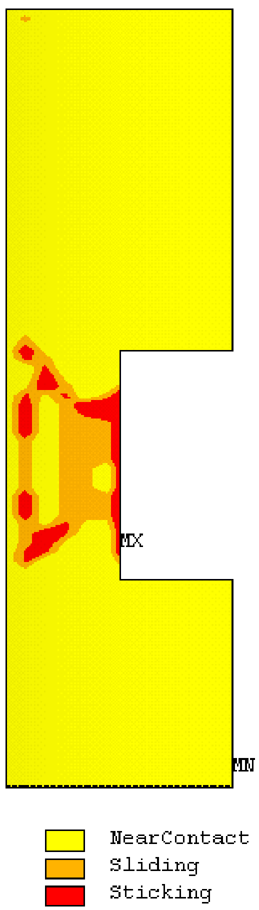
- Run Comparison to original building elastic design results

Preliminary Comparison of FEA Results to Extent of Condition Measurements

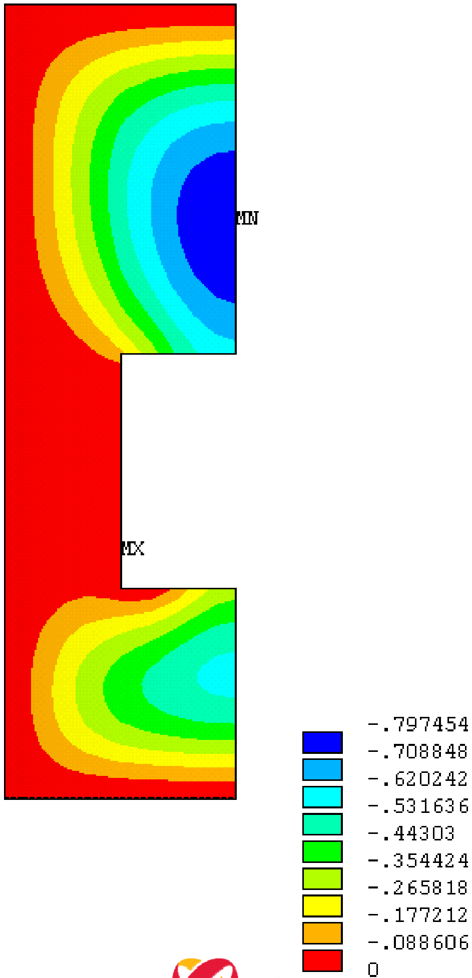
NDE Measurements (figure not to scale)



Calculated Gap Status behind Delamination



Calculated Displacements



REPAIR APPROACH

Repair Attributes

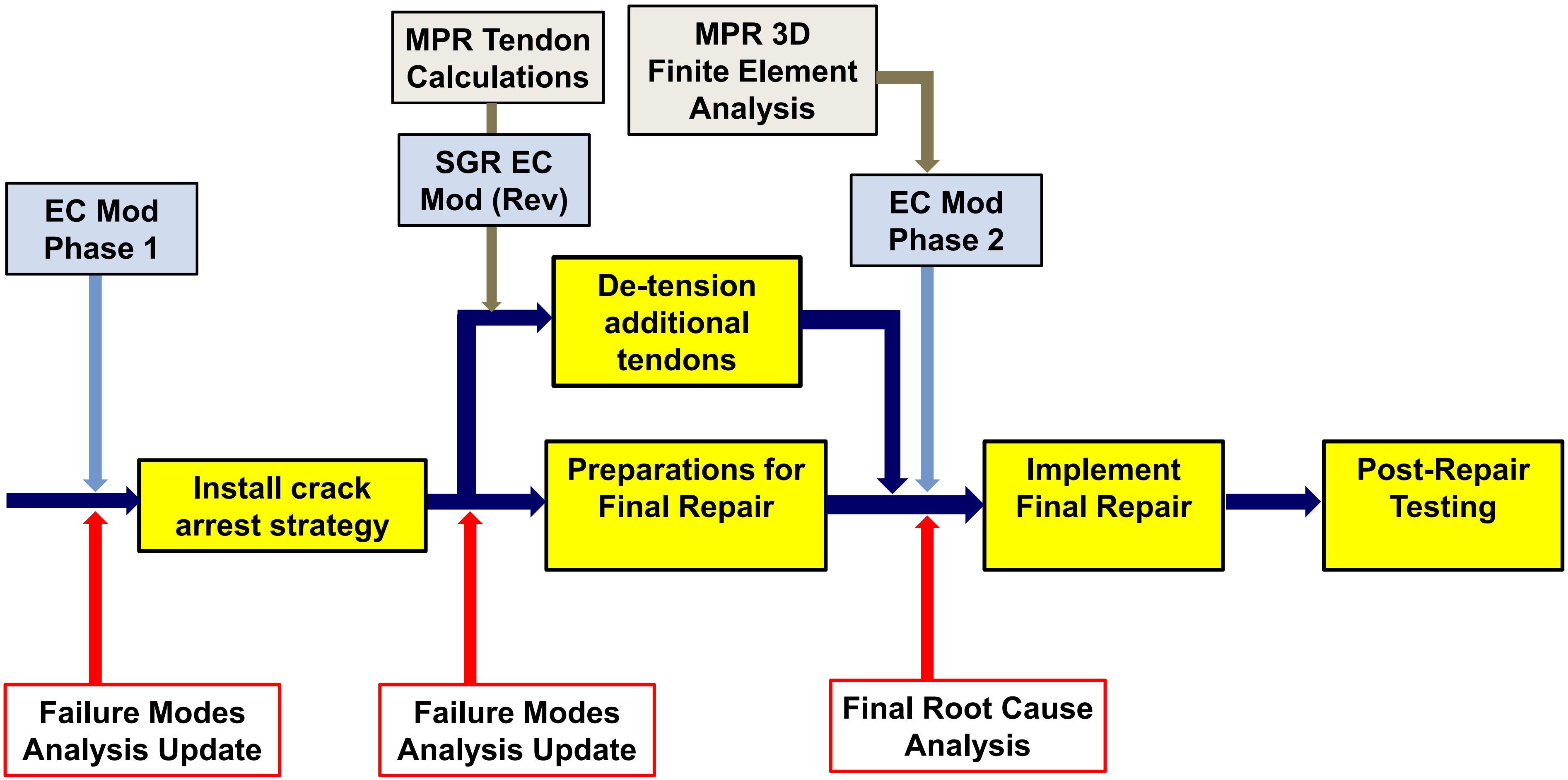
- Incorporates and is compatible with Root Cause Analysis findings
- Restores applicable design basis margins
- Incorporates Extended Life
  - Long Term Surveillance and/or Maintenance Requirements
  - License Renewal
- Constructability

Repair Alternatives Considered

- **Use-as-Is** - *Rejected*
- **Anchorage Only** - *Rejected*
- **Cementitious Grout** - *Rejected*
- **Epoxy Resin** - *Rejected*
- **Delamination Removal and Replacement** - *Selected*

Simplified Overview of Engineering & Repair Work Flow

Tentative – Subject to RCA and DBA Results



Post- Repair Testing

Tentative – Subject to RCA Results

- Approach - ILRT and System Pressure Test
- ASME Section XI IWE for the liner and IWL for the concrete
- Concrete exterior will be visually examined prior to pressurization and following de-pressurization
- Evaluating other additional instrumentation based on the final repair that is implemented, and as driven by:
  - Root cause analysis
- NDE will be required for restored liner plate

Stakeholder Interactions

- Prompt Notification of Regulator & Industry
- Engagement of Critical Industry Organizations
  - Nuclear Energy Institute (NEI)
    - Including Nuclear Safety Information Advisory Council (NSIAC)
  - Institute for Nuclear Power Operations (INPO)
  - Electric Power Research Institute (EPRI)
- Continued Transparency with Regulator
  - Special Inspection Team (SIT)
  - Region and NRR/RES technical discussions
- Periodic Updates with U.S. Licensees

Summary & Questions

Questions

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