SAND • CEMENT

Back to Basics

WATER • AGGREGATE

ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

2024 FALL CONVENTION

DENVER, COLORADO | OCTOBER 22-25, 2024

www.icri.org

Fundamentals of Repair Design – Anchorage in Concrete

PRESENTED BY:

Jeffrey M. Owad, PE, PMP

Luis R. Pelayo, PE, SE

www.icri.org

2024 FALL CONVENTION

OCTOBER 22-25, 2024

Objectives

- Review applicable codes and standards commonly used
- Review specific anchor design limit states and parameters considered
- Demonstrate common application of anchorages in repairs
- Discuss engineering best practices for repair design using anchorage

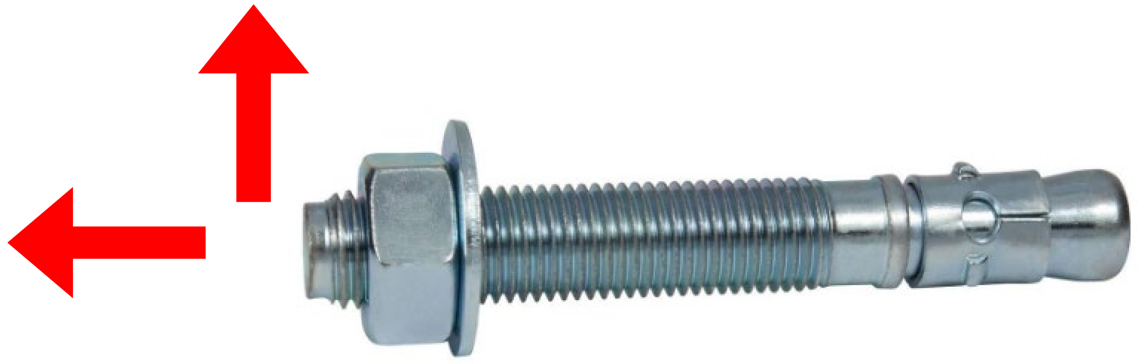
What is an Anchor?

anchor
a metal bolt, stud, threaded rod, or reinforcing steel, either cast in place, grouted in place, or drilled into hardened concrete, used to prevent dislodging of repairs from concrete substrate in the event of a bond failure; to hold various structural members or embedments in the concrete; and to resist shear, tension, and vibration loadings.

- **Anchor** – a steel element either cast into concrete or post-installed into a hardened concrete member and used to transmit applied loads to the concrete.

- **Cast in Anchor** - Headed bolt, headed stud, or hooked bolt installed before placing concrete

- **Post Installed Anchor** - Anchor installed in hardened concrete; adhesive, expansion, screw, and undercut anchors are examples of post installed anchors

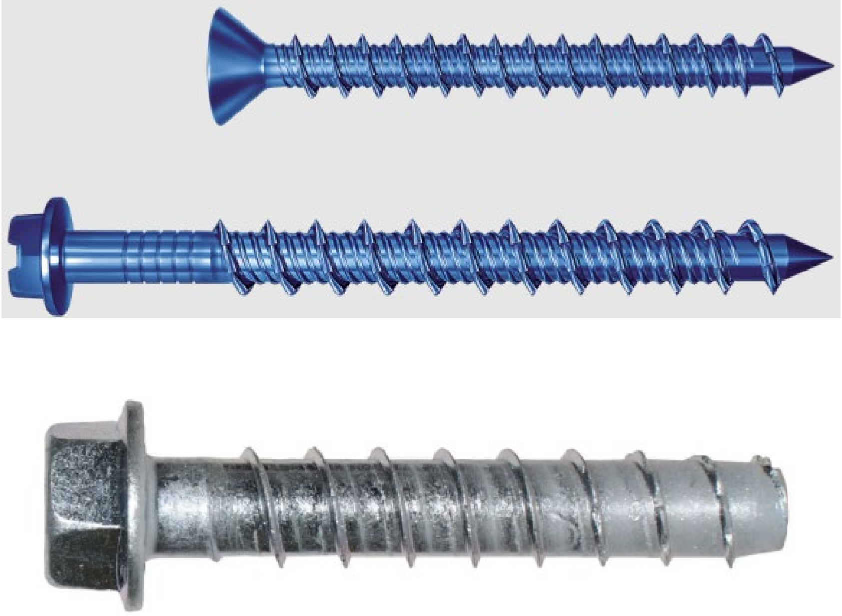


Classification:

- Anchors further classified by mechanism of force transfer:

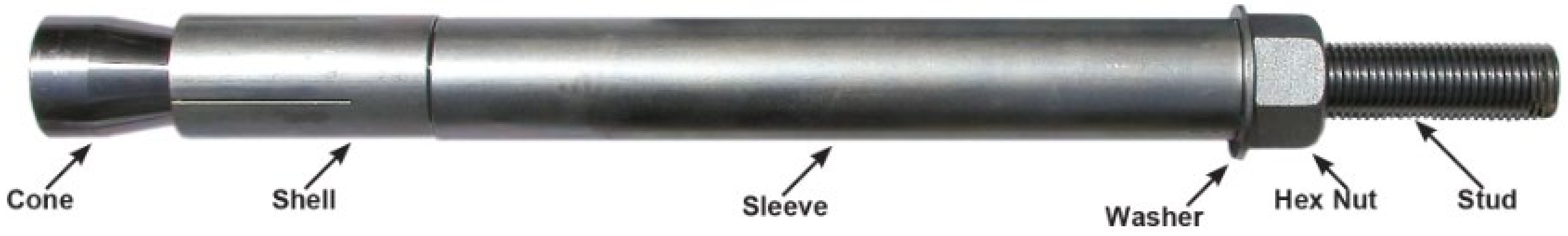
• Expansion Anchors	Friction
• Screw Anchors	Thread Engagement into Grooves
• Undercut Anchor	Mechanical Interlock at End of Anchor
• Headed Stud, Headed Bolt	Mechanical Interlock at End of Anchor
• Adhesive Anchor	Adhesive Bond
• Steel Reinforcement	Adhesive Bond (typical)

Examples:

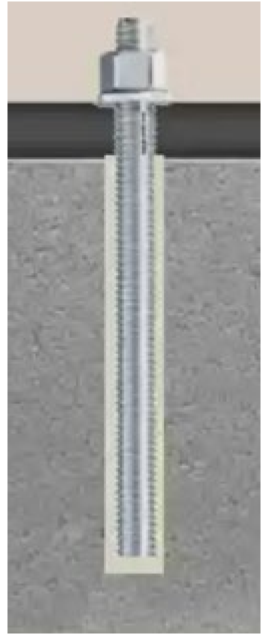


Screw Anchors

Expansion Anchor



Undercut Anchor



Epoxy Anchor

Headed Bolt Anchors

Live Content Slide

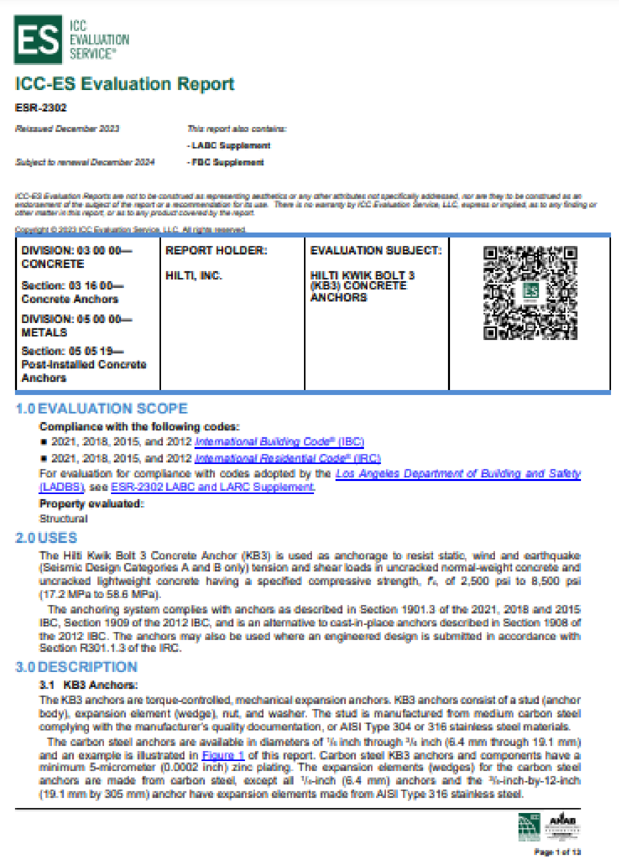
When playing as a slideshow, this slide will display live content

Poll: What type of concrete anchor do you use most often?

ICC-ES Reports:

- Free documents available in addition to published manufacturer data
- Qualification reports with summary of:
  - Code compliance
  - Detailed description of anchor including dimensional data
  - Design data (codes, tables, etc.)
  - Installation instructions
  - Testing qualifications
  - Identification

- ICC-ES Acceptance Criteria:
  - AC 193 (Mechanical Anchors)
  - AC 308 (Adhesive Anchors)
  - <u>Refers back to ACI qualification requirements</u>



CONCRETE REPAIR
Restore | Repurpose | Renew

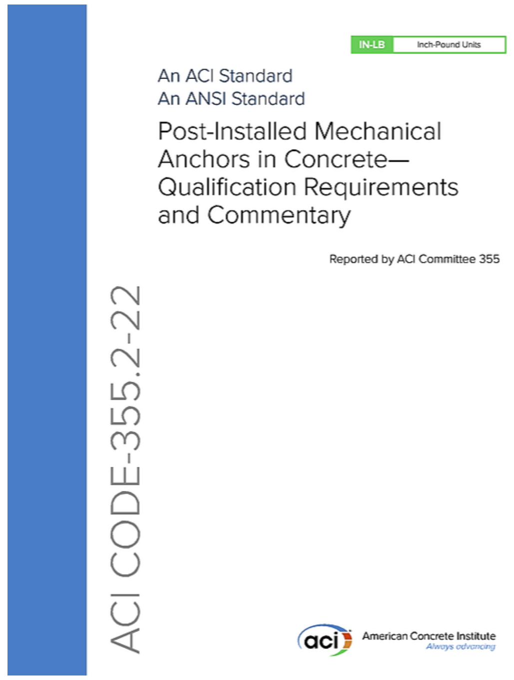
CONCRETE REPAIR
Restore | Repurpose | Renew

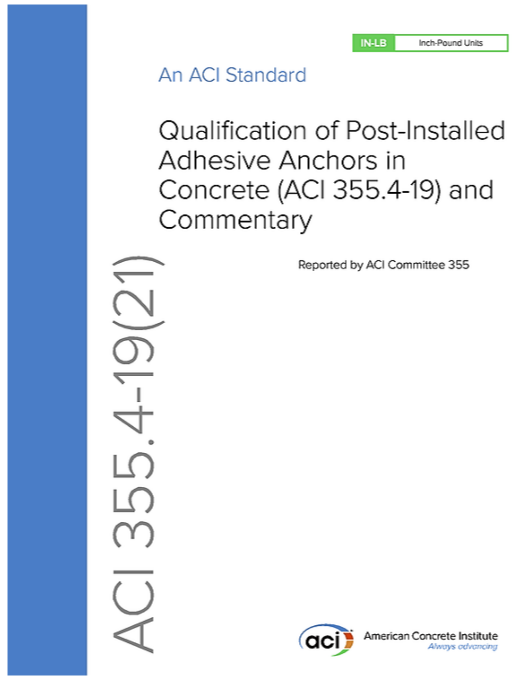
Post-Installed Anchors

- Post Installed anchors are of particular interest for repairs
  - Substantial product catalogs
  - Versatile installation (physical install/timing)
  - Cost effective

- Mechanical Anchors must meet ACI 355.2
  - Pullout failures must have acceptable load-displacement characteristics
  - OR prove pullout is precluded by different failure

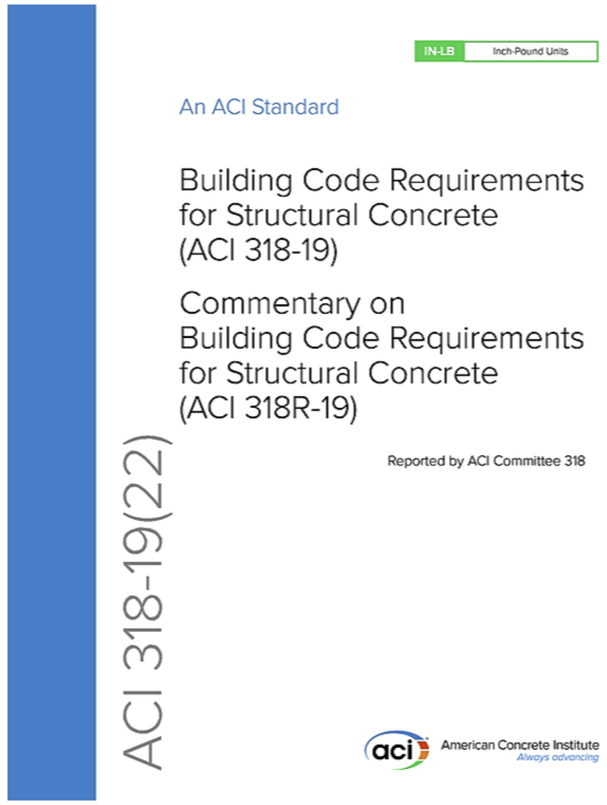
- Adhesive Anchors must meet ACI 355.4
  - Must establish characteristic bond strength
  - Prove suitability for structural use





Design Requirements:

- Design must meet requirements of codes adopted
  - Model codes like International Building Code (IBC, IRC, etc.)
  - Other site specifications
- IBC 1901.3 Anchoring to Concrete
  - references ACI 318 for anchorage design (with amendments)
- ACI 318 – Building Code Requirements for Structural Concrete
  - Requirements within **Chapter 17 – Anchoring to Concrete**
  - ACI 562 – Assessment, Repair, and Rehabilitation of Existing Concrete Structures
  - ASCE Anchorage Design for Petrochemical Facilities



ACI 318

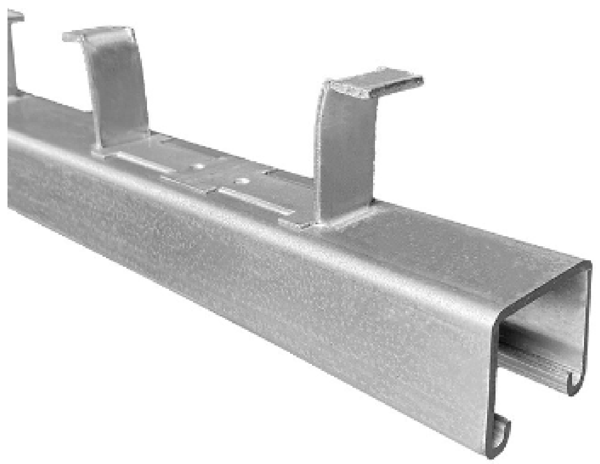
ACI 318 – Scope (17.1.2-17.1.3)

- Covers:
  - Headed Studs, Headed Bolts, & Hooked Bolts
  - Expansion Anchors
  - Undercut Anchors
  - Adhesive Anchors
  - Screw Anchors meeting ACI 355.2
  - Attachments with Shear Lugs

COMMON REPAIR ANCHORS

Excluded/ Not directly addressed:

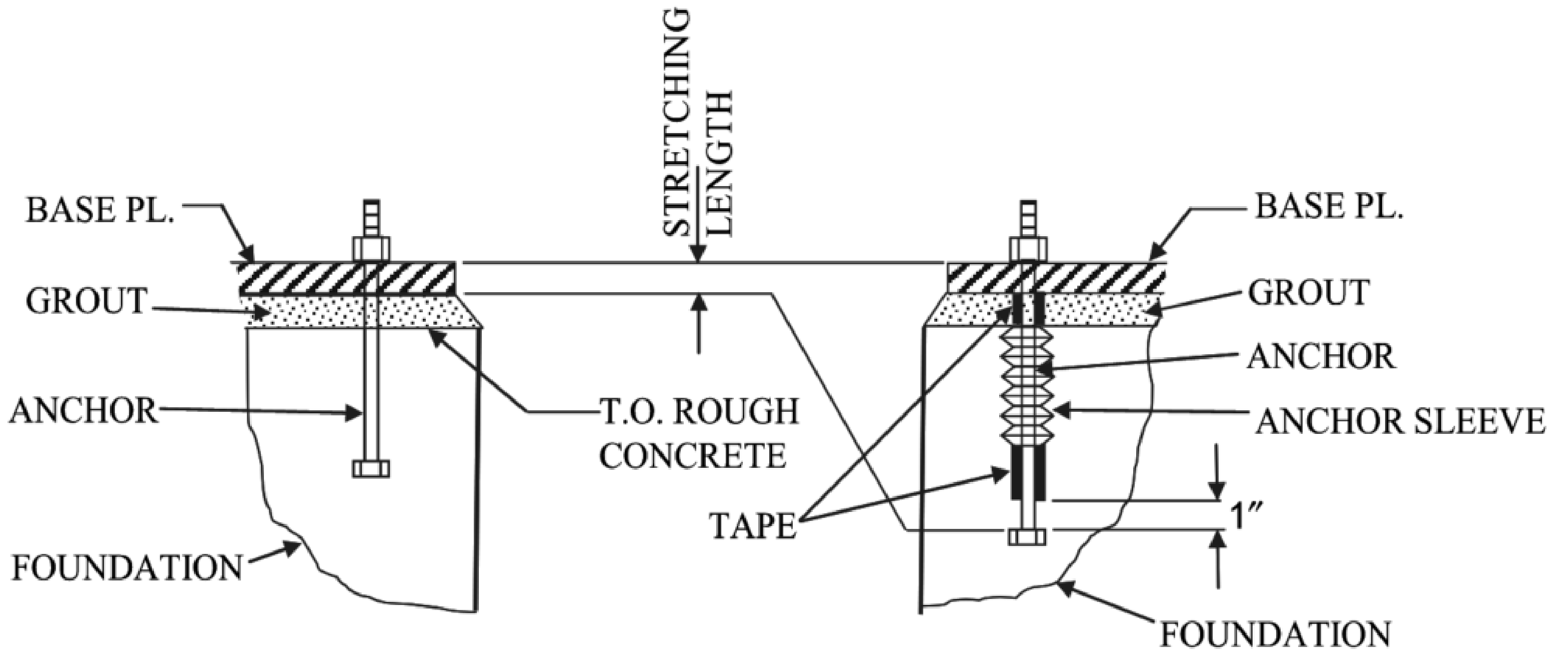
- Specialty inserts (too many types, need testing)
- Through-bolts
- Anchors with plate at embedded end (not recommended)
- Grouted anchors
- Direct anchors (Powder actuated, pneumatic)
- High cycle fatigue or impact related



Tensioned Anchors

ASCE - Anchorage Design for Petrochemical Facilities

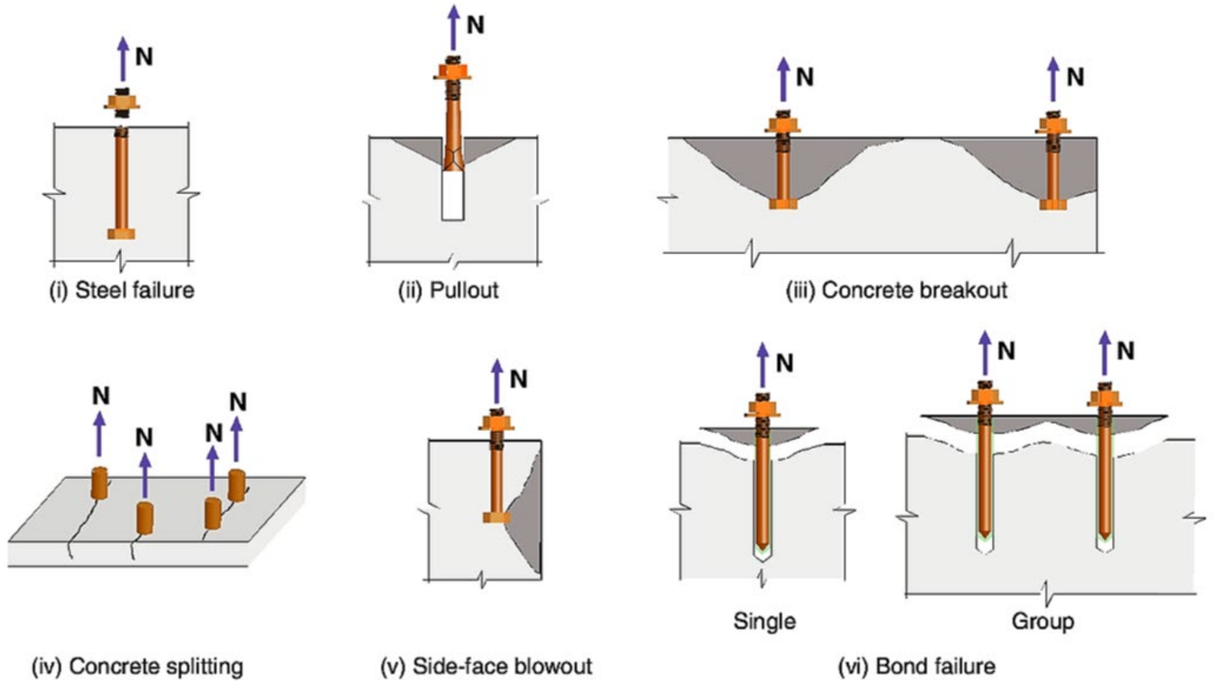
- Typically Cast-In Place
- Anchor tensioned through longitudinal elongation
- Sleeve provided for stretch
- Used with vessels when:
  - Additional frictional resistance is needed
  - Vibrations or deflections need to be reduced
  - Stress reversals need to be reduced
- Challenges:
  - Not covered by codes
  - May be difficult/costly to install
  - Proper tensioning not guaranteed
  - Creep/relaxation over time



NOTE: Stretching Length = That portion of anchor allowed to freely stretch

ACI 318

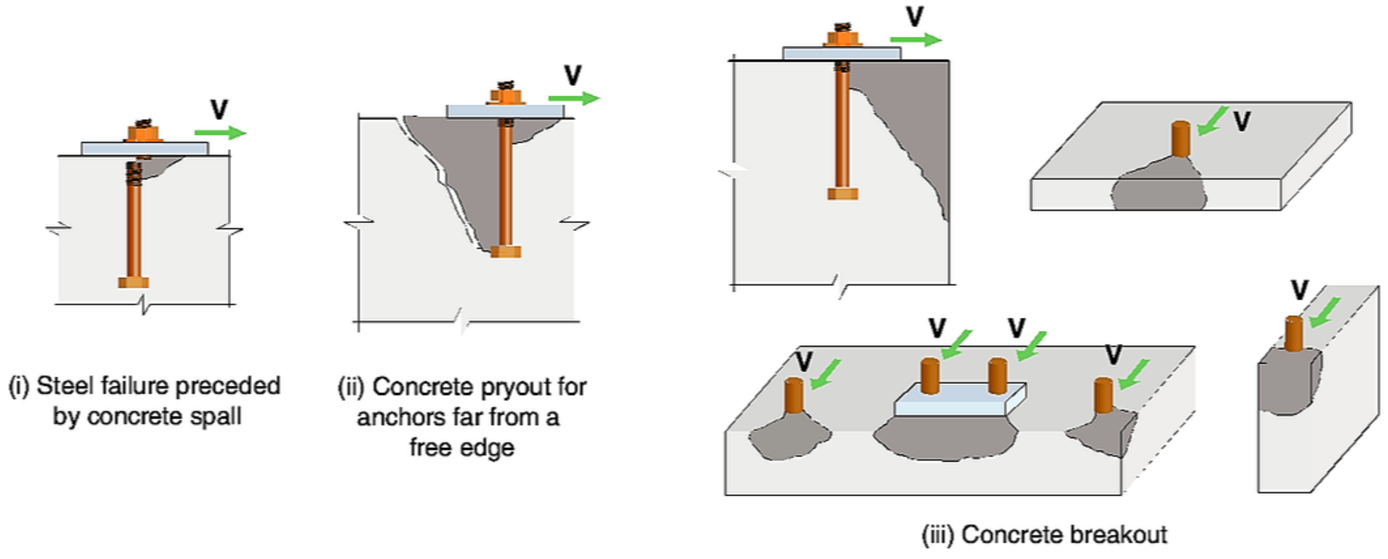
- 17.5 – Design Strength Requirements:
  - Meet min. edge distances, preventing splitting (17.7)
  - Satisfy 17.2.3 for Earthquake Loadings
  - Satisfy 17.3.1.2 for sustained loading
  - Design:
    - Concrete Capacity Design (CCD) Method
    - Testing (Required for some anchors)



(a) Tensile loading

KEY CONCEPTS:

1. **Anchor capacity proportional to volume of concrete engaged by anchors. (edge distance, spacing, bolt heads sizes)**
2. **Concrete substrate is essential to capacity. (compressive strength, weight, cracked/uncracked, reinforcement)**



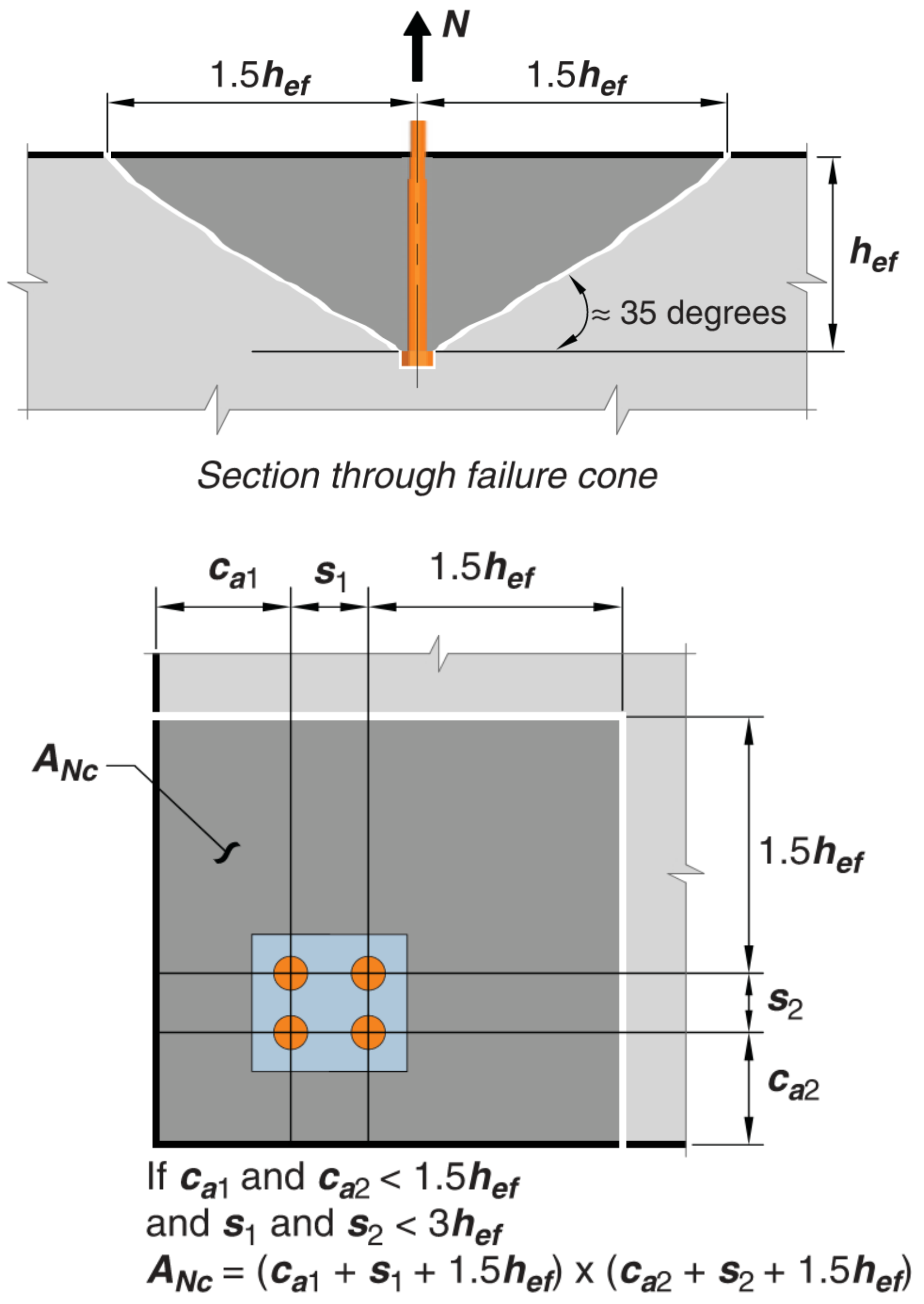
(b) Shear loading

"Can't we just go deeper?"

- Deeper embedment usually means more capacity (more engaged mass)**

Answer: It depends…

- Embedment depth limited by depth of member (ACI 17.9.4)
  - Embedment < max{ 2/3*member depth or depth-4"}
- ** For single anchors not near edges
  - Groups of Anchors – Spacing more important
- Deeper embedments run higher risk of impacting member reinforcement
- Time of installation increases significantly (coring or drilling)
- Deeper embeds most likely use epoxy anchors – higher cost



"What if we add more anchors?"

- Increasing number of anchors:
  - Load sharing decreases effective forces per anchor
  - More volume of concrete engaged – higher capacity overall

- **Answer: It depends…**
- Yes, if we can increase volume:
  - Avoid closely spaced anchors
  - Avoid edges of concrete
- Limited by the connection and what its used for
- More likely to hit reinforcement in member
- Higher install time and cost

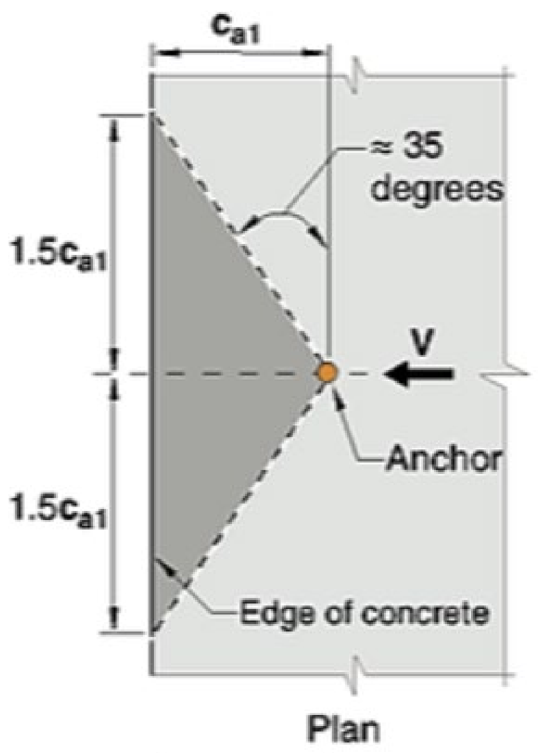
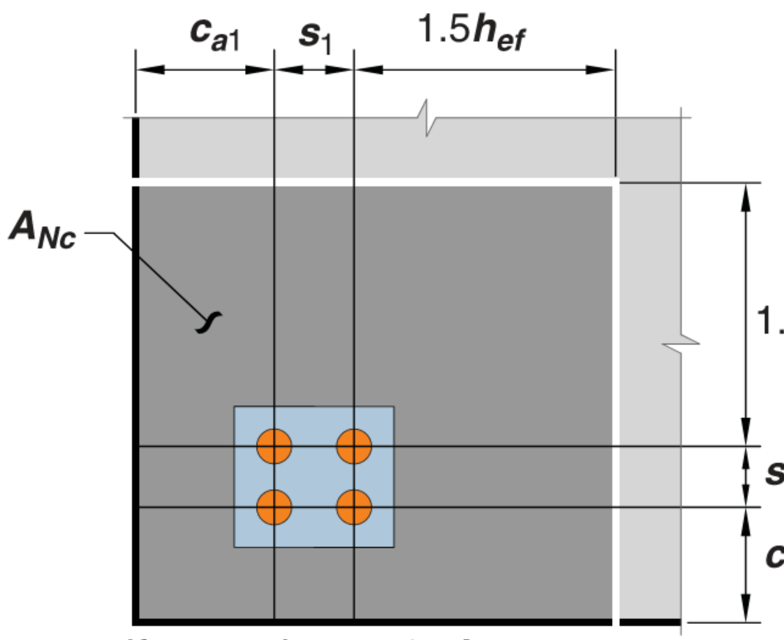


Fig. R17.5.1.3b—Breakout cone for shear.



If c_{a1} and $c_{a2} < 1.5h_{ef}$
and s_1 and $s_2 < 3h_{ef}$
$A_{Nc} = (c_{a1} + s_1 + 1.5h_{ef}) \times (c_{a2} + s_2 + 1.5h_{ef})$

Existing Concrete Info

- Depth of element
  - Must be known in most cases (minimum depth)
- Condition of Element
  - Steel and concrete condition and what can be counted on for design
- Plan locating anchors on the plan dimensions of element
  - Design can assume minimum edge distance – more RFI
- Structural use of the element
  - Cracked concrete assumed typically
- Concrete compressive strength
  - Can be assumed using ACI 562 – will be conservative
- Reinforcement layout of element
  - Avoid cutting reinforcement during anchor installation
  - Possible to use reinforcement to prove breakout not possible
  - Connections can use slotted holes or double holes to avoid reinforcement

Table 6.3.2a—Default compressive strength of structural concrete, psi

Time frame	Footings	Beams	Slabs	Columns	Walls
1900-1919	1000	2000	1500	1500	1000
1920-1949	1500	2000	2000	2000	2000
1950-1969	2500	3000	3000	3000	2500
1970-present	3000	3000	3000	3000	3000

Note: Adopted from ASCE/SEI 41.

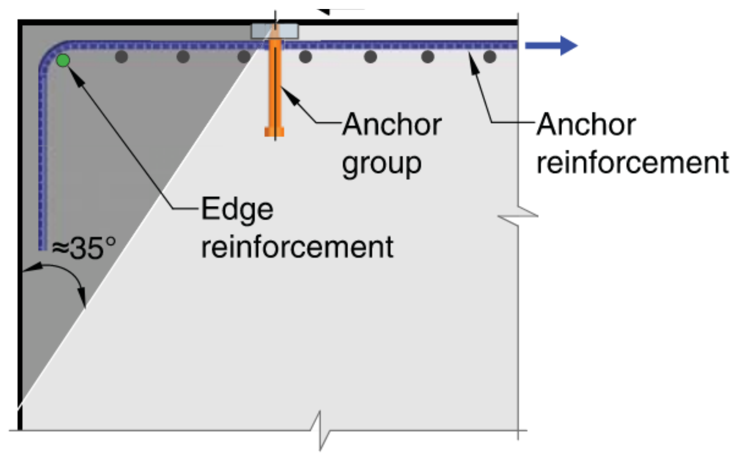


Fig. R17.5.2.1b(ii)*—Edge reinforcement and anchor reinforcement for shear.*

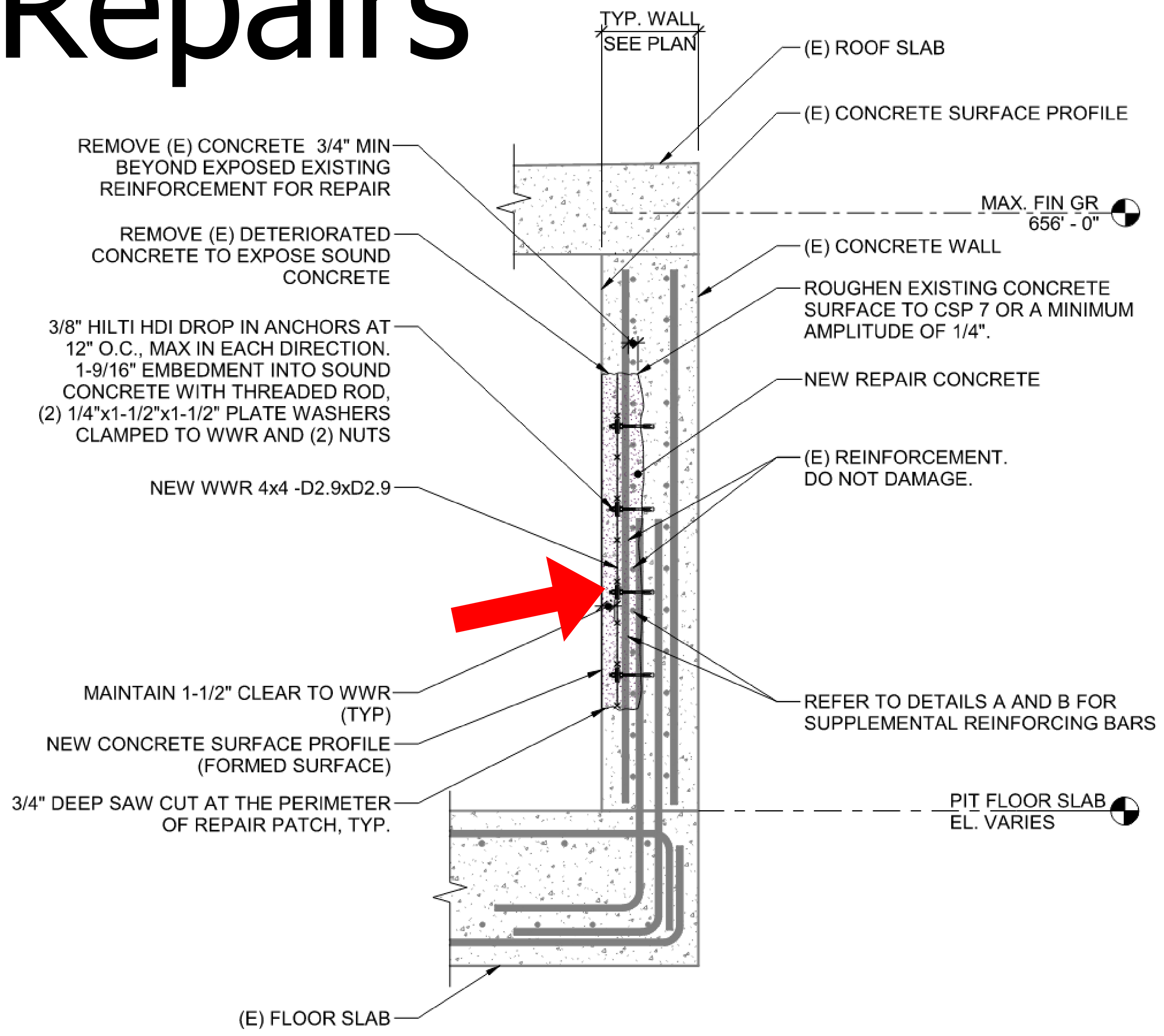
Types of Repairs/ Case Studies

www.icri.org

2024 FALL CONVENTION
OCTOBER 22-25, 2024

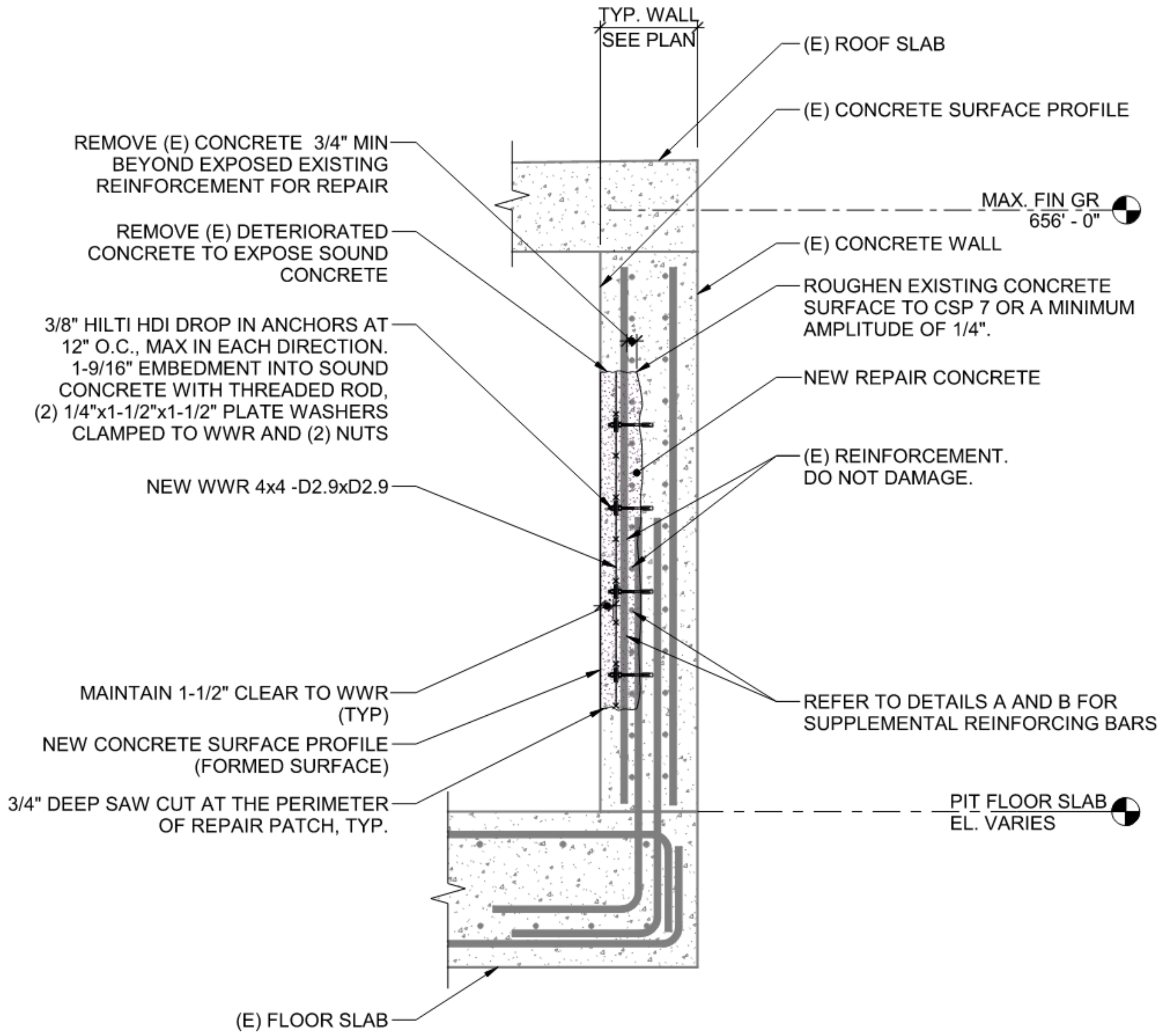
Type 1 - Partial Depth Repairs

- Common repair for restoring section loss on concrete section
  - Honeycombing, delaminations, spalling, etc.
- Repair needs to consider:
  - Loading during repair (partial section)
  - Loading after repair (full section)
  - Partial section capacity, full section capacity
- Role of Anchors:
  - Mechanical anchorage at new/old interface
  - Hold mesh/small rebar if needed in repair
  - Transfer loading to original section



Pit Wall PD Repairs

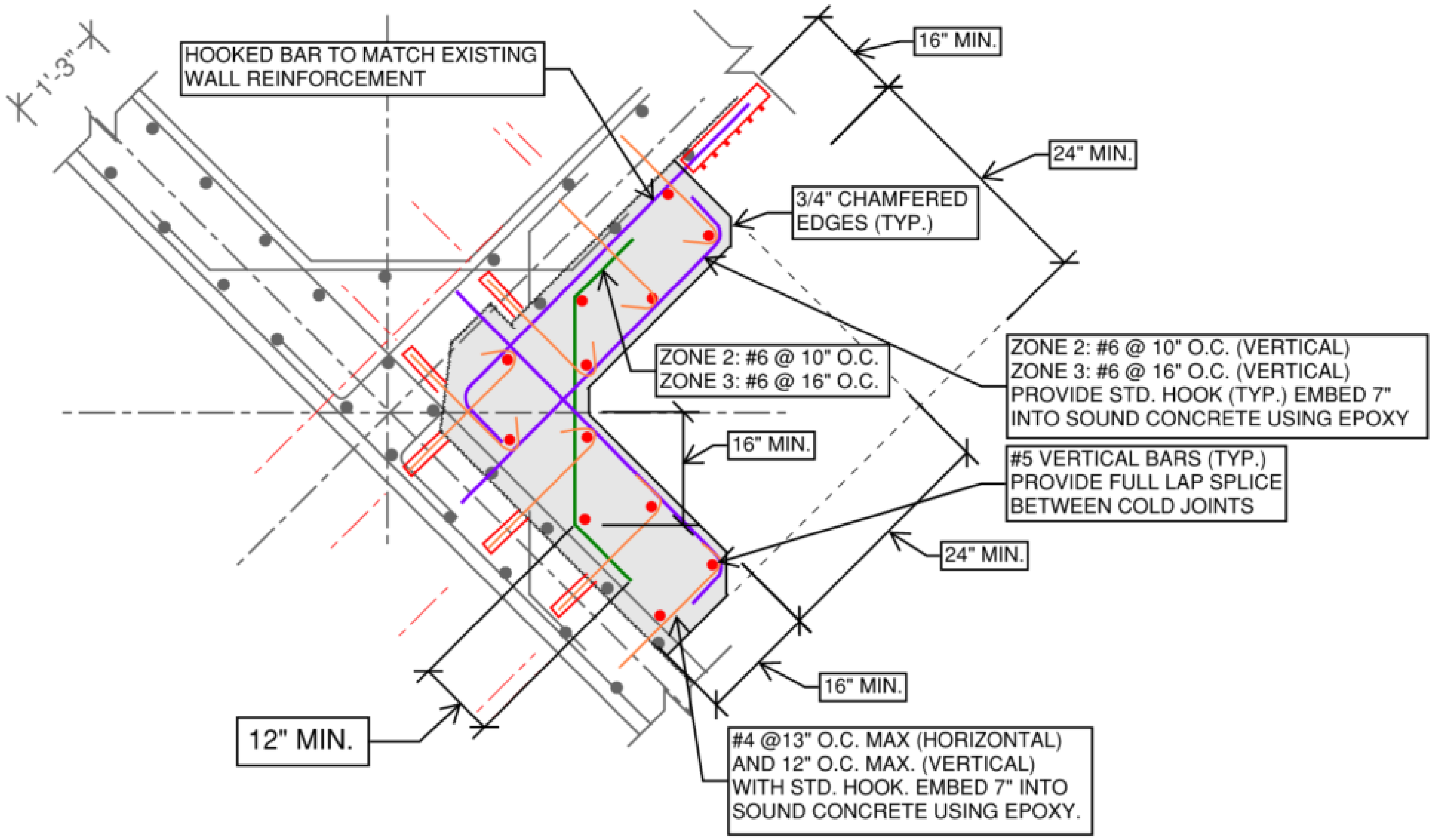
- Scope:
  - Subgrade pit wall partial depth repair in-kind
- Condition of Walls:
  - Depth of spalling varied from cover depth to 5”
  - Pit emptied during repairs
  - Surcharge around pit limited during repairs
  - Compressive strength data, reinforcement available
- Design Approach:
  - Design remaining section to carry reduced load
  - Check for redistribution of forces to “good” sections
  - Supplement existing reinforcement as needed



ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

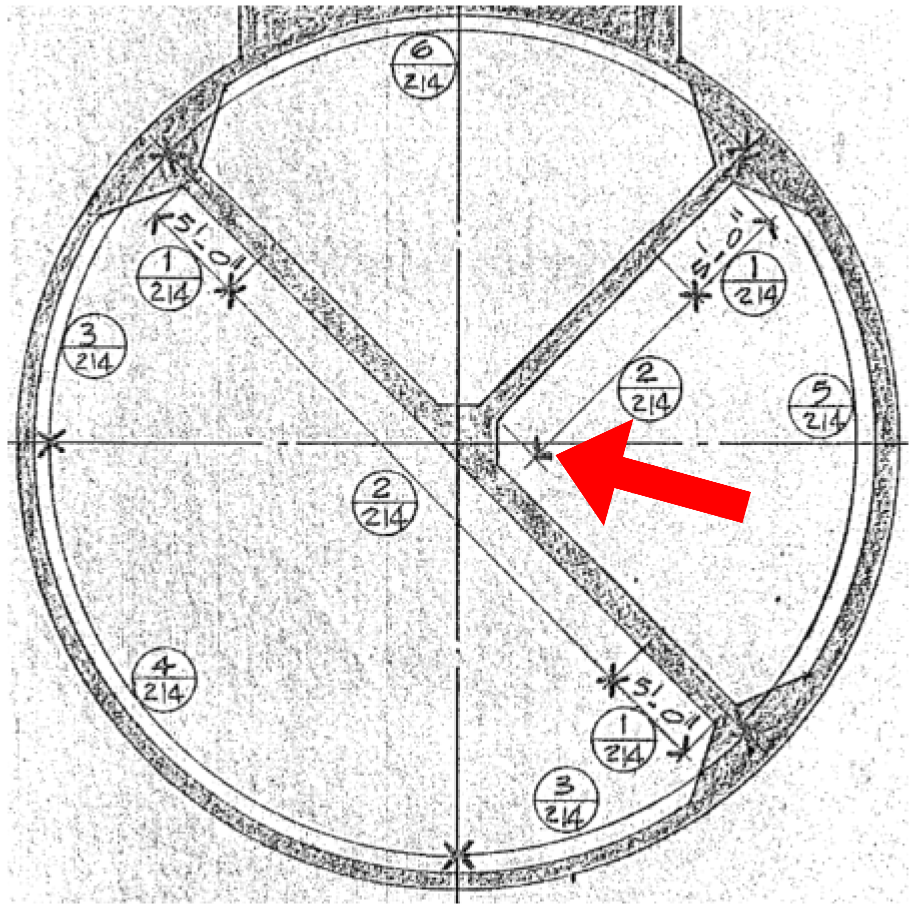
Type 2 - Section Enlargement

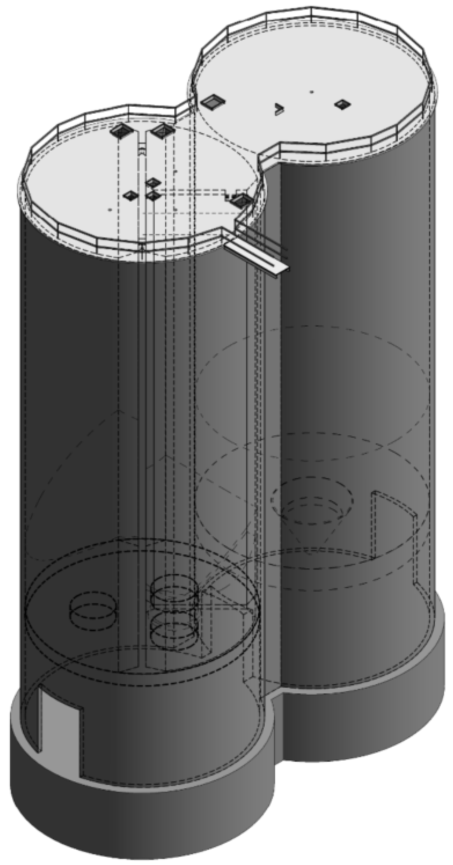
- Common repair when deteriorated element not sufficient
  - Adding capacity to element
  - Need more room for installation of repair
- Repair needs to consider:
  - Loading during repair (partial section)
  - Loading after repair (full section)
  - Partial section capacity, full section capacity
- Role of Anchors:
  - Mechanical anchorage at new/old interface
  - Hold mesh/small rebar if needed in repair
  - Transfer loading to composite section (shear flow, shear friction, etc.)



Rock Silo Wall Joint Enlargement

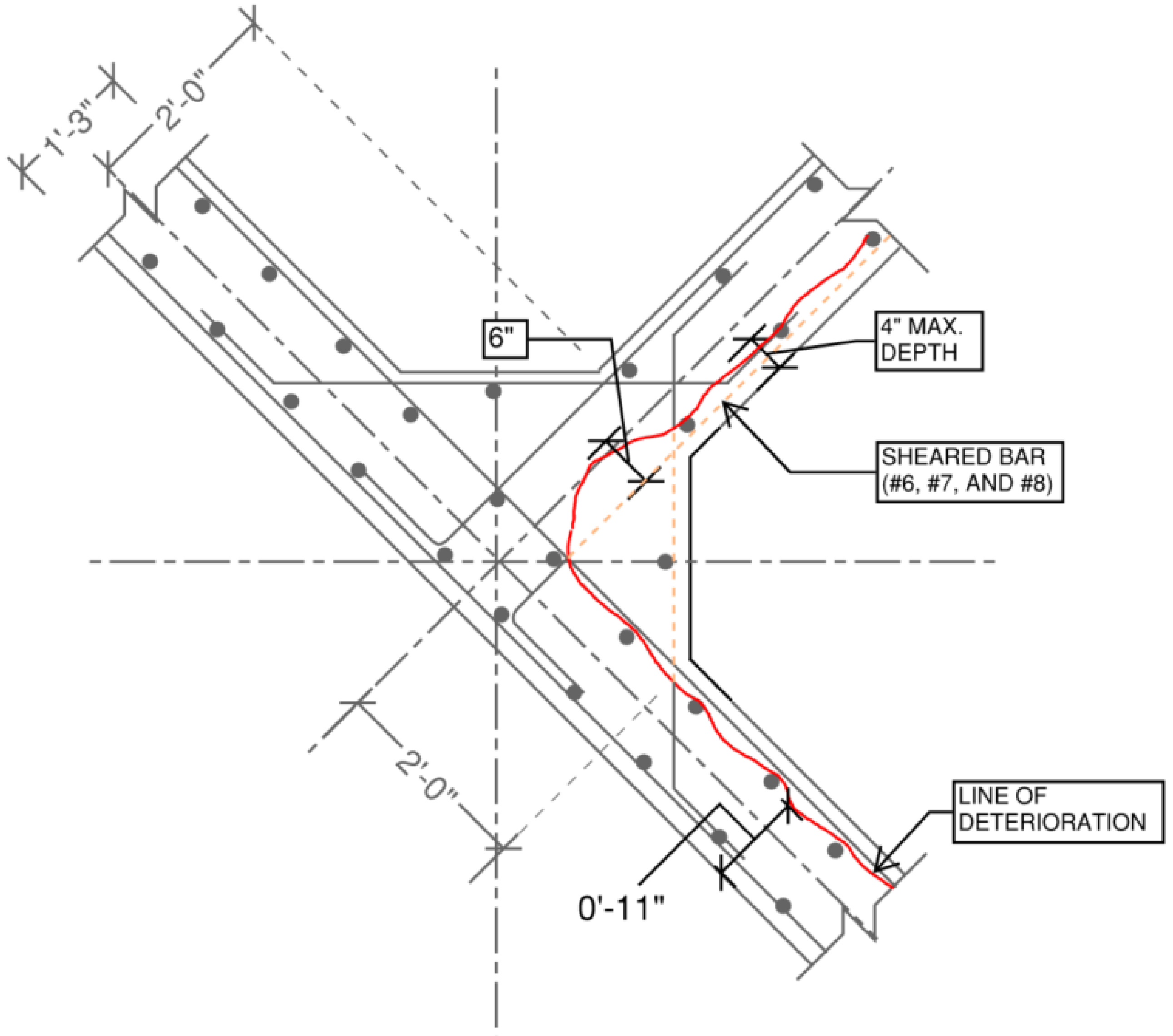
- Scope:
  - Segmented rock silo wall partial depth repairs
- Condition of Walls:
  - Wear from rock up to 8” from original surface
  - Adjacent quadrants in operation during repairs
  - Remaining wall thickness of 9” (Impact Echo)
  - Reinforcement sheared off
  - Compressive strength, reinforcement data available
- Design Approach:
  - Dowels create enlarged composite section to resist loading
  - Couplers to re-tie existing wall reinforcement into joint



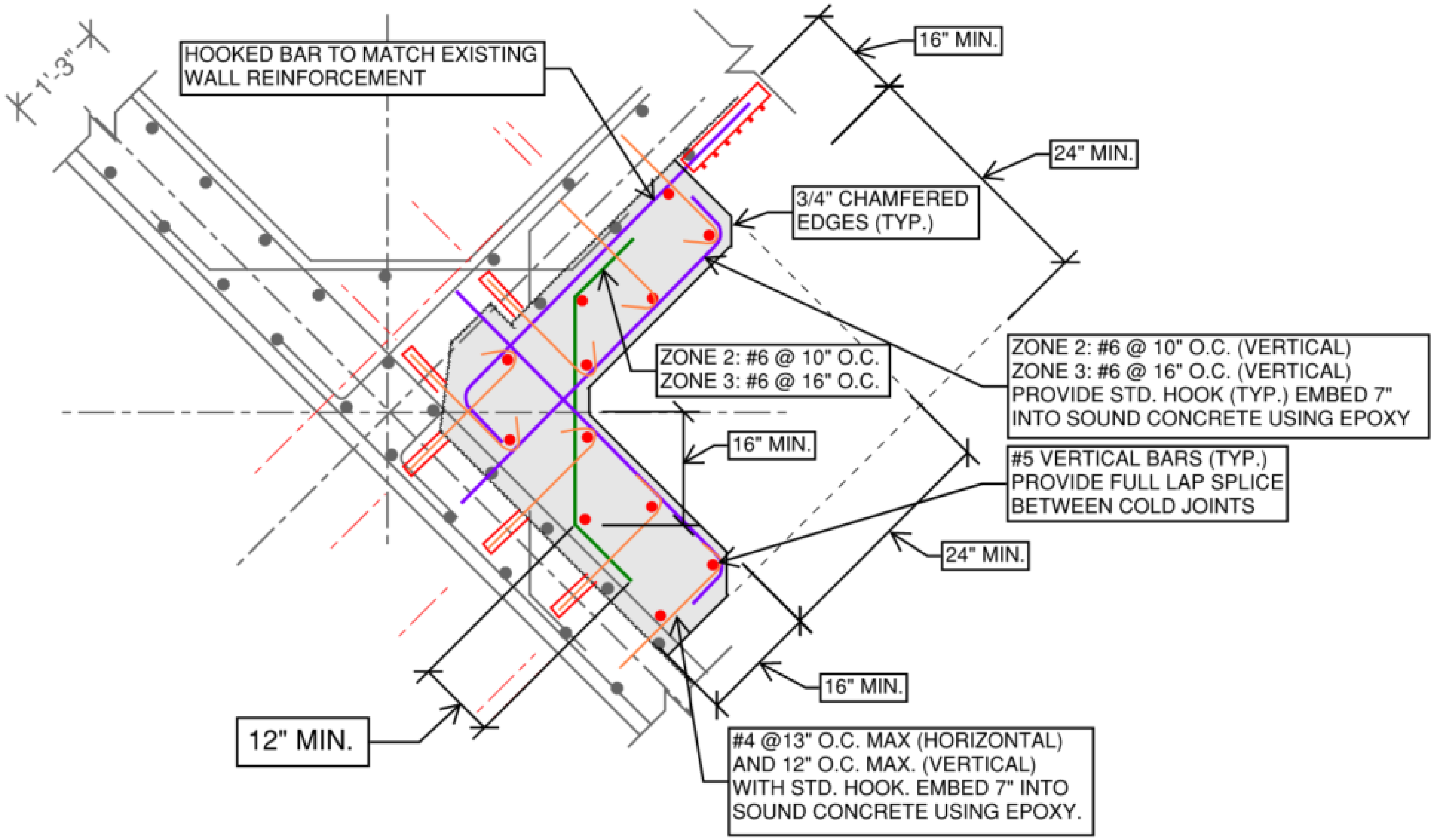


FACING JOINT AT TOP OF SILO

LOOKING DOWN AT JOINT



INTERIOR WALL INTERSECTION JOINT



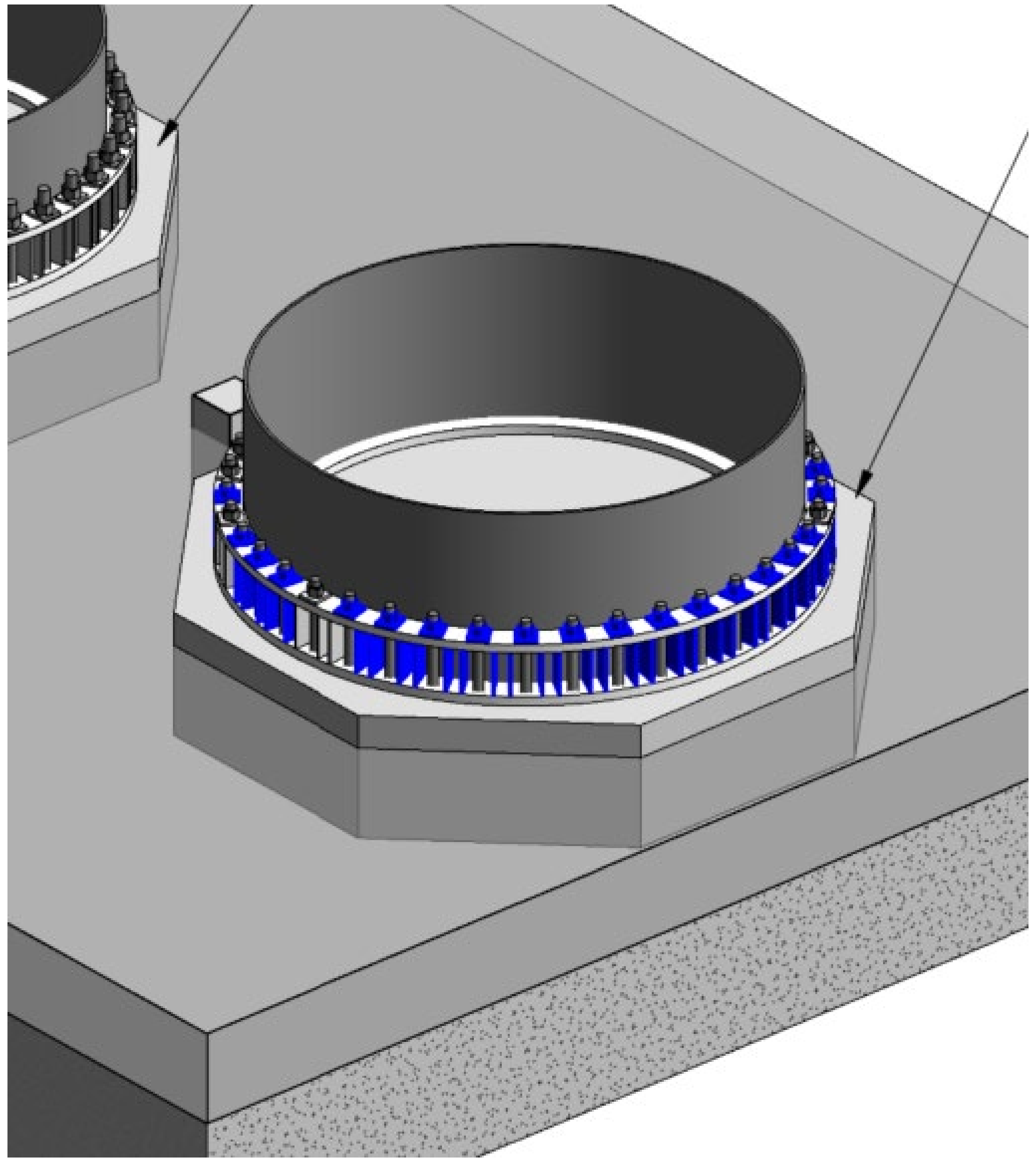
INTERIOR JOINT REPAIR DETAIL

Type 3 - Full Replacement

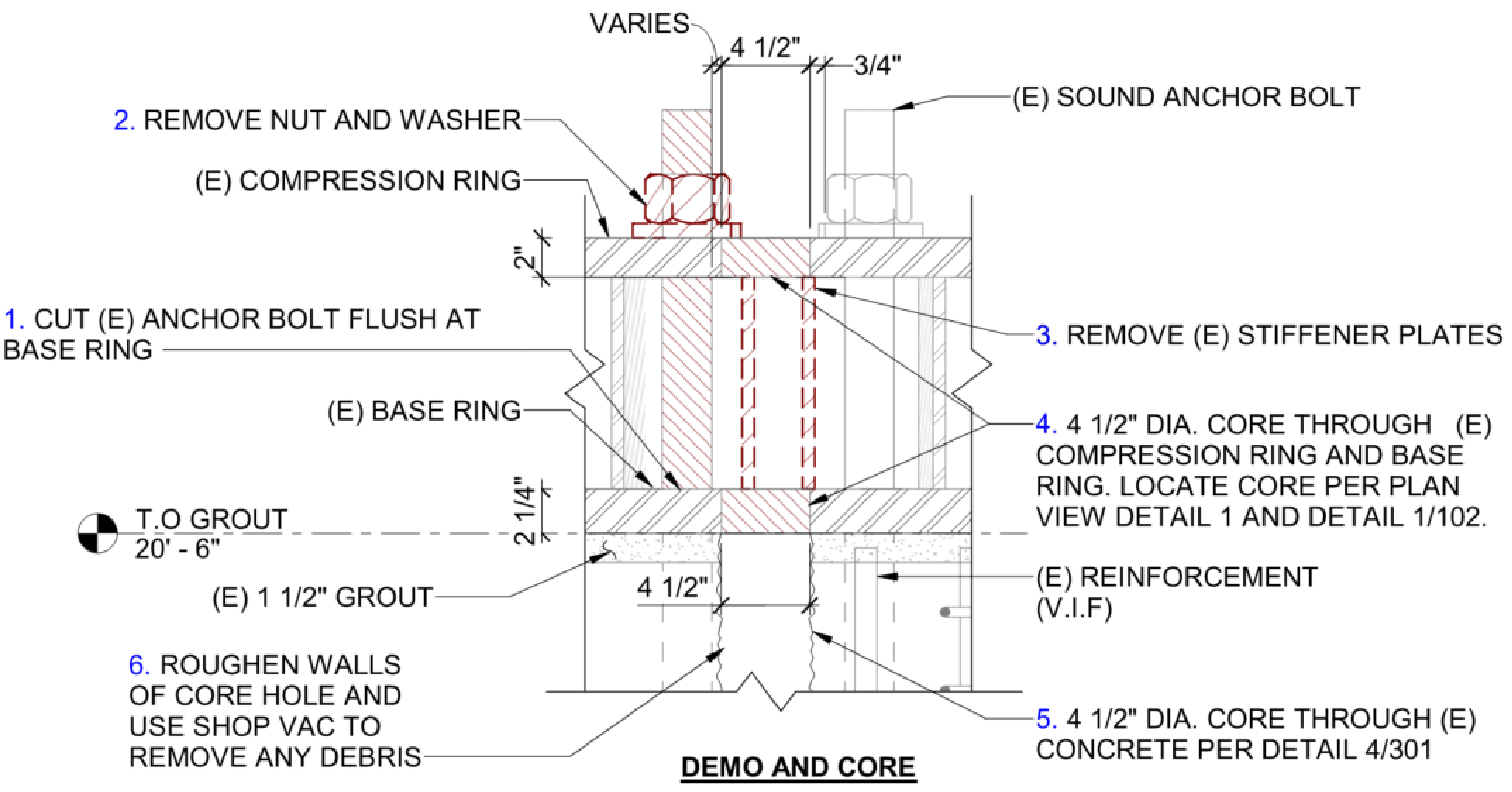
- Common repair when a new element/connection required
  - Existing fully deteriorated
  - Modifications require reinstallation of member
  - Constructability (less shoring, etc.)
- Repair needs to consider:
  - Loading during repair
  - Loading after repair (service condition)
- Role of Anchors:
  - Transfer loads from new members to the existing structure

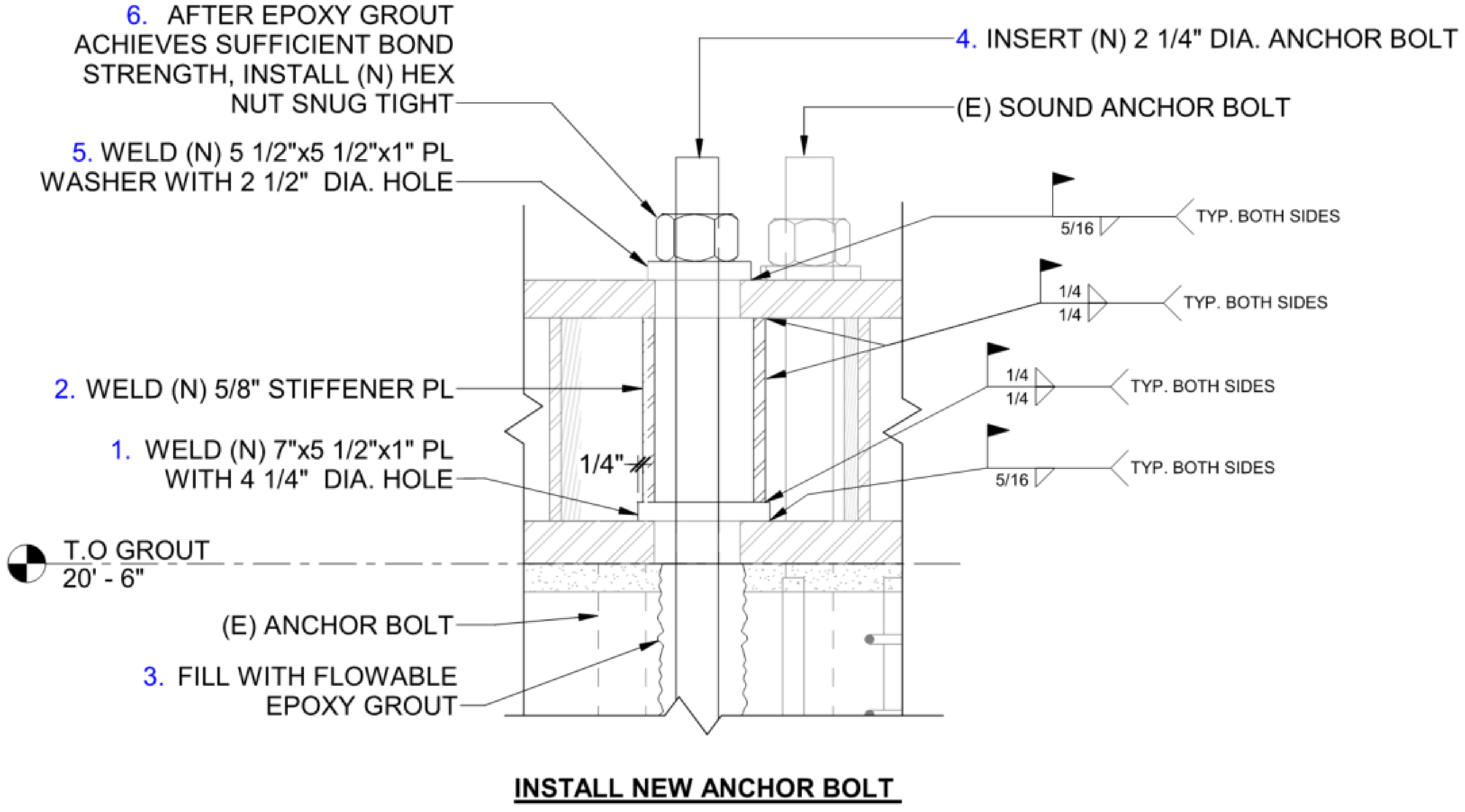
Vessel Anchor Replacement

- Scope:
  - Replacement of deteriorated anchor bolts of (3) existing vertical vessel
- Condition of Bolts:
  - Corrosion of existing anchor bolts, base ring, and stiffener plates as a result of age, exposure, and environmental condition
- Design Approach:
  - Optimized to replace a minimum number of anchor bolts to maintain safety until the vessel is replaced.
    - No replacements on (1) vessel
    - (1) anchor bolt replacement on (1) vessel
  - New anchor bolts located between existing anchor bolts to minimize removal of existing anchor bolts and stiffener plates to minimize costs



Vessel Anchor Replacement





www.icri.org

2024 FALL CONVENTION
OCTOBER 22-25, 2024

Vessel Anchor Replacement

Presenters:

CONCRETE REPAIR
Restore | Repurpose | Renew

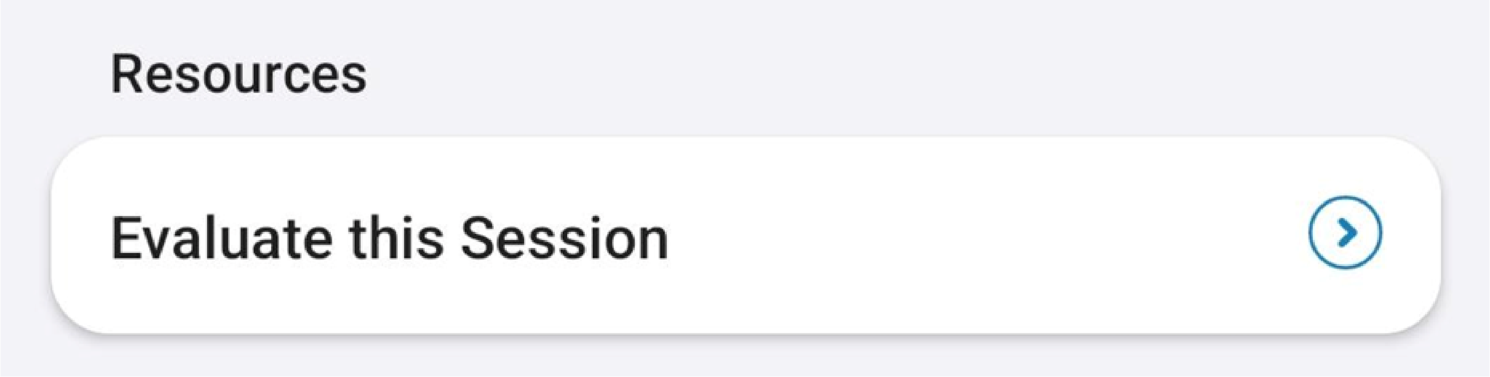
Jeffrey M Owad, PE, PMP
Director of Engineering
jowad@structuraltec.com

Luis R. Pelayo, PE, SE
Engineer II
lpelayo@structuraltec.com

structural TECHNOLOGIES

CONCRETE REPAIR
Restore | Repurpose | Renew

SESSION EVALUATION



To complete the session evaluation, open the ICRI Convention App.

Under **Plan Your Event,** select Schedule, and then the Technical Session you are attending. Select the sub-session you are attending, scroll down to Resources, and select Evaluate this Session.

www.icri.org

2024 FALL CONVENTION
OCTOBER 22-25, 2024

ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

THANK YOU

FOR YOUR ATTENTION

www.icri.org

2024 FALL CONVENTION
OCTOBER 22-25, 2024