Crystal River Unit #3

Presentation to PNSC Containment Update & Discussion of Repair Options

November 16th 2009
Presented by Garry Miller

Progress Energy

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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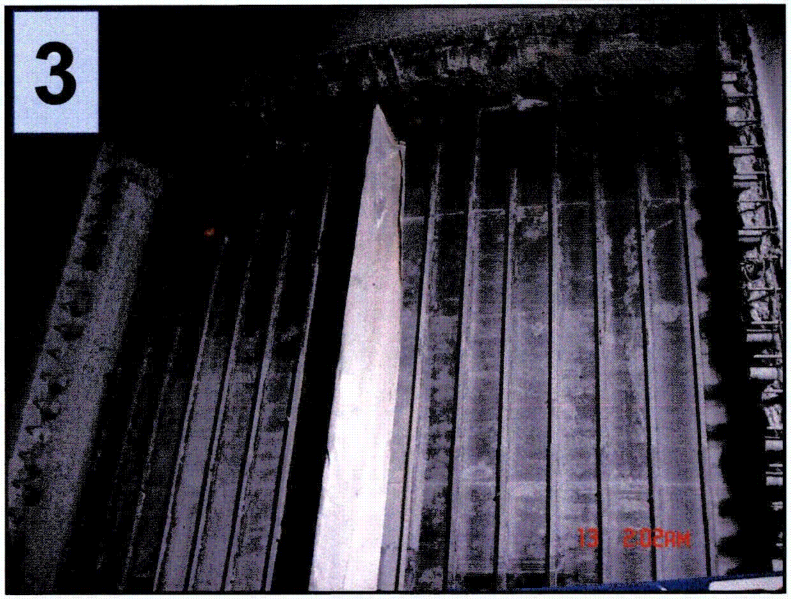
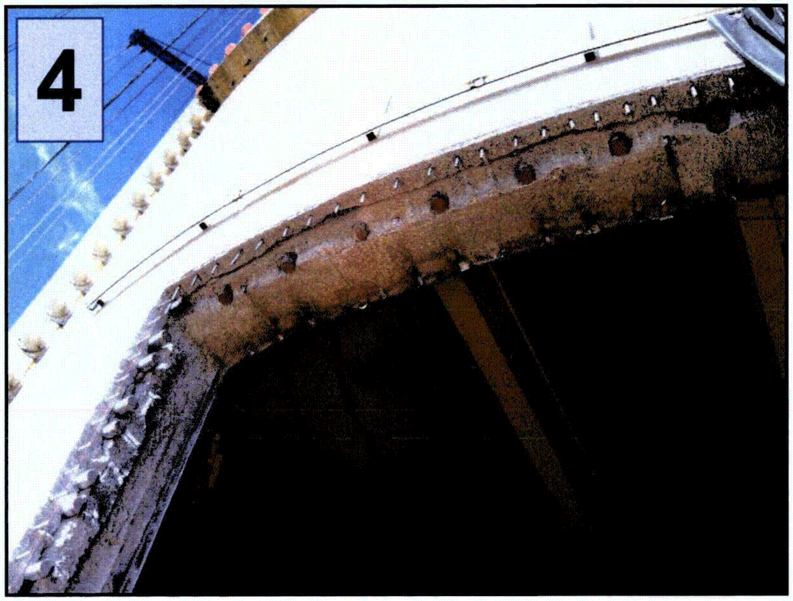
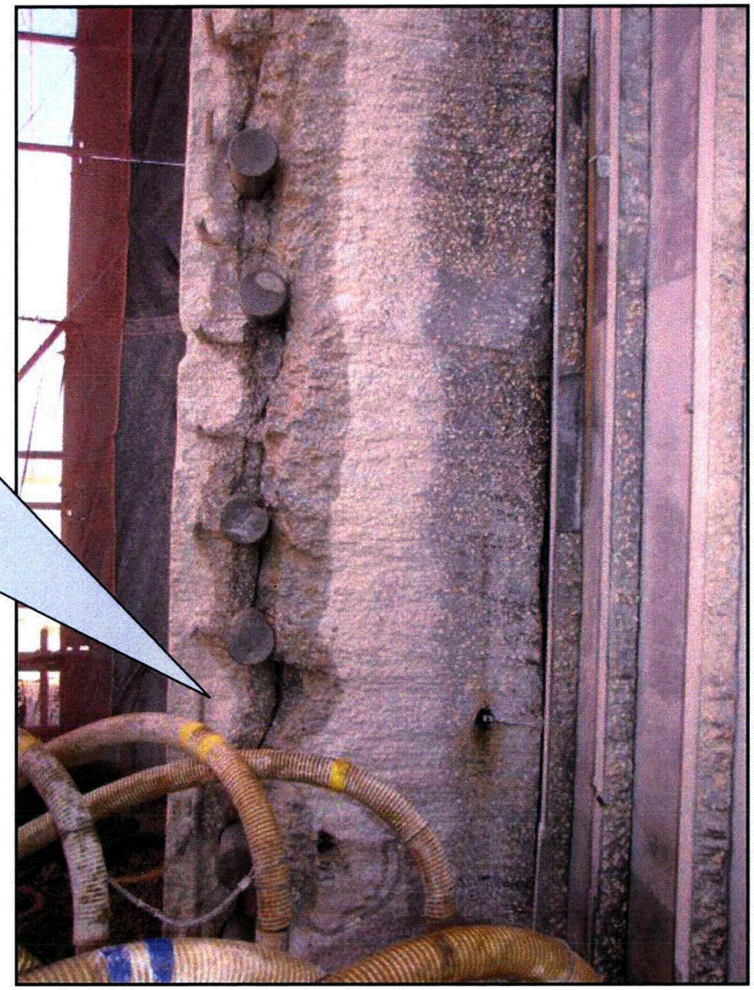
Hydro-Demolition & Liner Removal Sequence





Delamination Close-up



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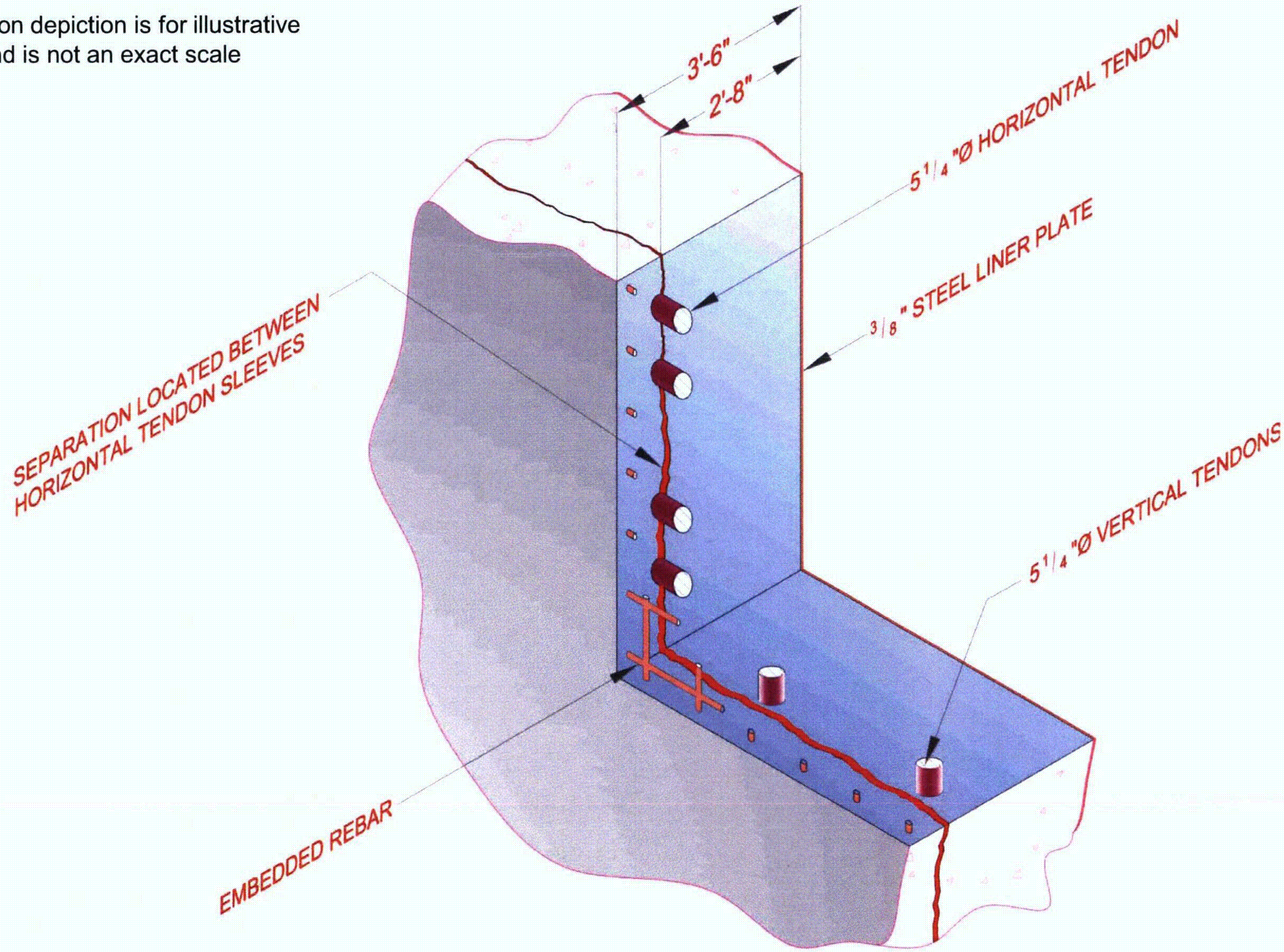
Location of the Delamination

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



Condition Assessment Techniques
Completed or Planned

- Impulse Response (IR) Scanning of Containment Wall Surfaces
  - Comprehensive on external exposed surfaces
  - Representative sampling inside buildings
- Core bores
  - Use to cross-check IR results
  - Includes visual inspection/documentation of surface inside the bored hole
- IWL visual inspection of containment external surface (affected areas)
- Dome Inspections
  - IR scans in selected area
  - Core bore samples in repaired and non-repaired areas
  - Physical survey (compared to 1976 results)

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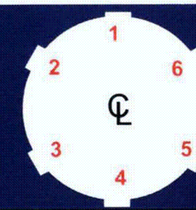
Containment "Unfolded" – Buttress 2 to 5

Updated Nov 16th, Mosaic IR Overlay scale is approximate



IR scans completed per PT-407T:

Blue = no delamination

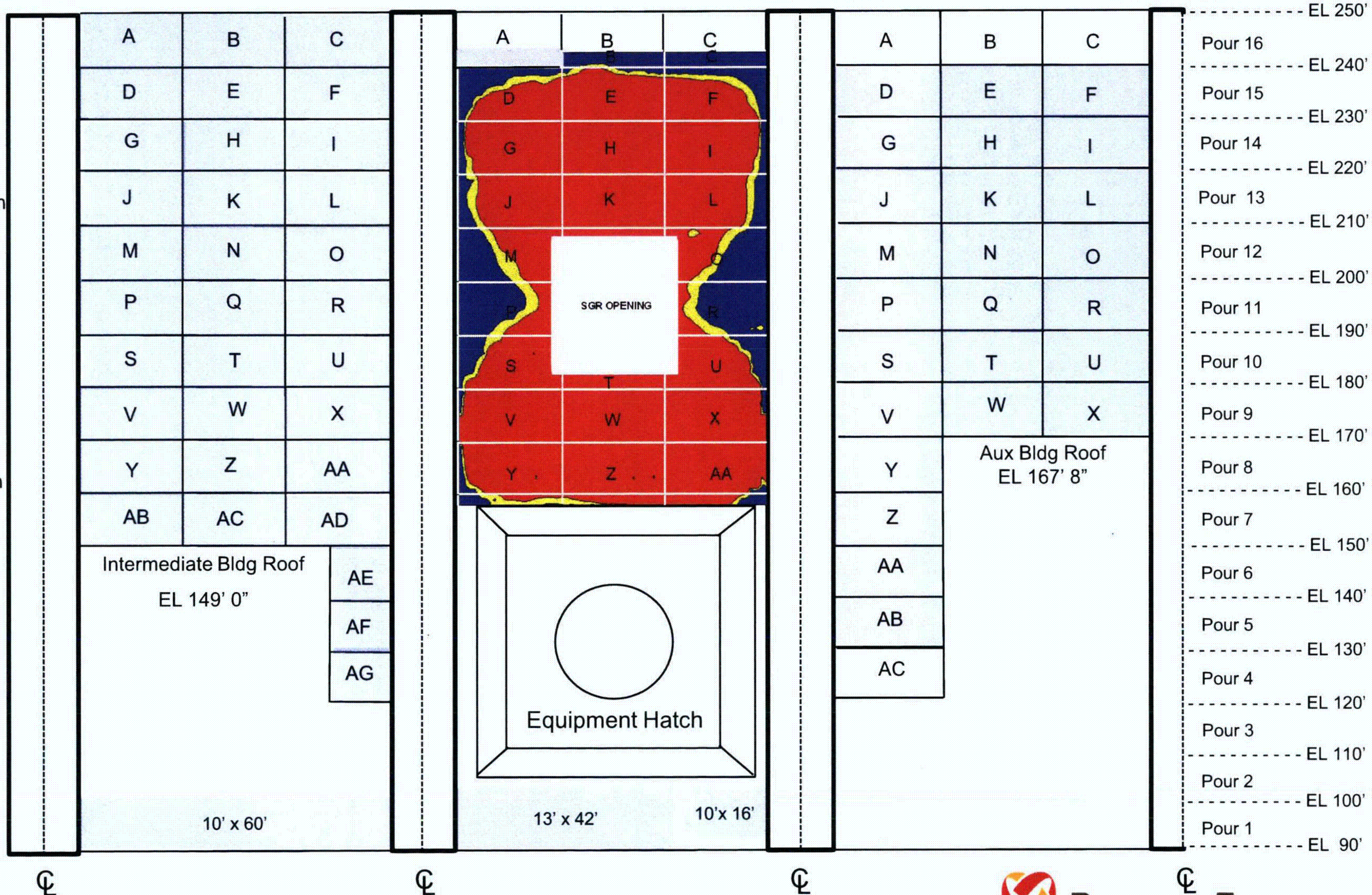
Actual IR scan output data:

Blue = no delamination

Yellow= transition

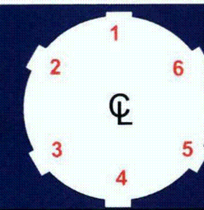
Red = delaminated

Drawing scale is not exact



Containment "Unfolded" – Buttress 5 to 2

Updated Nov 16th 2009



IR scans completed per PT 407T:

Blue = no delamination

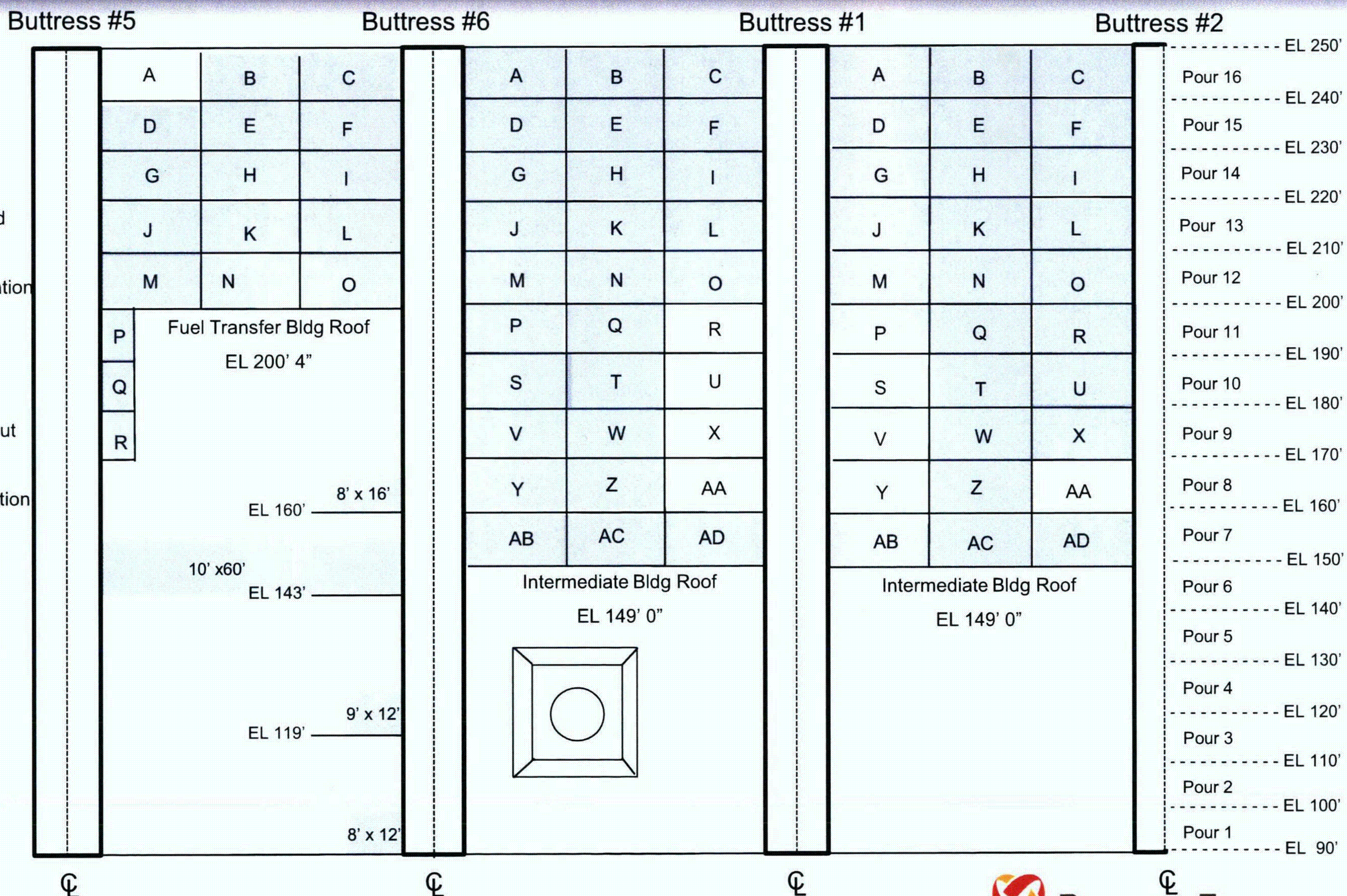
Actual IR scan output data:

Blue = no delamination

Yellow= transition

Red = delaminated

Drawing scale is not exact



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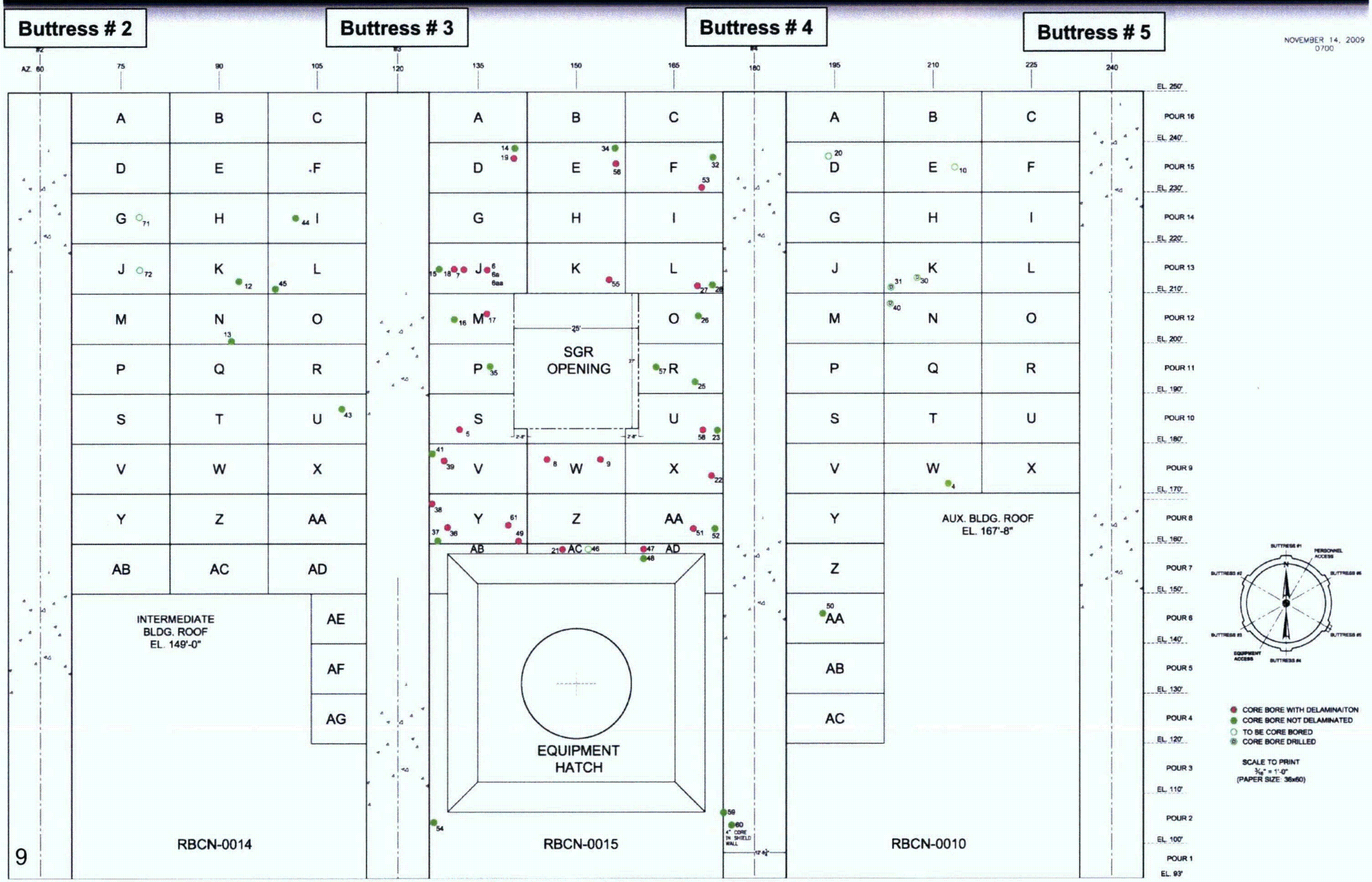
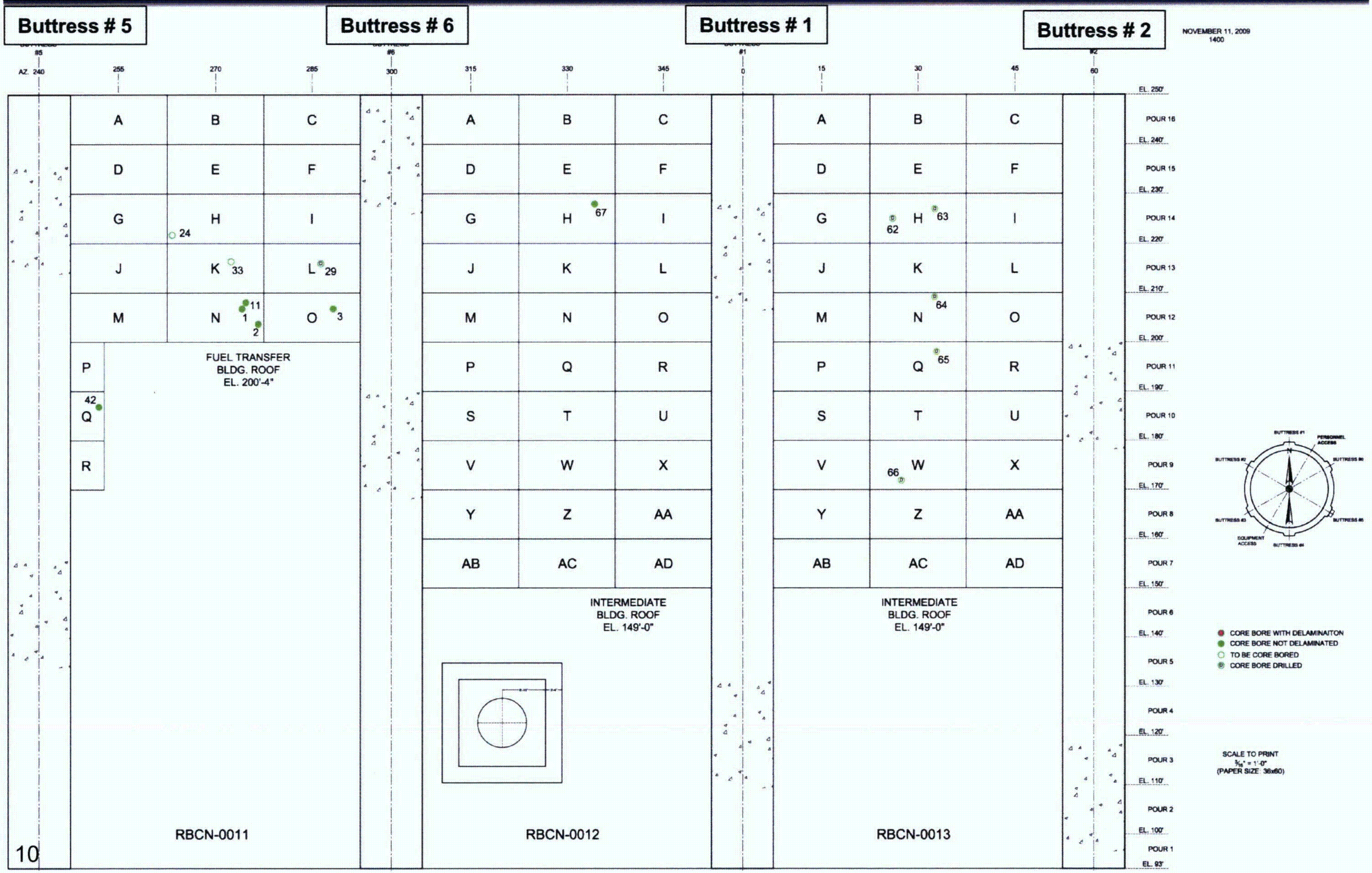
Core Bores

Buttress spans 2- 3- 4- 5 (as of Nov 14th 2009)

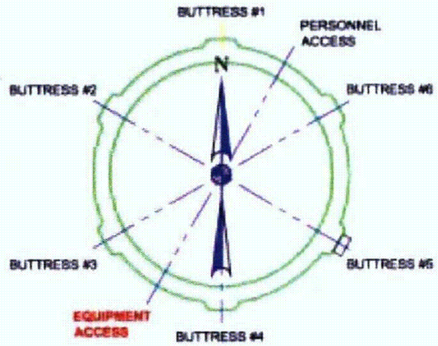


Core Bores

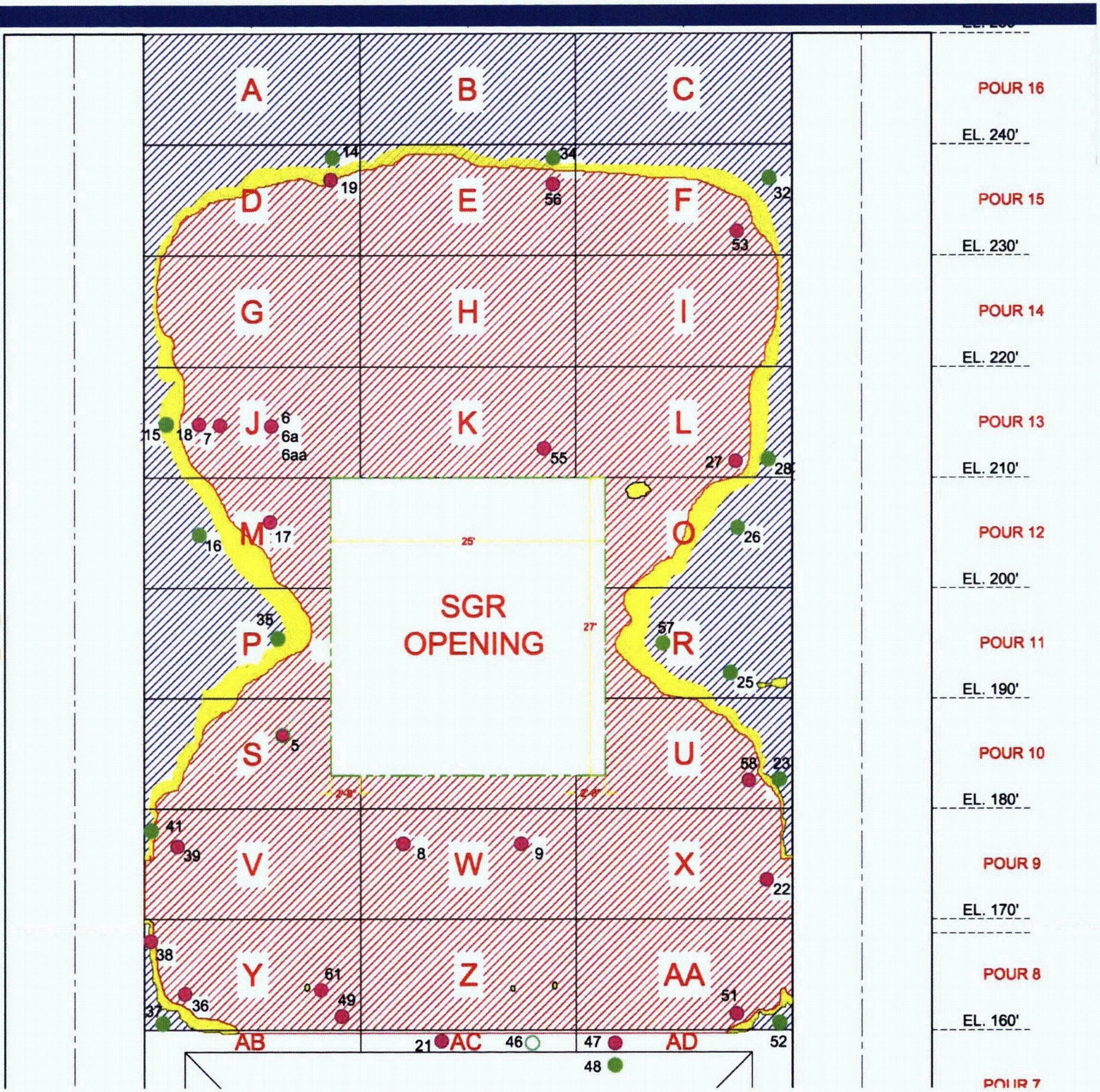
Buttress Spans 5 - 6 - 1 – 2 (as of Nov 14th 2009)



Core Borings



- CORE BORE WITH DELAMINAT
- CORE BORE NOT DELAMINATI
- TO BE CORE BORED
- CORE BORE DRILLED



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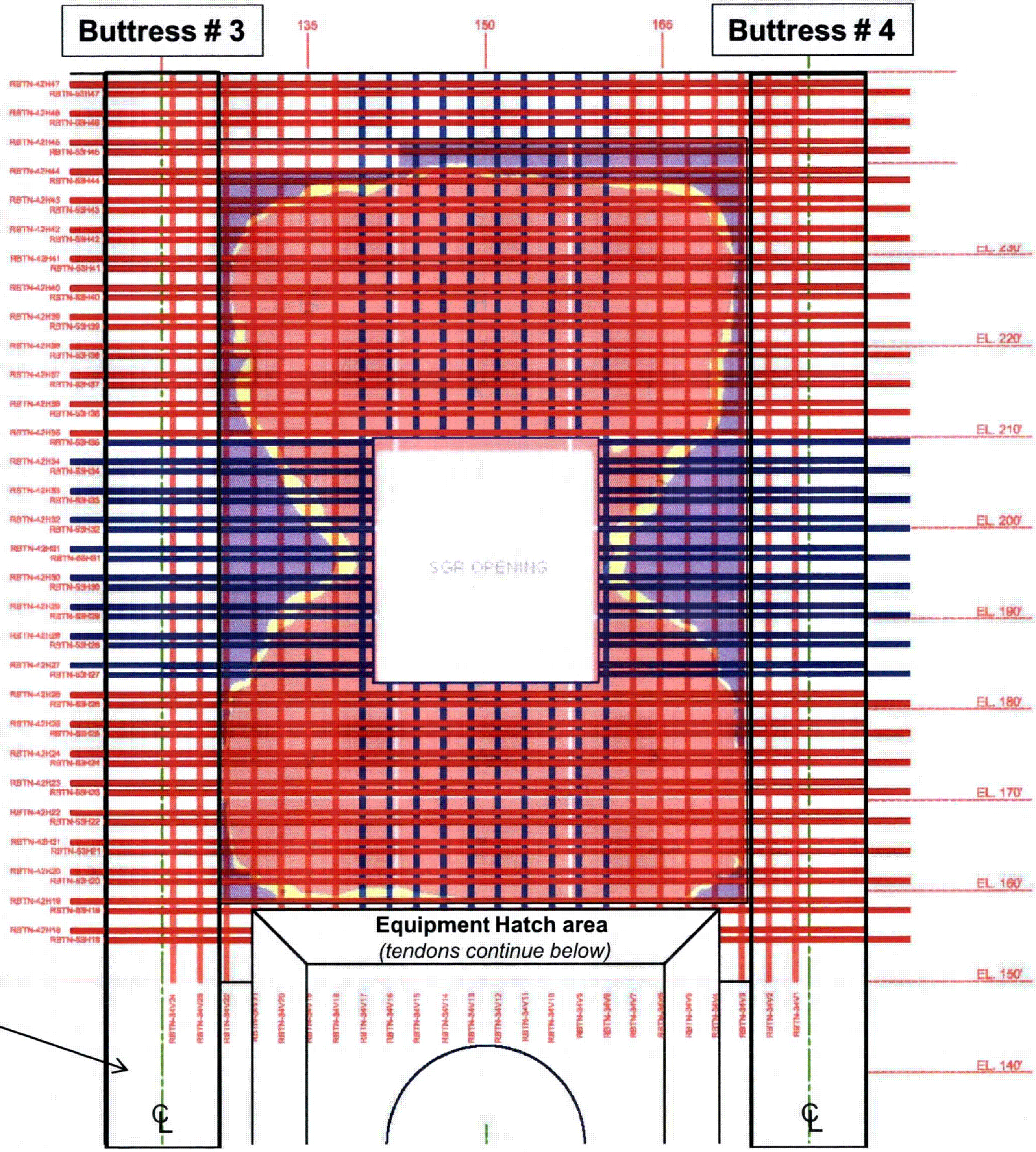
Tendon Pattern

Tendon Pattern at time of cutting SGR Opening

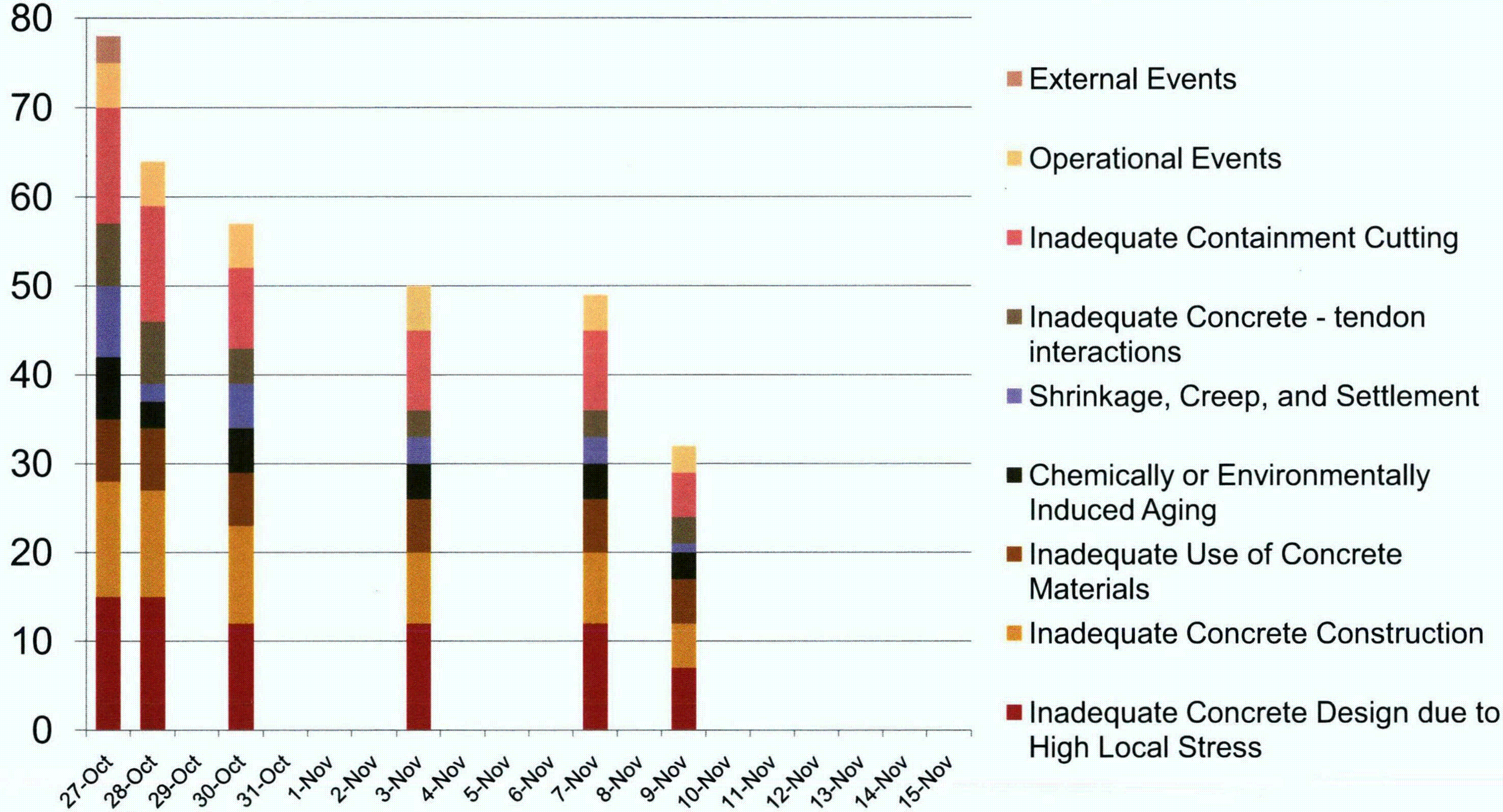
- Energized Tendon
- Removed Tendon



Buttress (typical)

Root Cause Analysis – PII Metrics

Un-refuted Failure Modes as of Nov 9th 2009



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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 ID measurements
- Strain gauge measurements
- Linear variable displacement transducer (LVDT) gap monitoring
- Building Natural Frequency

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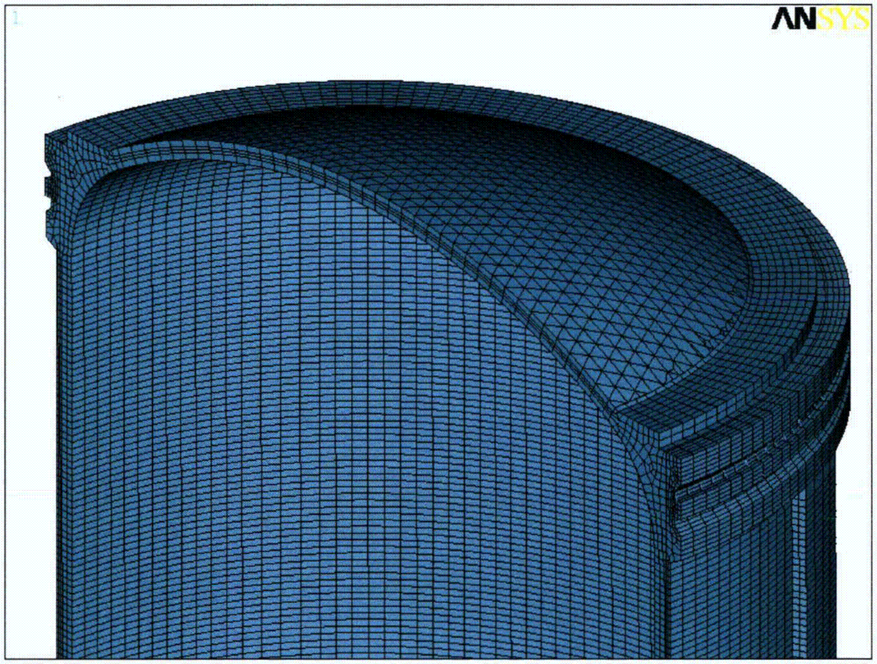
Root Cause Analysis
Field Data Acquisition (continued)

- 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

DESIGN BASIS ANALYSIS



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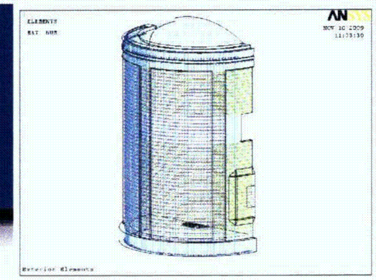
MPR 3D FE Model
Model Features



- **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
- **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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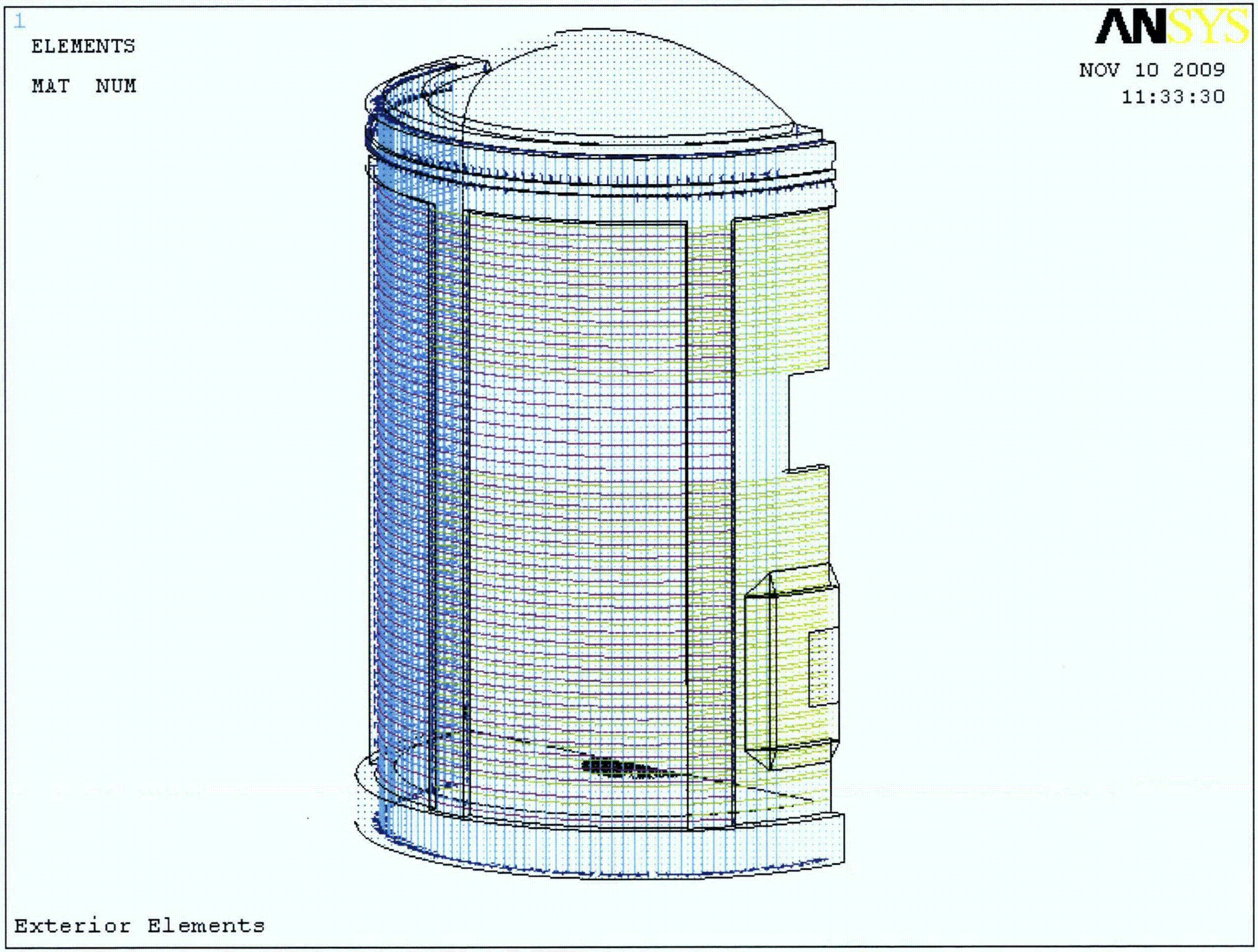
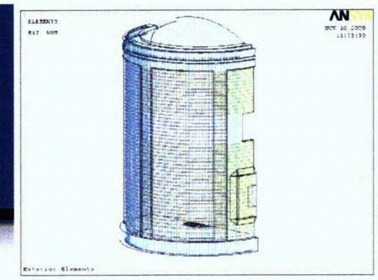
MPR 3D FE Model
Model Features (continued)



MPR 3D FE Model
Load Cases



- 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 (-2.5 psig)

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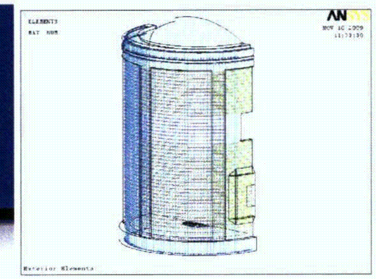
MPR 3D FE Model
Specific Analysis to be Performed



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

- **Planned Analysis Sequence**
  - 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) Root cause must confirm delamination timing
(2) Sequence of replacing SGR concrete plug or repair may be adjusted

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Repair Attributes

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

Repair Alternatives Considered

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

Repair Alternatives
"Use-as-Is" and "Anchorage Only"

- **Use as Is -** *Rejected*
  - Degraded safety related structure
  - Design margins are reduced
- **Anchorage Only-** *Rejected*
  - Containment and delaminated layer will not structurally perform as monolithic shell
    - Would function as two independent shells pinned together
  - Detensioning is not expected to close the delamination gap (greater than 2" in some places)
    - Would require some competent fill material be added
  - Anchorage plate washers (acting to distribute the load) would have minimal separation creating difficulty in the field
    - Tendons are not always equally spaced
    - Rebar mat interference at targeted anchorage locations

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Repair Alternatives
"Cementitious Grout"

- **Cementitious Grout** - *Rejected*
  - Will not be able to penetrate all of the fissures observed along the delaminated surface
    - Creates un-repaired weak planes, affecting tensile capacity
  - Multi-fissure segmented cracking and dislodgement could block adjacent areas from being filled
  - Mock-up testing to simulate all of the in-situ conditions is problematic
    - Examples - Cleanliness of surfaces, parallel fissures
    - Would likely require in-situ testing that would be difficult to control in the field

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Repair Alternatives
"Cementitious Grout"

- **Cementitious Grout** – *Rejected (continued)*
  - Mock-up test needed to validate tendon duct integrity (leak tightness against grouting injection)
    - Test may indicate leak tightness is not assured
  - Requires anchorage to resist grout injection pressures(≥20 psig), and this has all of the same difficulties as detailed in the "Anchorage Only" repair
    - This anchorage system limits access to effectively perform IR scans to ensure complete grout coverage
  - Physical properties of grout would require detailed evaluation and/or verification to prior to use
    - Many grouts are blended for geotechnical applications
    - Tensile strength of typical grouts is significantly lower than epoxy resins

Repair Alternatives
"Epoxy Resin"

- **Epoxy Resins** - *Rejected*
  - Not viable in gaps greater than ¼" due to exothermic reaction
    - Delamination gaps are well beyond this limit, including > 2" in some locations
  - May not be able to penetrate all of the fissures observed along the delaminated surface
    - Creates un-repaired weak planes, affecting tensile capacity
  - Raising the injection pressure to improve penetration in fissures
    - Anchorage becomes more difficult
    - Tendon conduit integrity becomes more difficult
  - Mock-up test needed to validate tendon duct integrity (leak tightness against epoxy injection)
    - Test may indicate leak tightness is not assured

Repair Alternatives
"Epoxy Resin"

- **Epoxy Resins** – *Rejected (continued)*
  - Mock-up testing to simulate all of the in-situ conditions is problematic
    - Examples - Cleanliness of surfaces, parallel fissures
    - Would likely require in-situ testing that would be difficult to control
  - Requires anchorage to resist epoxy injection pressures (8 to 20 psig), and this has all of the same difficulties as detailed in the "Anchorage Only" repair
    - This anchorage system limits access to effectively perform IR scans to ensure complete coverage

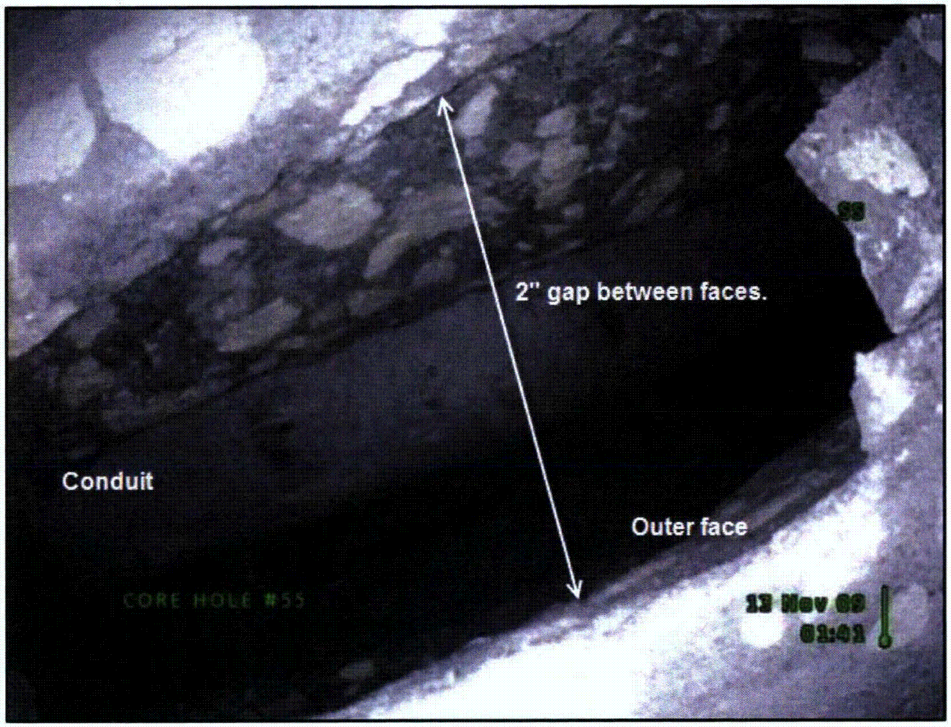
Repair Alternatives
Repair and Replacement

- **Delamination Removal and Replacement** – *Selected*
  - Delamination Removal Challenges
    - Safe removal of delaminated concrete at elevated heights
    - Avoiding collateral damage to tendon conduits
    - Minimize damage to the remaining substrate to minimize concrete bruising and to provide a favorable bonding surface
    - Requires verification planar fissures are removed
  - Requires new radial reinforcement design (anchored to the substrate)
  - Will require treatment of planar fissures (if encountered) at periphery

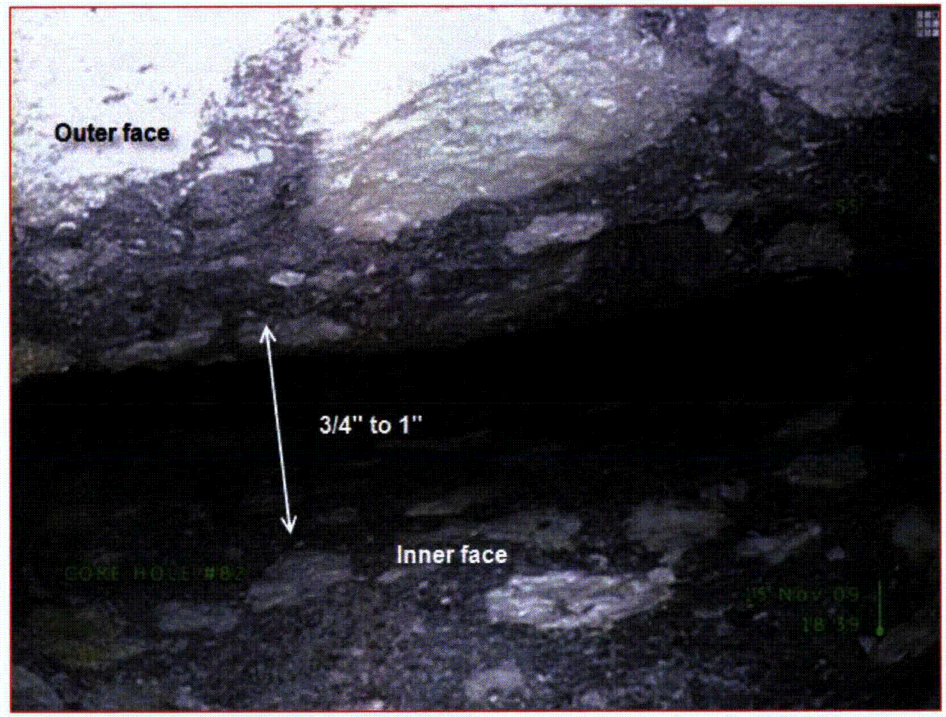
Repair Alternatives
Repair and Replacement

- **Repair and Replacement** – *Selected (continued)*
  - Need to secure and verify same constituents to use the existing qualified design concrete mix (for the SGR Opening)
  - Concrete Placement
    - Needs to construct ganged forms for placing the pours
    - Need to determine method to anchor the forms
    - Elevations create work execution challenge

Boroscopic Photos
Delamination Gap Dimensions



Buttress 3-4, Cell K, Core #55



Buttress 3-4, Cell H, Core #82

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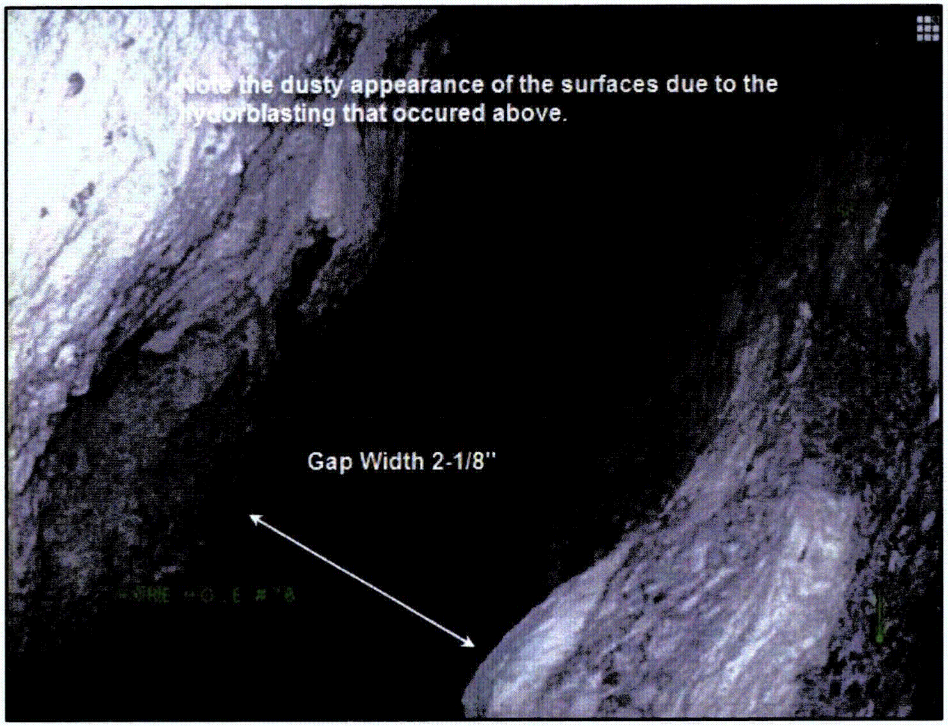
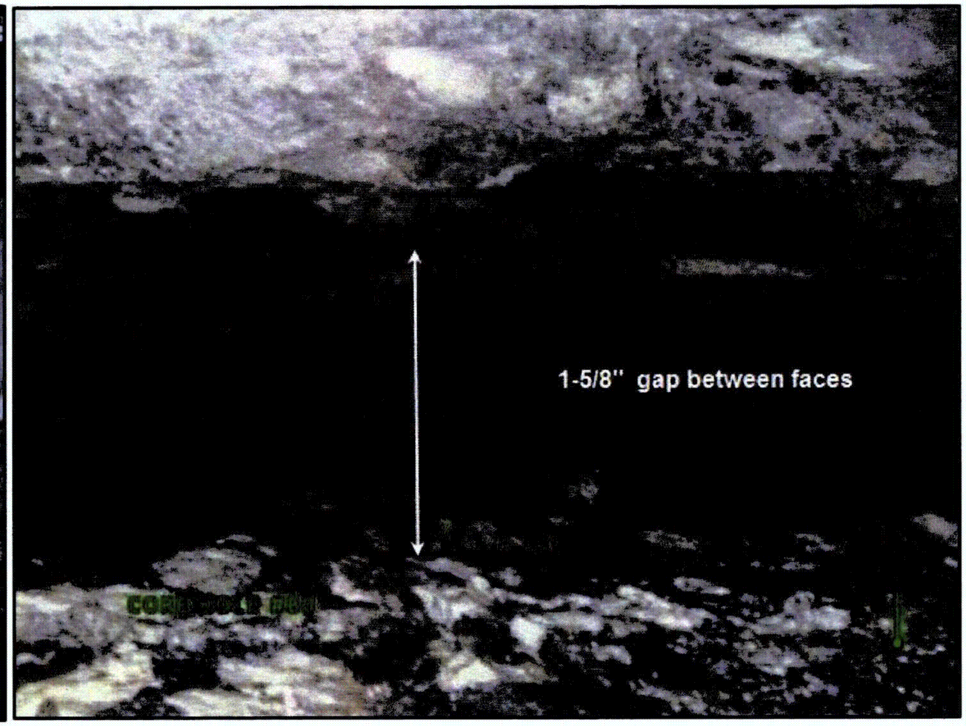
Boroscopic Photos
Delamination Gap Dimensions



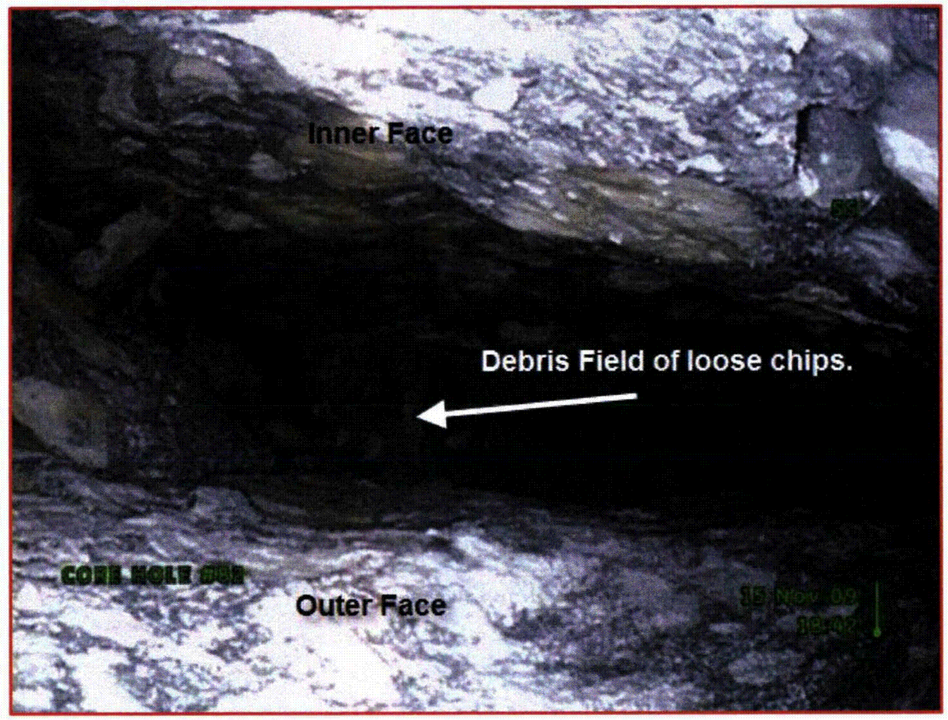
Buttress 3-4, Cell Z, Core #78



Buttress 3-4, Cell X, Core # 80

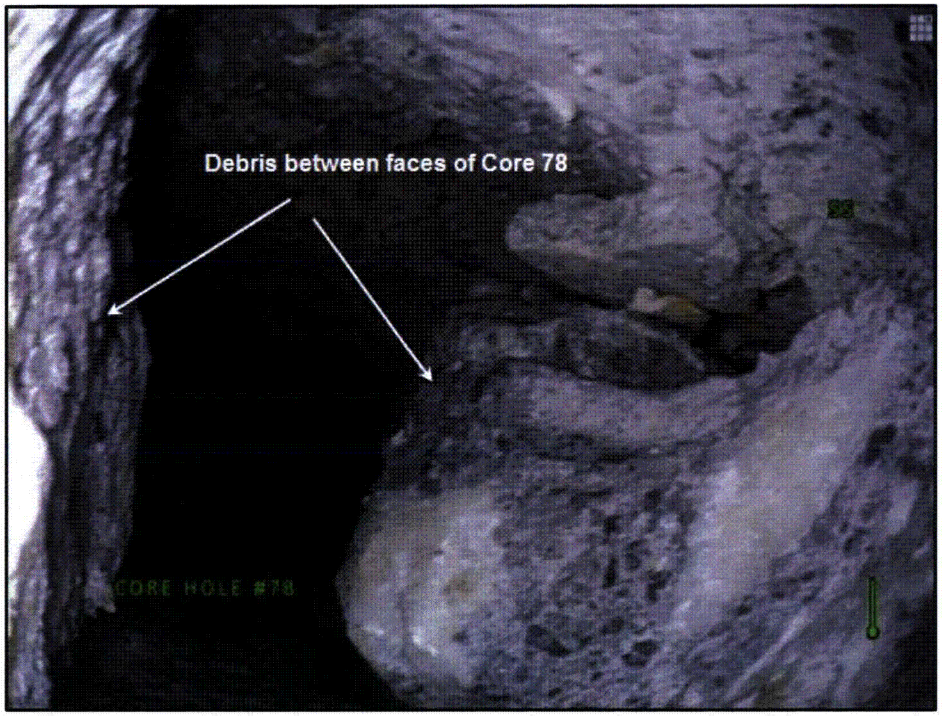
Boroscopic Photos
Debris in the Delamination Gap

Buttress 3-4, Cell H, Core #81

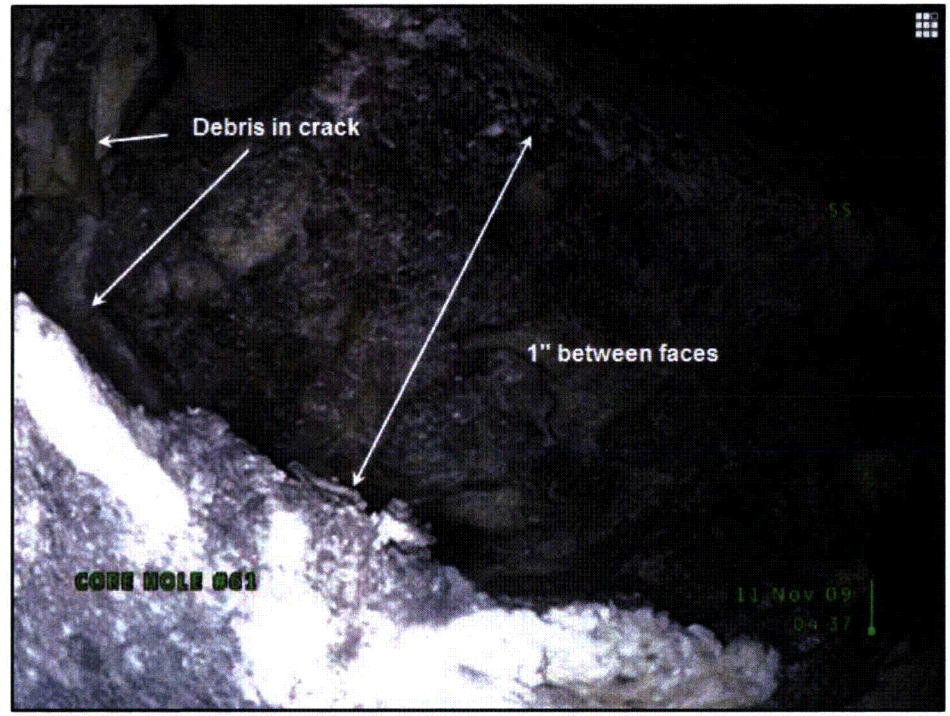


Buttress 3-4, Cell H, Core #82

Boroscopic Photos
Debris in the Delamination Gap



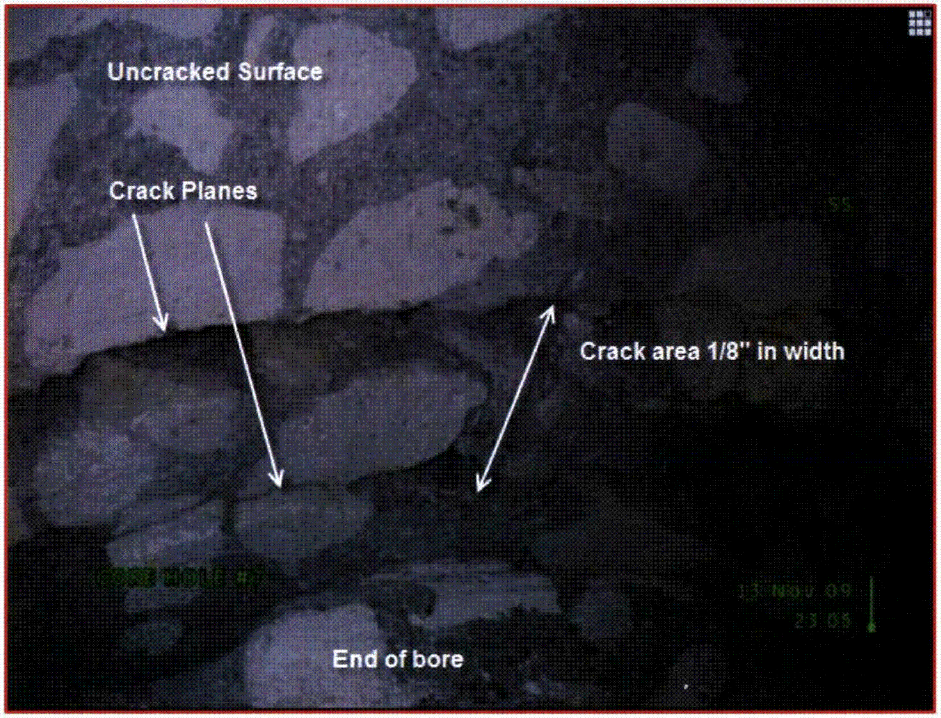
Buttress 3-4, Cell Z, Core # 78



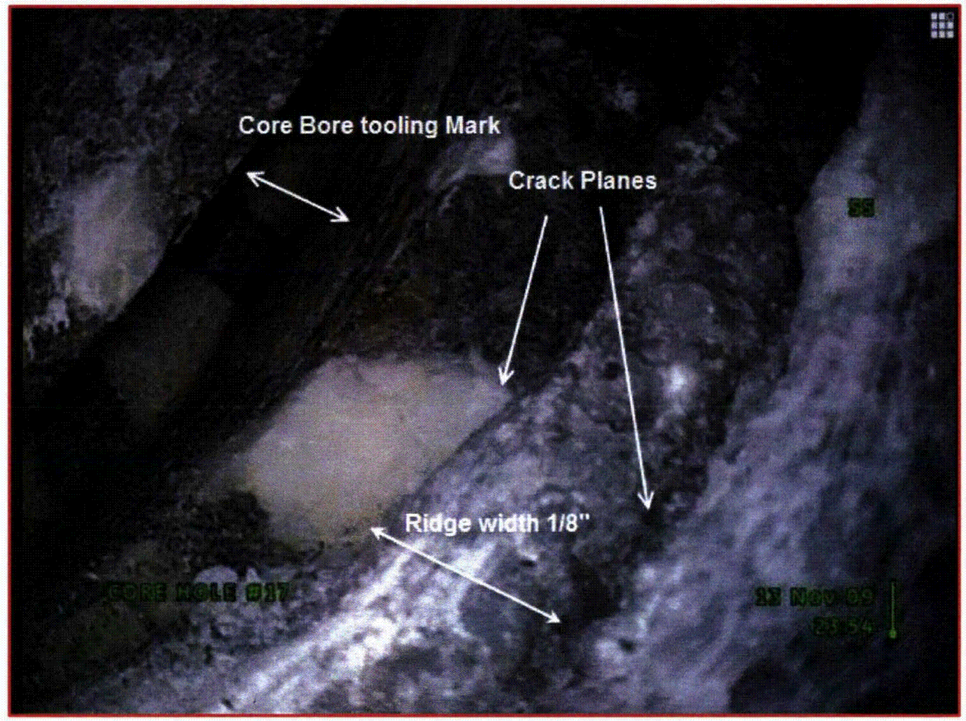
Buttress 3-4, Cell Y, Core # 61

Boroscopic Photos

Fissures in the Delamination Gap

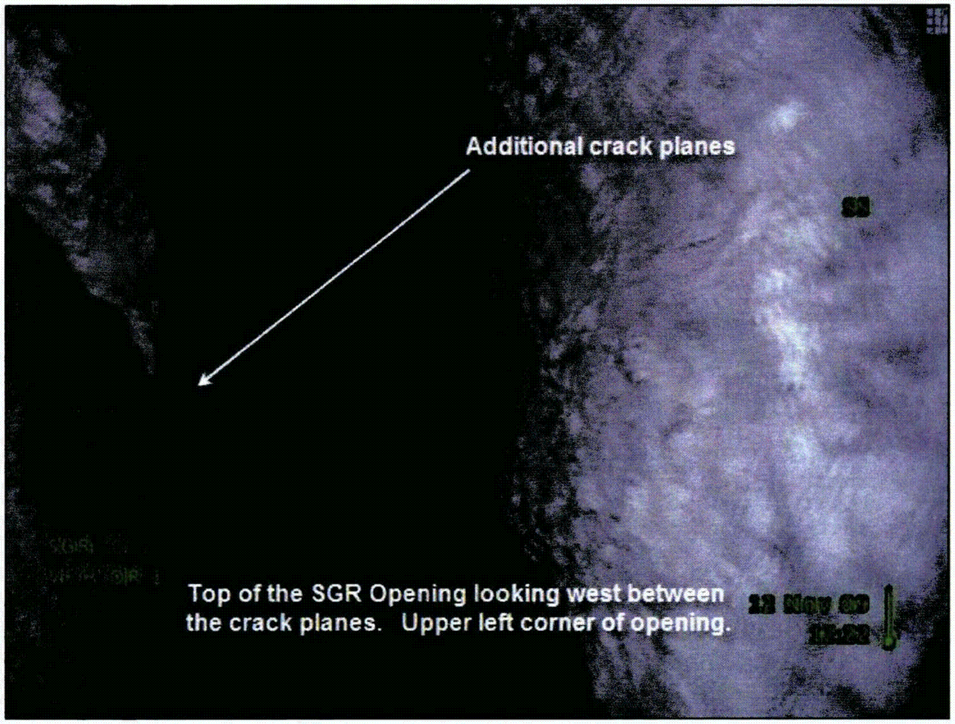


Buttress 3-4, Cell J, Core #7

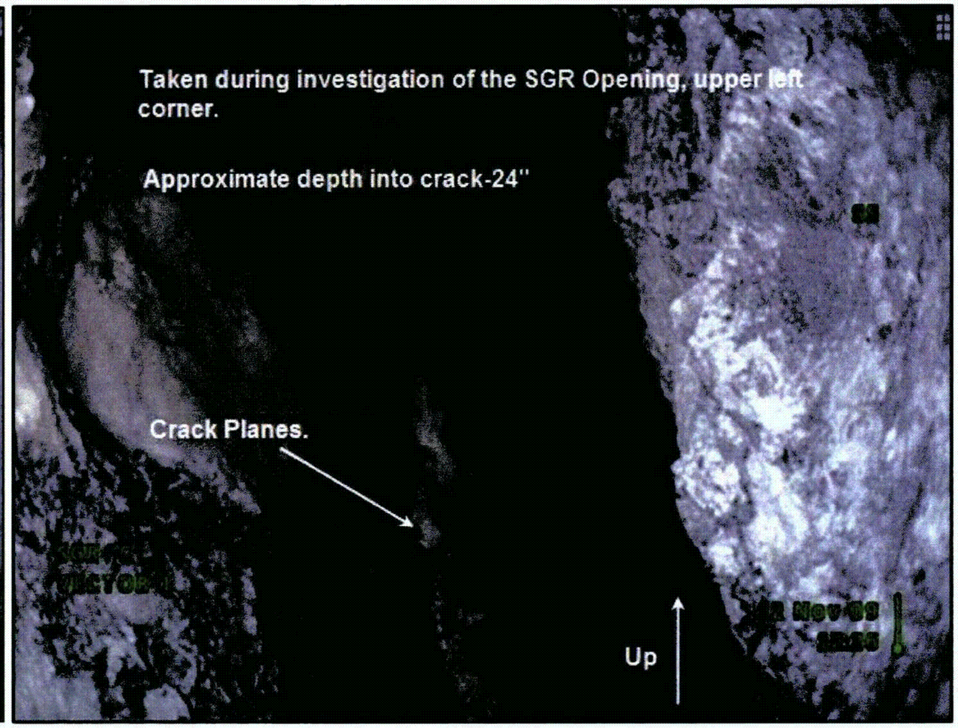


Buttress 3-4, Cell M, Core #17

Boroscopic Photos
Fissures in the Delamination Gap



Buttress 3-4, Top of SGR Opening
Upper Left Corner, Looking West



Buttress 3-4, Top of SGR Opening
Upper Left Corner

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Summary & Questions

Questions

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