Adhesive and Cementitious Anchorage Systems: Researching the Behavior of Anchors

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Presentation

- Anchor Systems
- Acceptance Criteria
- Design and Research Issues
- UMass/MassDOT Project

Anchor Systems

Cast in Place

Cast in Place Anchors – Headed Bolt, Headed Stud, or Hooked Bolt Installed Before Placing Concrete. (ACI 318-02)

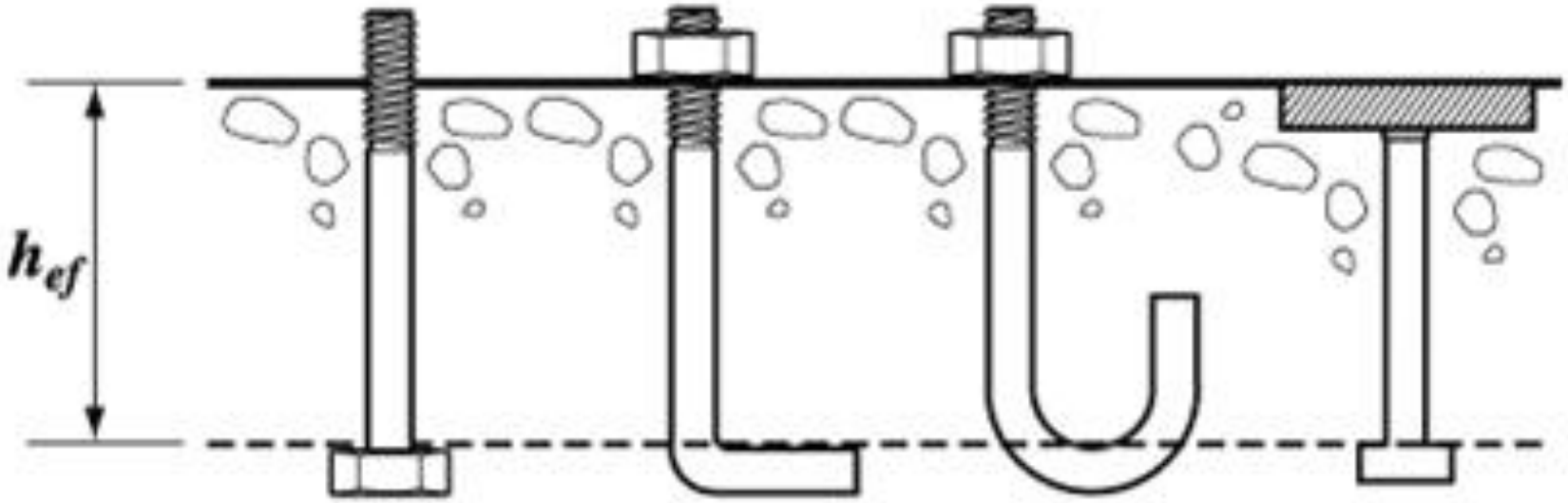
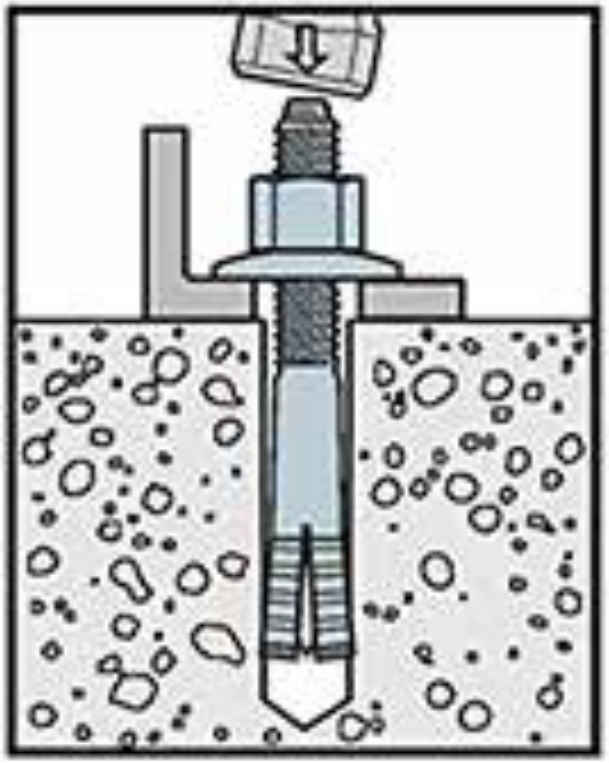


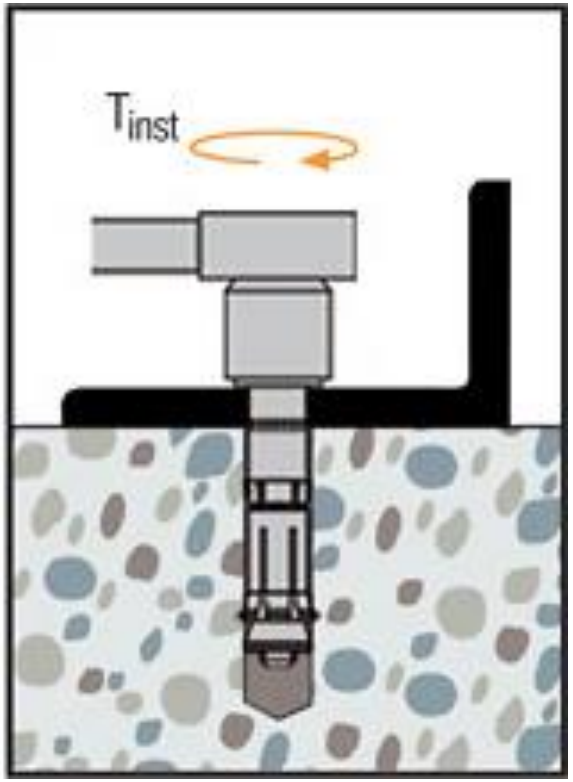
Figure Courtesy of NEES

Post Installed - Mechanical

Expansion – Friction by wedging steel sleeve against base concrete



Undercut– Mechanical Interlock by cutting into base concrete



Figures Courtesy of Simpson Strong Tie

Post Installed – Adhesive or Cementitious

- Bonded:
  - Hole Diameters Less Than 1.5 x Anchor Diameter
  - Typically Adhesives (Polymers such as Epoxies)

- Grouted:
  - Hole Diameters Greater Than 1.5 x Anchor Diameter
  - Either Adhesive (with filler material) or Cementitious

Post Installed – Bonded

Transfer Applied Load from Anchor Rod to Base Concrete through shear stress in the bonding agent.

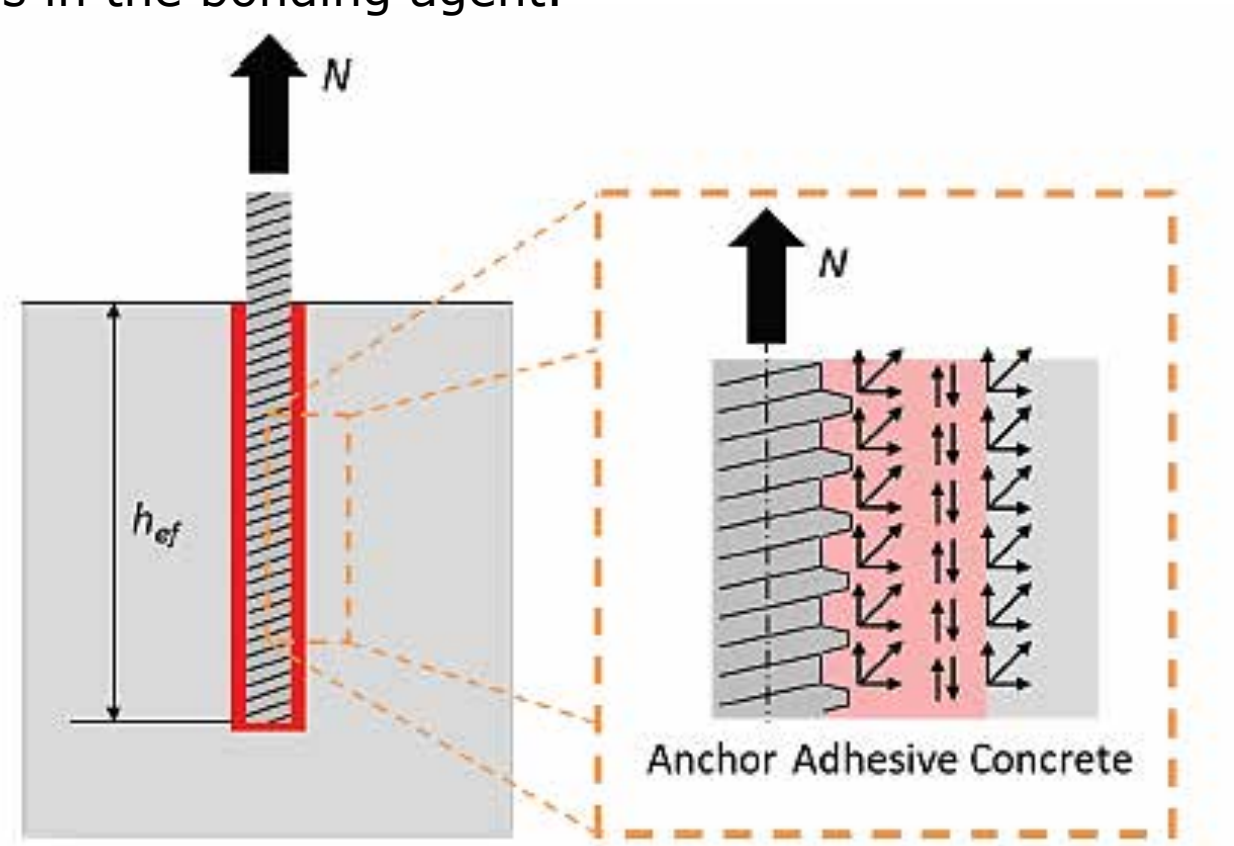


Figure Courtesy of NCHRP Report 757

Post installed - Grouted

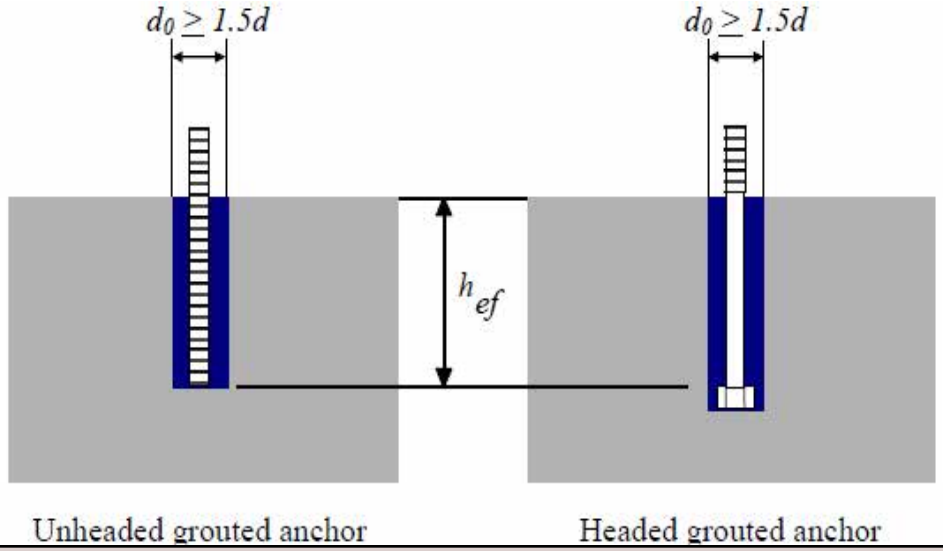
Researched Less Than Bonded Anchors

Polymer Grout

Same polymer structure as polymer adhesives, but fine aggregate is used to increase bond material between anchor rod and base concrete

Cementitious Grout

Mixture of sand, cement, water, and other additives



h_{ef} = embedment depth
d_0 = hole diameter
d = anchor rod diameter

Figure Courtesy of FDOT Report No. BC354 RPWO #48

Post Installed – Grouted

Researched Less Than Bonded Anchors

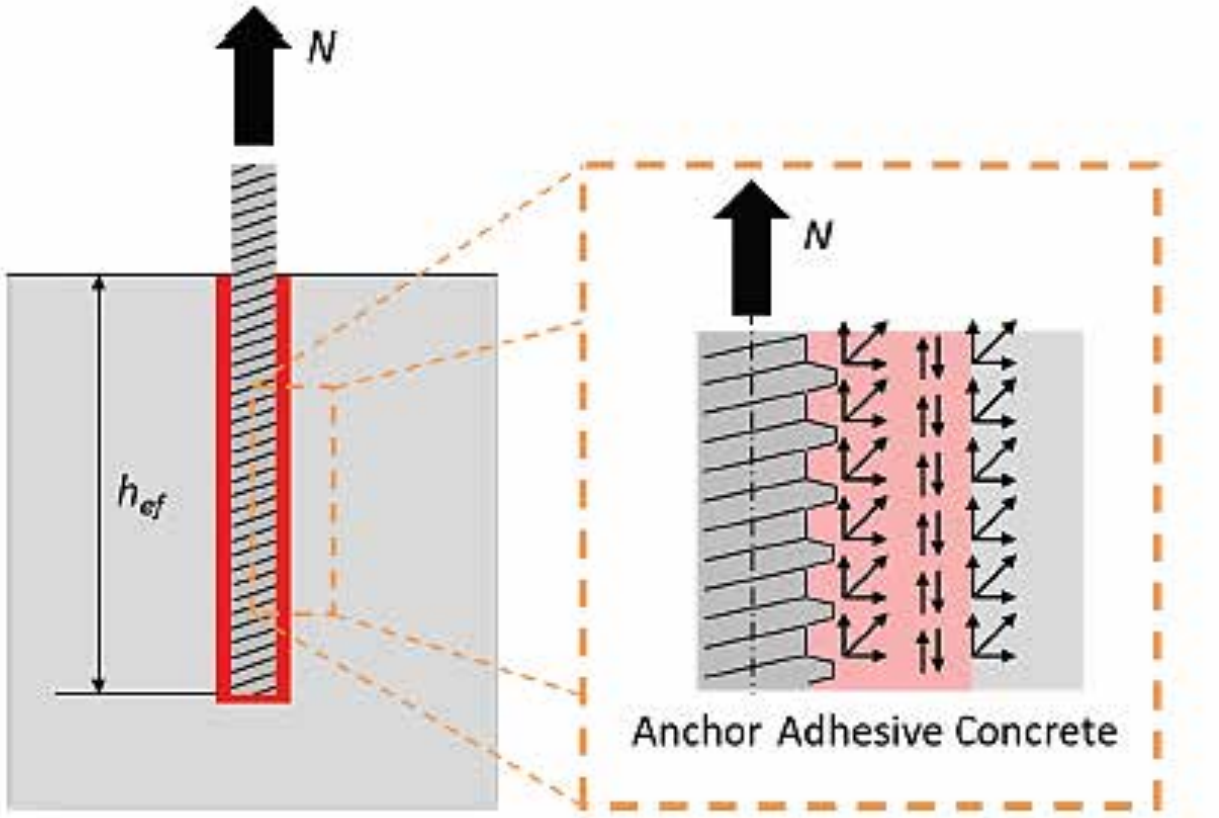
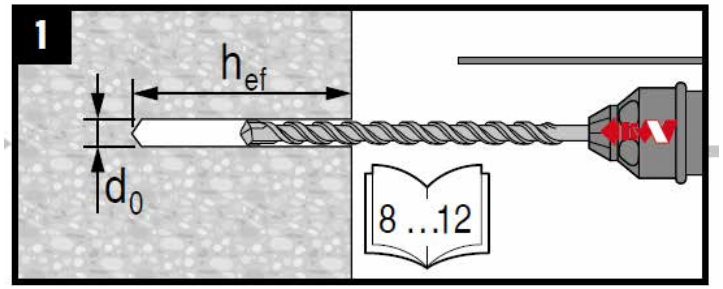
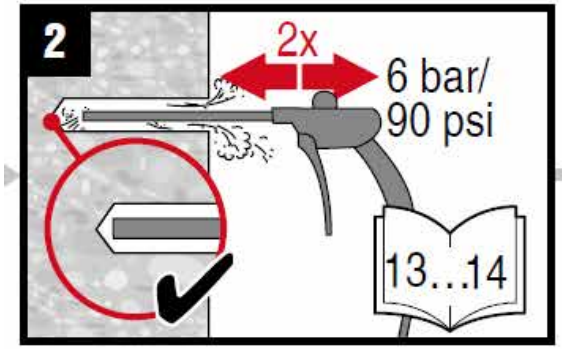


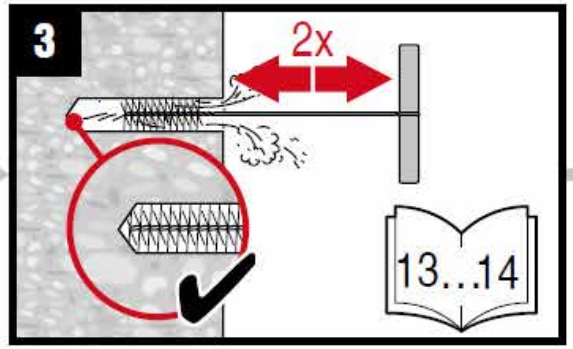
Figure Courtesy of NCHRP Report 757

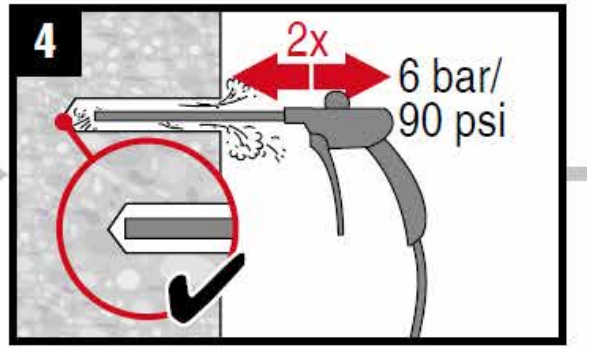
Installation Procedure

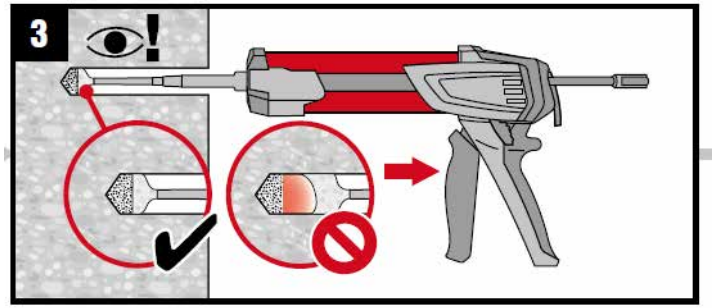
- Drill Hole
- Clean Hole
- Install Bonding Material
- Install Anchor

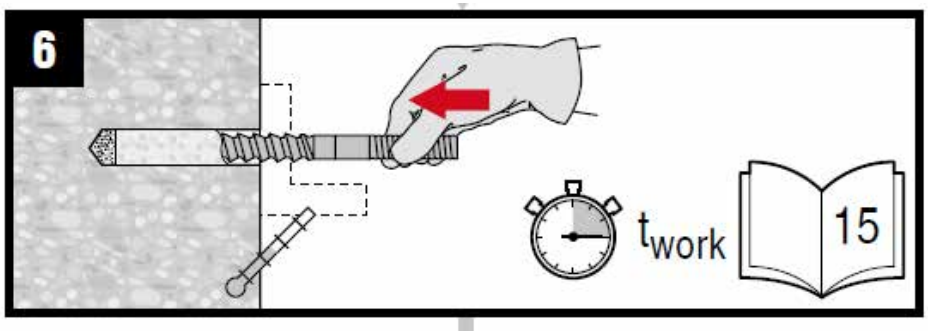












Figures Courtesy of Hilti

Failure Modes

Bonded Anchor Failure Modes

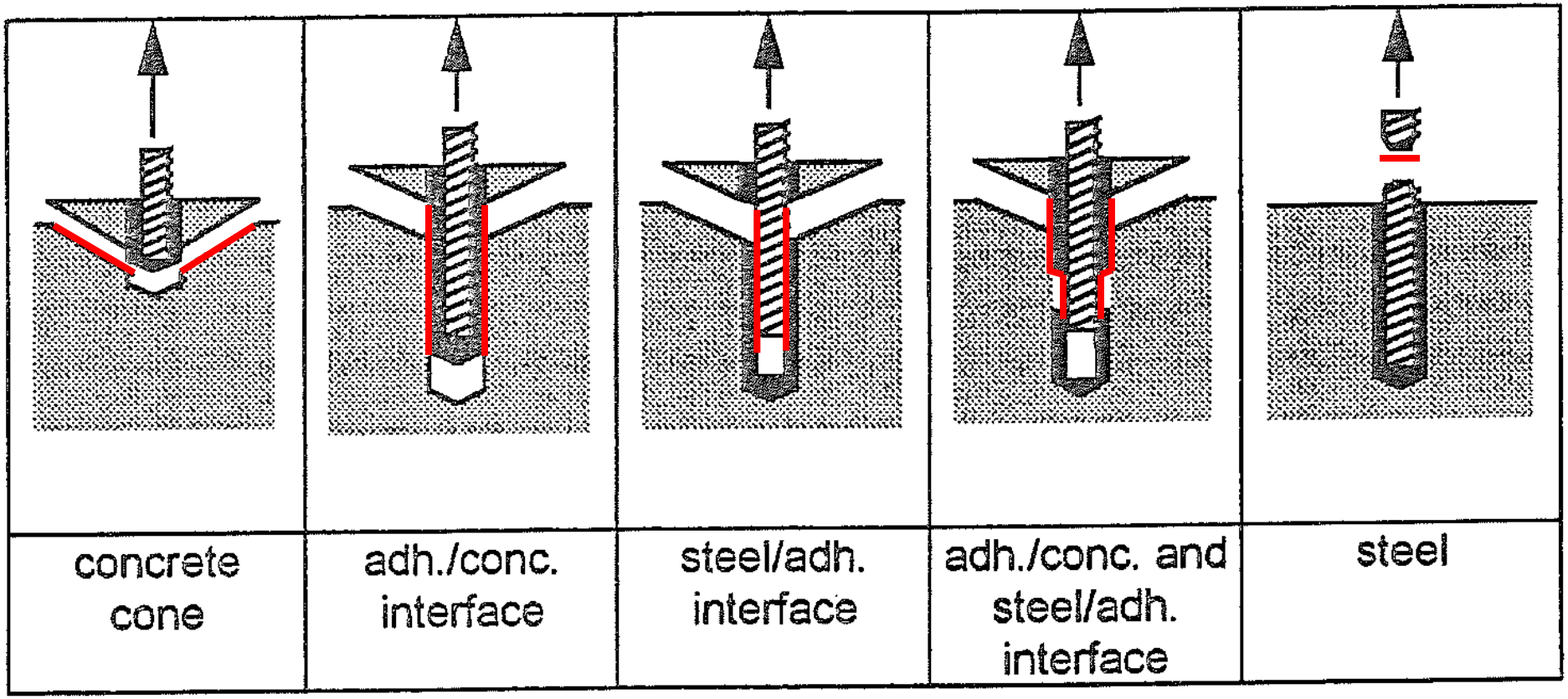


Figure from NCHRP Report 757

Concrete Capacity Design (ACI 318 Appendix D)

$$N_b = k\sqrt{f'_c}h_{ef}^{1.5}$$

Photo Courtesy of Hilti

N_b = *concrete breakout strength in tension of a single anchor in cracked concrete*

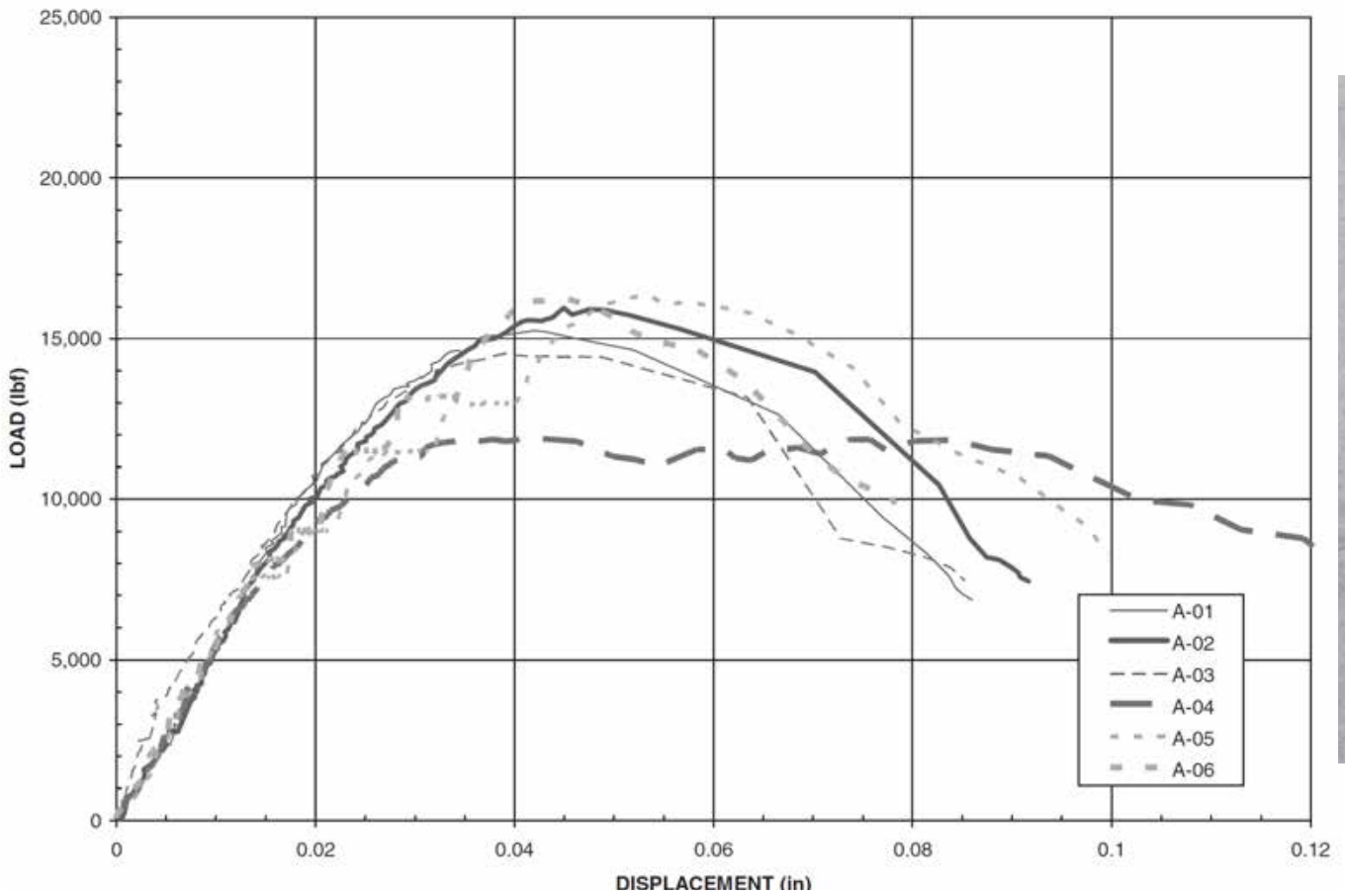
k = *Coefficient for basic concrete breakout strength in tension*

(24 for Cast in Place Anchors, 16 for Mechanical Post-Installed Anchors)

f'_c = *Specified Compressive Strength of Concrete (psi)*

h_{ef} = *Effective anchor embedment depth (in)*

Static Test – Confined Failure



Behavior Models: Adhesive Uniform Bond Stress Model

$$N_{bond} = \tau' \pi d h_{ef}$$

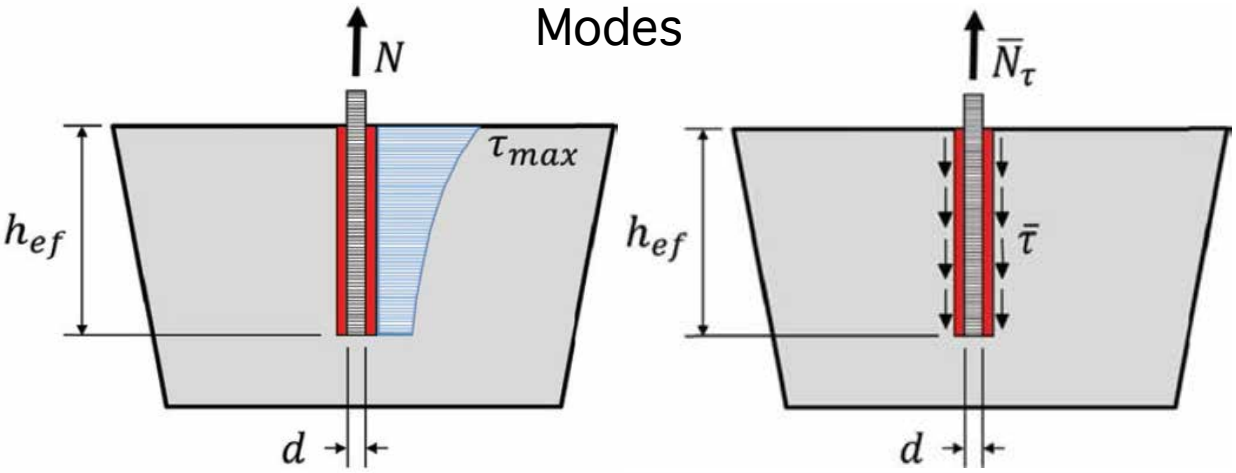
$\tau' = nominal\ bond\ stress = \tau_k \alpha_1 \alpha_2 \alpha_3$

$\tau_k = 5\%\ lower\ fractile\ of\ mean\ bond\ stress$

$\alpha_1 \alpha_2 \alpha_3 = reduction\ factors\ for\ different\ parameters$

Assumptions
- Embedment depth ≤ $20d$
- Hole diameter ≤ $1.5d$

Applies to Bond Failure Modes



$$N_u \leq \emptyset N_{bond}$$

$N_u = Factored\ Tension\ Load$
$\emptyset = capacity\ reduction\ factor$
$d = anchor\ diameter\ \ h_{ef} = embedment\ depth$

Figures Courtesy of NCHRP Report 757

Behavior Models: Grouted Uniform Bond Stress Model

$$N_{bond,inner} = \tau'_{inner}\pi d h_{ef}$$

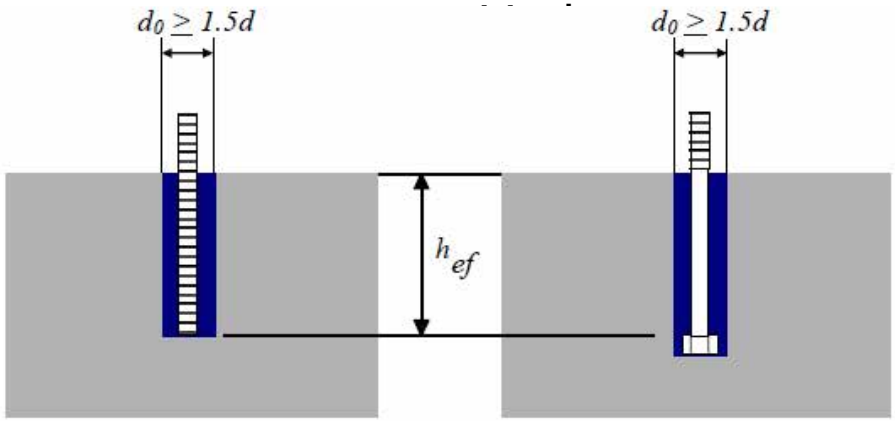
$$N_{bond,outer} = \tau'_{outer}\pi d_0 h_{ef}$$

Assumptions
- Embedment depth ≤ $20d$
- Hole diameter $\geq 1.5d$

τ'_{inner} = nominal bond stress steel/grout interface (non-headed)

τ'_{outer} = nominal bond stress grout/concrete interface

Applies to Bond Failure



$$N_u \leq \emptyset N_{bond}$$

$N_u = Factored\ Tension\ Load$
$\emptyset = capacity\ reduction\ factor$
$d = anchor\ diameter\ \ h_{ef} = embedment\ depth$

Figure Courtesy of FDOT Report No. BC354 RPWO #48

Static Capacity vs Sustained Load Capacity

- Polymer adhesives exhibit rigid behavior in short term tests (~5 minutes)
- Polymer adhesives deform over time under a sustained load (Creep)

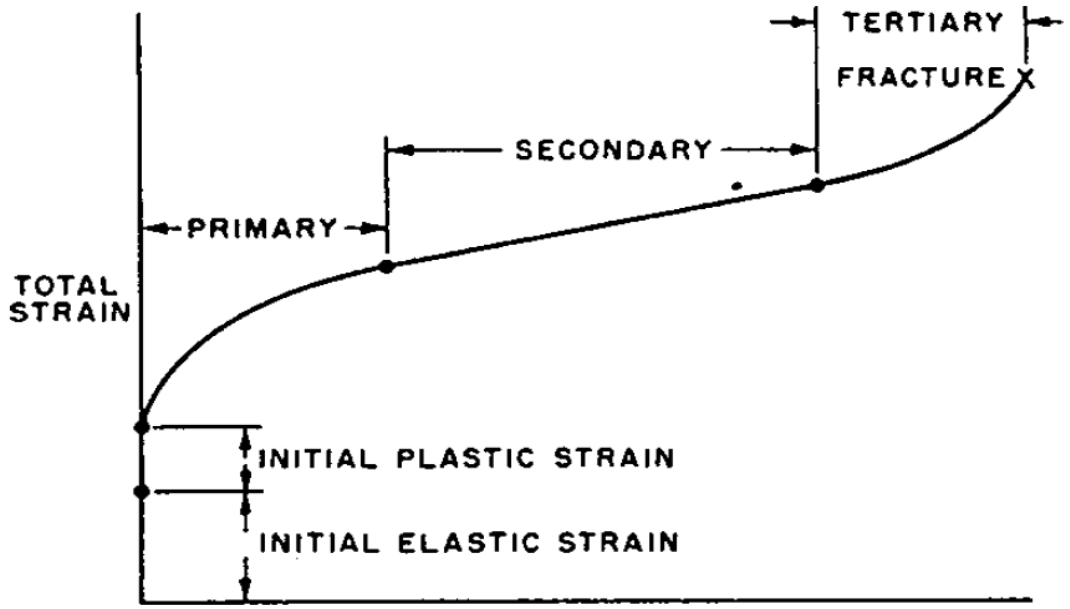


Figure Courtesy of ASTM D2990

I-90 Connector Tunnel July 10, 2006

Displaced Anchors Found During Inspection

- 78 of 198 westbound tunnel
- 57 of 248 eastbound tunnel
- 26 of 188 high occupancy vehicle (HOV) tunnel

Photos Courtesy of NTSB Ceiling Collapse of the I-90 Connector Tunnel Accident Repo

Parameters Affecting Capacity

In-Service Factors (1 of 1)

- **Elevated Temperature:** temperature variations during the life of the structure, and effects of sustained elevated temperature.
- **Reduced Temperature:** brittleness associated with reduced temperature.
- **Moisture-in-Service:** adhesive anchor subjected to dry, damp, or immersed conditions during the life of the anchor.
- **Freeze–Thaw:** magnitude and frequency of freeze–thaw cycles.

Adhesive Related Factors (1 of 1)

- **Type of Adhesive:** for example: epoxy-mercaptan, epoxyamine, vinylester, polyester, or hybrid.
- **Mixing Effort:** how well are the constituent parts mixed prior to installation.
- **Adhesive Curing Time When First Loaded:** 24 hours, 7 days, 28 days, or longer.
- **Bond Line Thickness:** how much space is there between the anchor and the sides of the hole.
- **Fiber Content of Adhesive:** type and proportion of fillers in the adhesive.
- **Chemical Resistance:** alkalinity, sulfur dioxide, and other compounds.

Installation Related Factors (1 of 2)

- **Hole Orientation:** downward, horizontal, overhead.
- **Hole Drilling:** rotary hammer, core drill, or drilled in accordance with manufacturer's instructions.
- **Hole Cleaning:** uncleaned, partially cleaned, or cleaned in accordance with the manufacturer's instructions.
- **Moisture in Installation:** dry, damp, submerged, or installed in holes with moisture limitation conditions in accordance with manufacturer's instructions.
- **Installation Temperature:** concrete below freezing, adhesive below freezing, or preheated.

Installation Related Factors (2 of 2)

- **Depth of Hole (Embedment Depth):** the depth of the anchor can affect not only the bond strength but the type of failure.
- **Anchor Diameter:** anchor diameter can affect bond strength.
- **Type of Concrete:** Portland cement only, Portland cement with blast furnace slag, fly ash, or other additives.
- **Concrete Strength:** low compressive strength, high compressive strength.
- **Type of Coarse Aggregate:** mineralogy, absorption, and hardness (affects hole roughness).
- **Cracked or Uncracked Concrete:** the presence of cracks can reduce the bond strength significantly (30%-70%).
- **Concrete Age:** installed and/or loaded at early age.

Testing and Certification

Test Standards (Partial Listing)

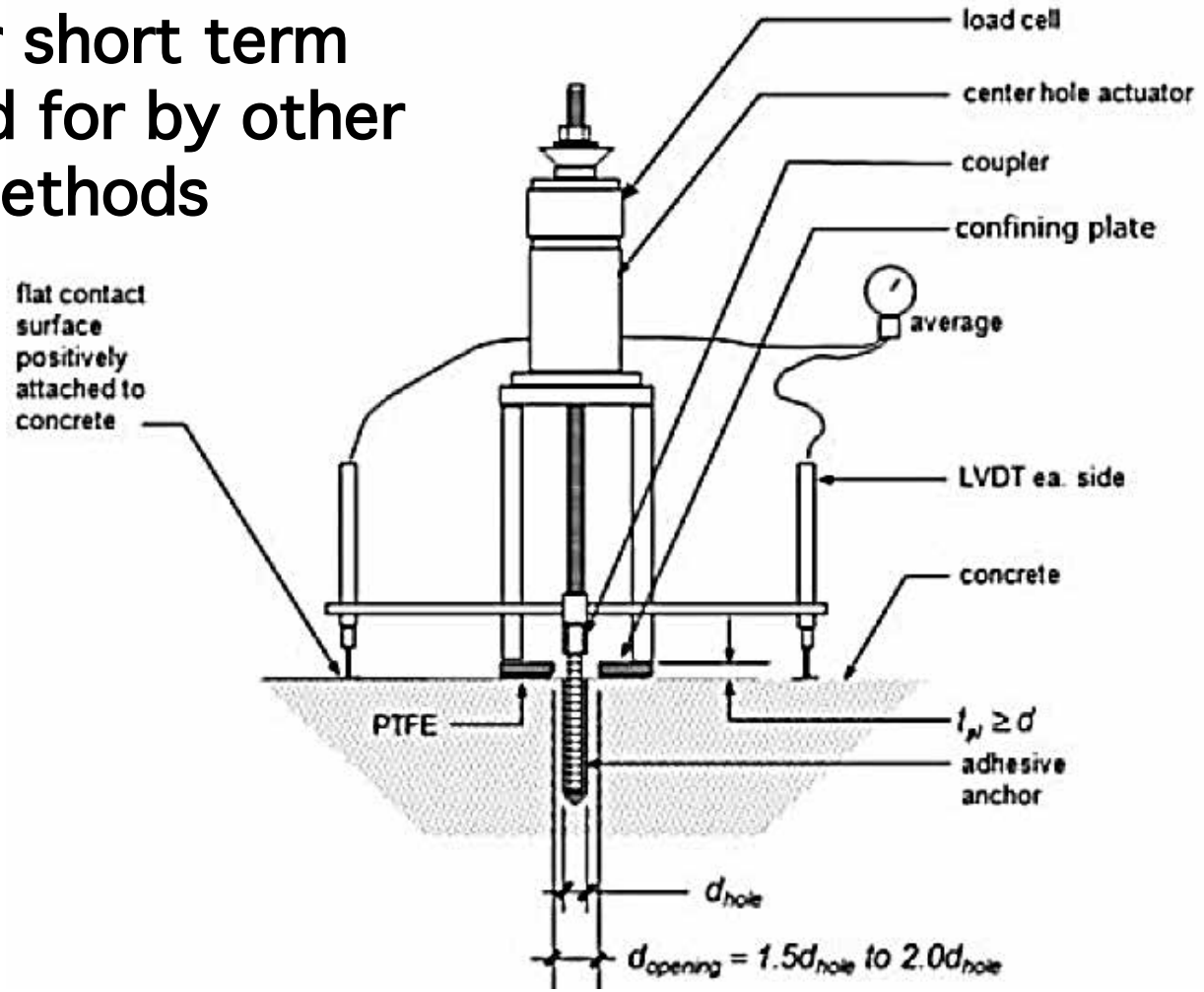
- ASTM E488: *Standard Test Methods for Strength of Anchors in Concrete Elements*
- ASTM E1512: *Standard Test Method for Testing Bond Performance of Bonded Anchors*
- ACI 355.4: *Qualification of Post-Installed Adhesive Anchors in Concrete*
- AASHTO TP-84: *Standard Method of Test for Evaluation of Adhesive Anchors in Concrete under Sustained Loading Conditions*

ASTM E488: *Standard Test Methods for Strength of Anchors in Concrete Elements*

- Published: 1996 (reapproved 2003), changed 2010
- Anchors Tested: All (cast in place, mechanical post installed, bonded)
- Parameters Tested
  - **In Service**: Seismic, Fatigue, Shock, Freeze/Thaw, Elevated/Reduced Temperature, Moisture, Corrosion
  - **Installation**: Hole Cleaning, Moisture, Temperature
  - **Anchor Related**: N/A
  - **Concrete Related**: Cracked, Uncracked
- Data Output: Force, Displacement
- Qualification Criteria: None

ASTM E488: *Standard Test Methods for Strength of Anchors in Concrete Elements*

The test standard for short term (static) capacity used for by other test standards and methods



ASTM E1512: *Standard Test Methods for Testing Bond Performance of Bonded Anchors*

- Published: 2001 (reapproved 2007)
- Anchors Tested: Bonded (Chemical Compound)
- Parameters Tested
  - **In Service**: E488 (Seismic, Fatigue, Shock), Freeze/Thaw, Elevated/Reduced Temperature, Moisture, Corrosion, Fire, Radiation, Sustained Load
  - **Installation**: Moisture, Cleaning, Temperature
  - **Anchor Related**: Embedment Depth
  - **Concrete Related**: Cracked, Uncracked
- Data Output:
  - **Static Tests**: Force, Displacement
  - **Creep Tests**: Time, Force, Displacement, Extrapolated Displacement

ASTM E1512: *Standard Test Methods for Testing Bond Performance of Bonded Anchors*

- Qualification Criteria: None

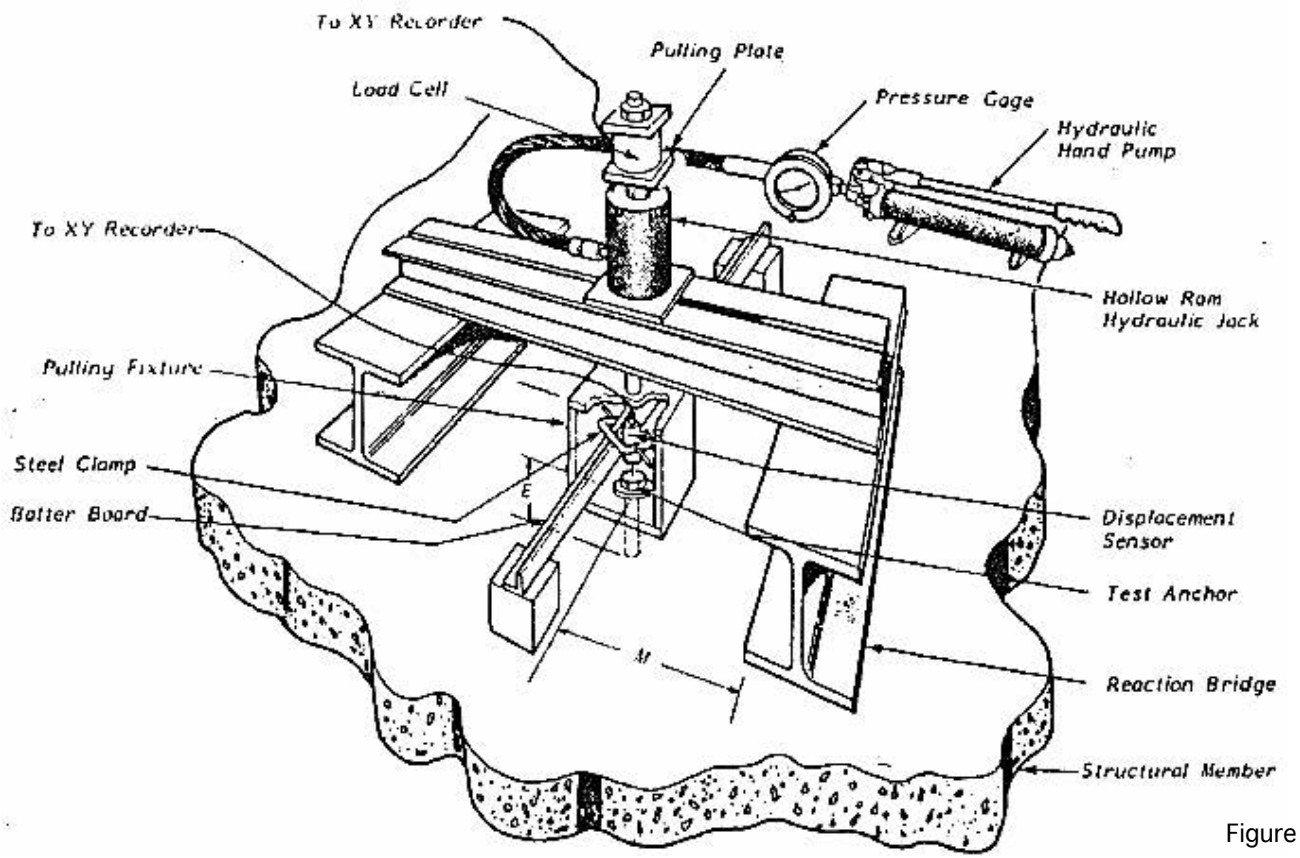


Figure Courtesy of ASTM E1512

ACI 355.4: *Qualification of Post-Installed Adhesive Anchors in Concrete*

- Published: 2011
- Anchors Tested: Adhesive
- Parameters Tested:
  - **In Service**: Moisture, Chemical Exposure, Sustained Load, Seismic (optional), Freeze/Thaw (optional), Elevated Temperature (optional)
  - **Installation**: Moisture, Cleaning, Temperature, Orientation, Drilling Method
  - **Anchor Related**: Anchor Rod, Embedment Depth, Anchor Diameter
  - **Concrete Related**: Cracked, Un-cracked

ACI 355.4: *Qualification of Post-Installed Adhesive Anchors in Concrete*

- Data Output:
  - **Static Tests**: Force, Displacement
  - **Creep Tests**: Time, Force, Displacement, Extrapolated Displacements
  - **Alpha Reduction Ratio**:

$$\alpha = \frac{\bar{\tau}_{u,i}}{\bar{\tau}_{0,i}}$$

$\bar{\tau}_{u,i} = Mean\ bond\ stress\ from\ reliability\ (parameter)\ test\ series\ in\ test\ member\ i$

$\bar{\tau}_{0,i} = Mean\ bond\ stress\ from$ reference (baseline)$test$ series $in\ test\ member\ i$

ACI 355.4: *Qualification of Post-Installed Adhesive Anchors in Concrete*

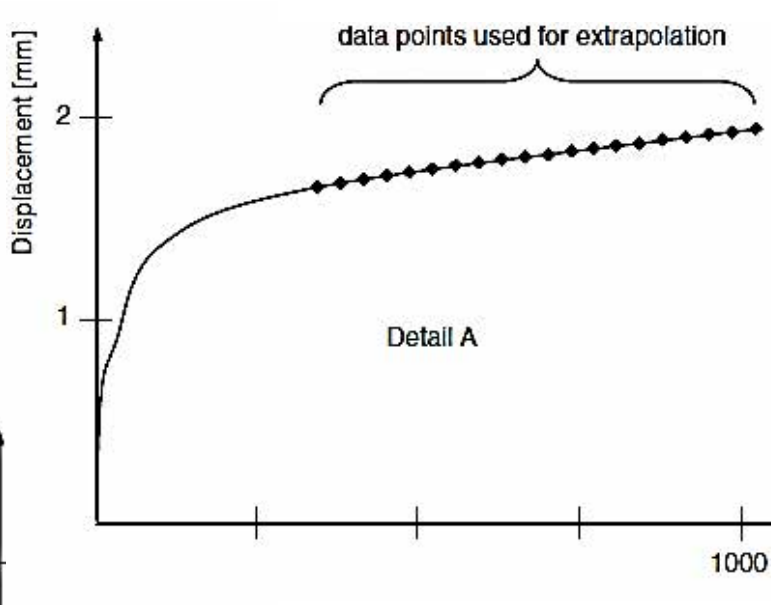
Creep Tests (modified from ASTM E1512)

- Separate tests for Standard Temperature, 73º F ± 8º F (23º C ± 4º C), and Elevated Temperature ≥ 110˚ F (50˚ C)
- 42 Day Test; loaded at 55% of Short Term Capacity
- Displacement is measured and extrapolated out to 600 days for elevated temperature and 50yrs for standard temperature

Why 600 days?

- Study of Bridge in California Desert yields maximum bridge temperatures between 110° F and 120° F (43° C and 48° C) for 2.4 hours per day
- 4 Months of Summer = 288hrs/year at elevated temperature
- 50 year design life = 600 days at temperatures between 110° F and 120° F (43° C and 48° C)

ACI 355.4: *Qualification of Post-Installed Adhesive Anchors in Concrete*



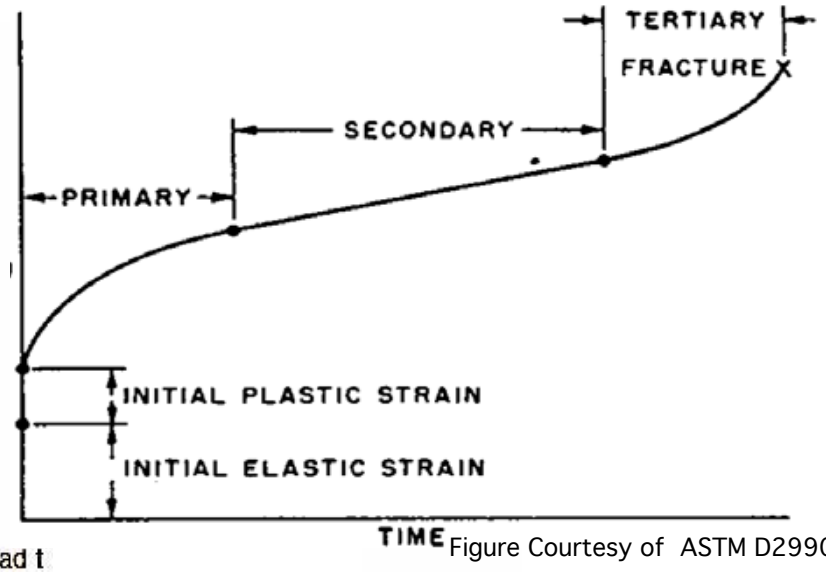


Figure Courtesy of ASTM D2990

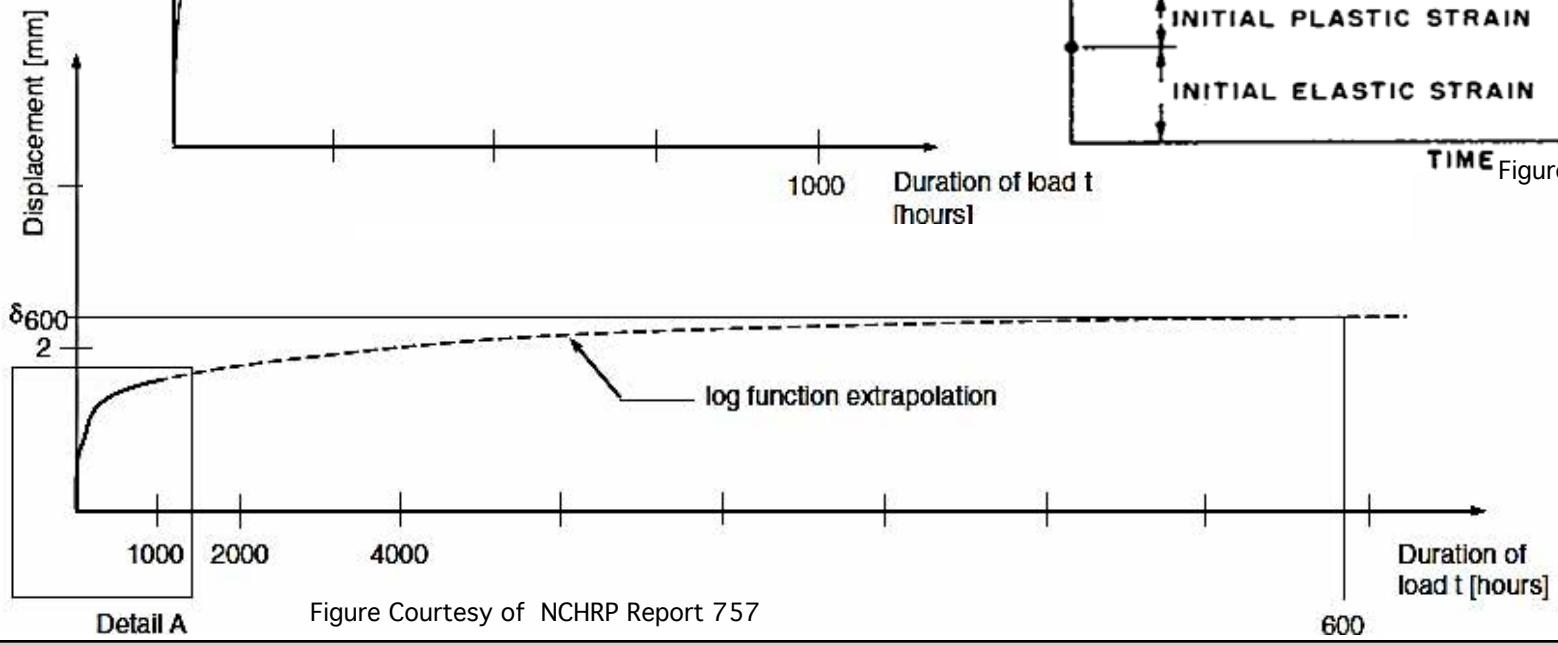


Figure Courtesy of NCHRP Report 757

ACI 355.4: *Qualification of Post-Installed Adhesive Anchors in Concrete*

Acceptance Criteria

- 600 day displacement must be less than displacement at failure of short term elevated temperatures test
- 50yr displacement must be less than displacement at failure of short term standard temperatures test
- Residual capacity must be 90% of short term tests

Qualifications of Post Installed Anchors

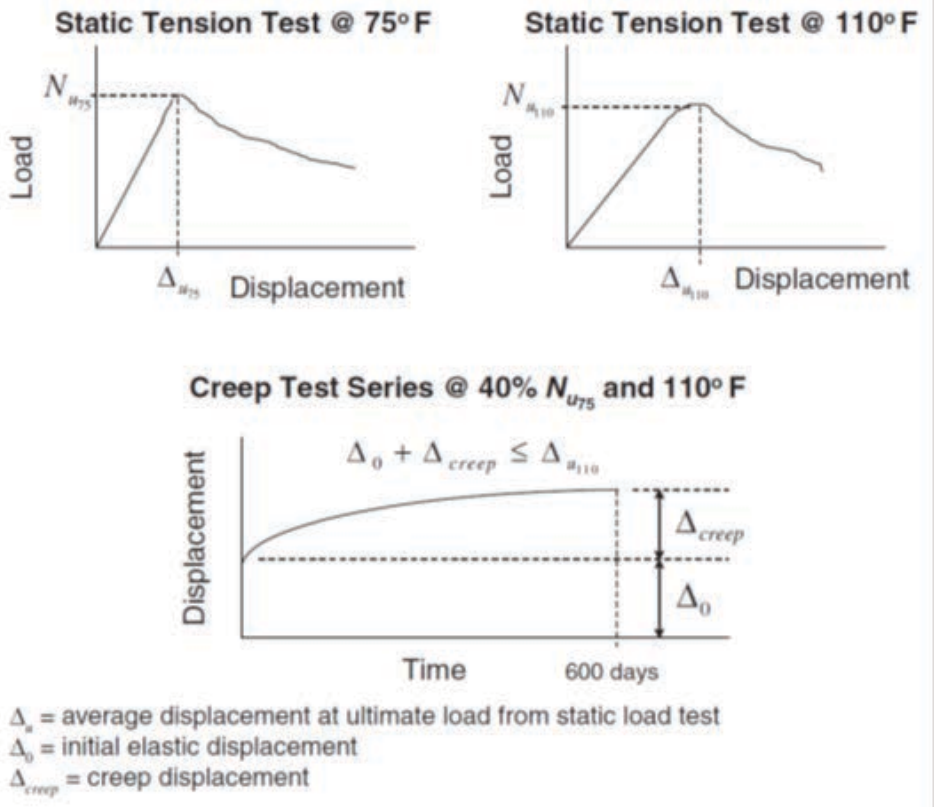
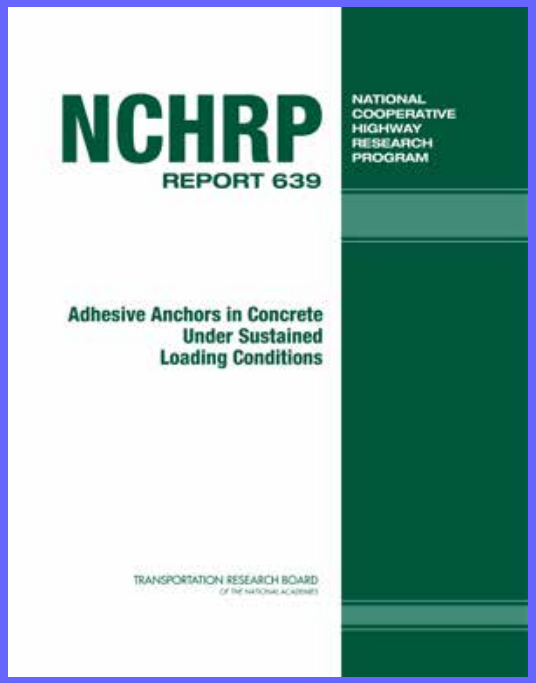
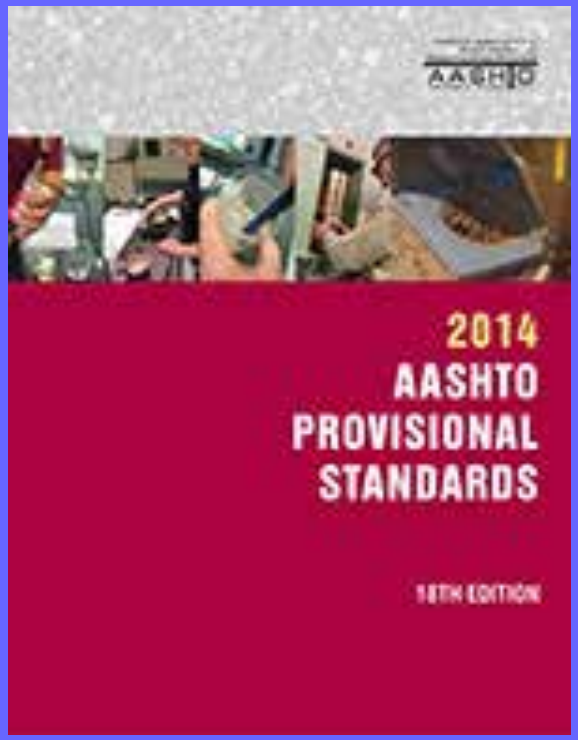


Figure 11. Basic pass/fail criteria per ICC-ES AC58.

Figure Courtesy of NCHRP Report 757


NCHRP
REPORT 639
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Adhesive Anchors in Concrete Under Sustained Loading Conditions
TRANSPORTATION RESEARCH BOARD


NCHRP
REPORT 757
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Long-Term Performance of Epoxy Adhesive Anchor Systems
TRANSPORTATION RESEARCH BOARD


AASHTO
2014
AASHTO
PROVISIONAL
STANDARDS
1 8TH EDITION

AASHTO TP-84: *Standard Method of Test for Evaluation of Adhesive Anchors in Concrete under Sustained Loading Conditions*

- Published: 2009, Approved 2014
- Anchors Tested: Bonded
- Parameters Tested:
  - **In Service**: Sustained Load at Elevated Temperature 110° F to 120° F (43° C to 48° C)
  - **Installation**: None
  - **Anchor Related**: None
  - **Concrete Related**: None

AASHTO TP-84: *Standard Method of Test for Evaluation of Adhesive Anchors in Concrete under Sustained Loading Conditions*

- Data Output:
  - **Static Tests**: Force, Displacement
  - **Creep Tests**: Time, Force, Displacement, Stress vs Time to Failure Plot

- Creep Tests Conducted to Failure
  - 5 Short Term Tests
  - 5 Tests at a sustained load between 60% and 70% of short term capacity
  - 5 Tests at a sustained load between 70% and 80% of short term capacity

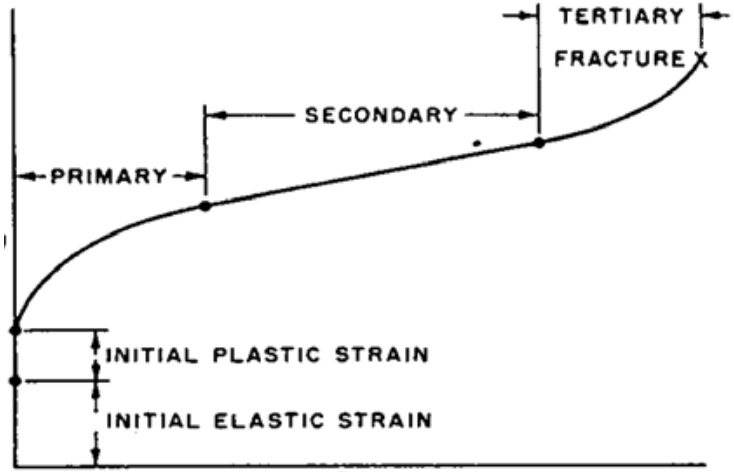
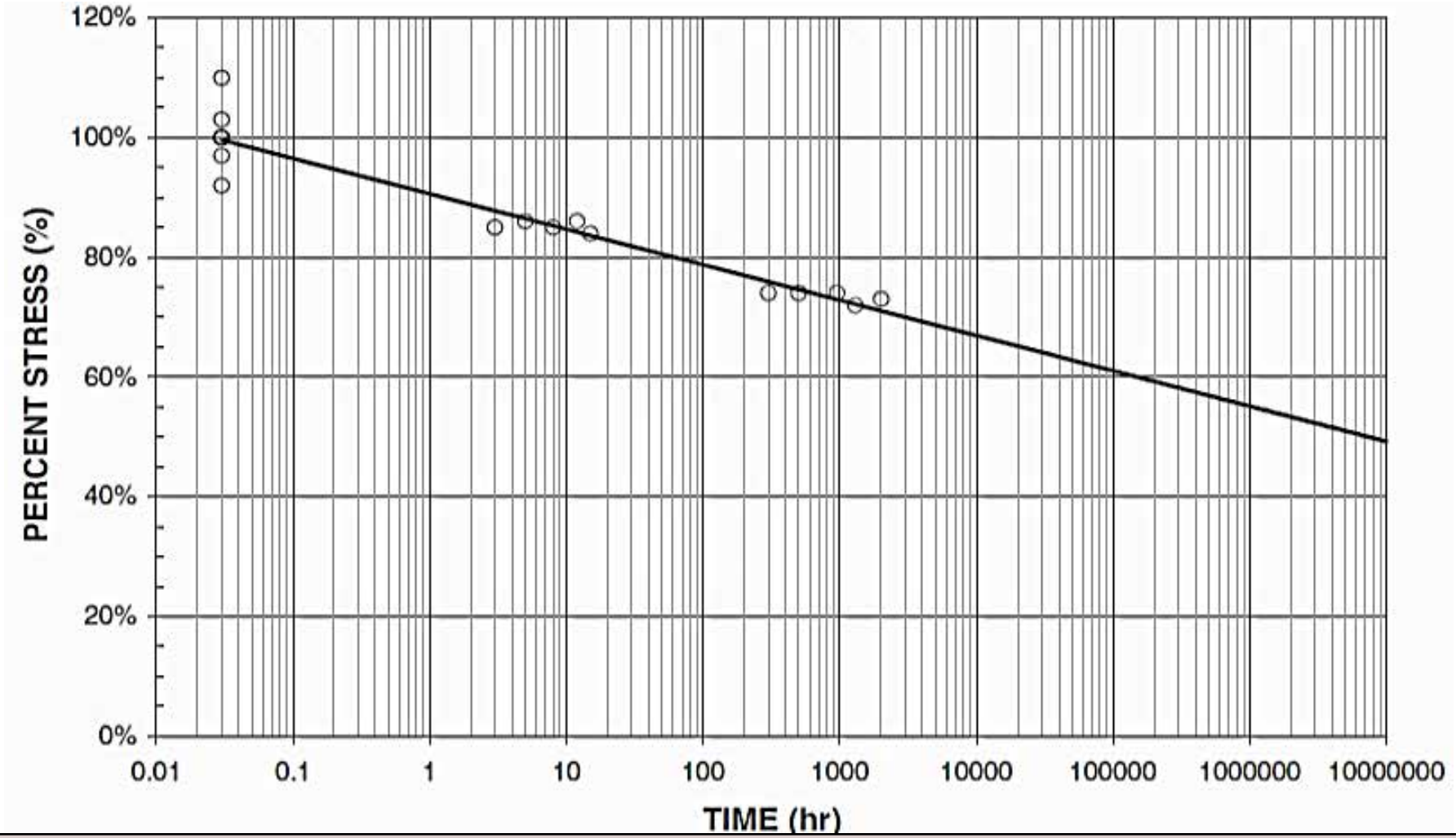


Figure Courtesy of ASTM D2990

Stress Vs Time to Failure Plot



Recommended Changes to AASHTO TP-84

1. Do not use short term test data in building stress vs time to failure plot
2. Use three sustained load levels instead of two

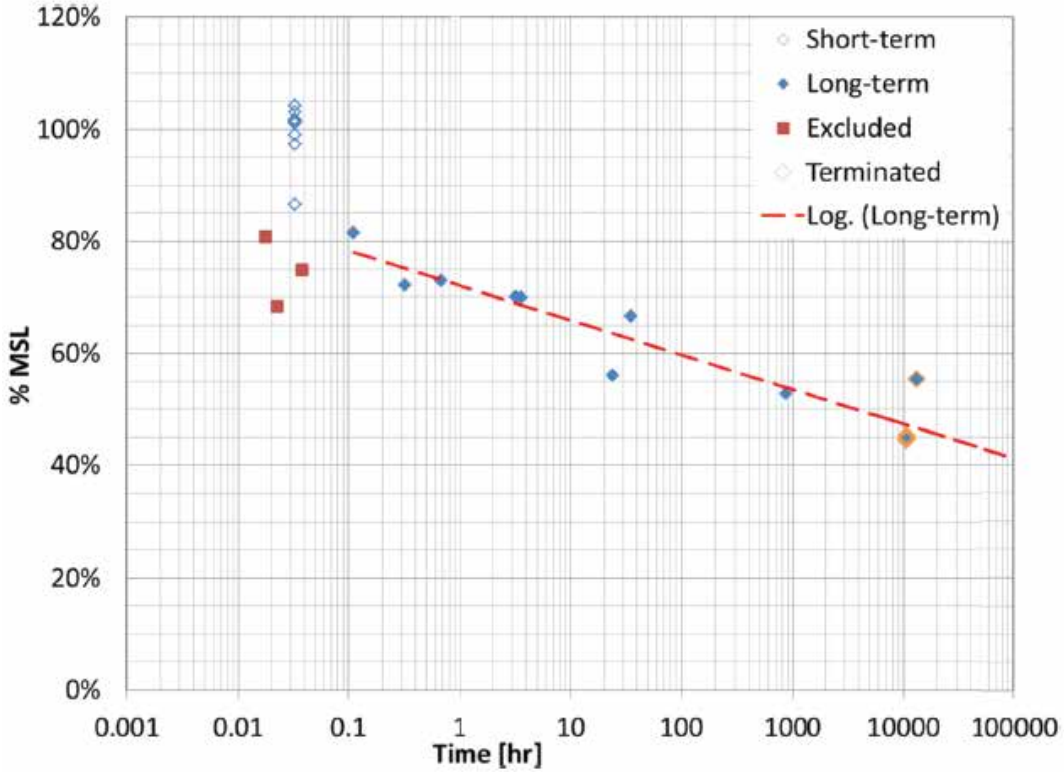
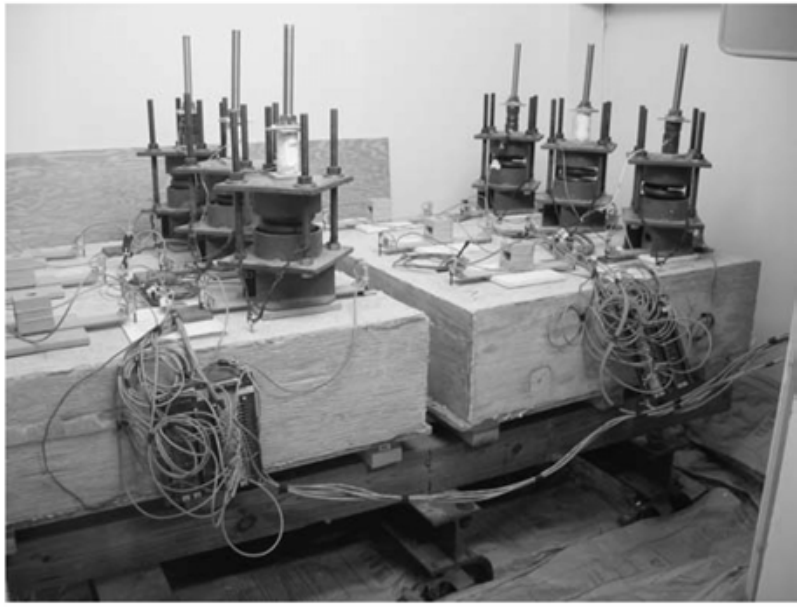


Figure Courtesy of NCHRP Report 757

- NCHRP 757
  - 48 Sustained Load Tests of Time to Failure
  - 30 Reference Tests (Static) of Time to Failure
  - 72 Sustained Load Tests of Standard Method
  - 30 Reference Tests (Static) of Standard Method
  - 216 Sustained Load Tests Total
  - 185 Reference Tests (Static) Total

Proposed UMass Research Program

RESEARCH APPROACH



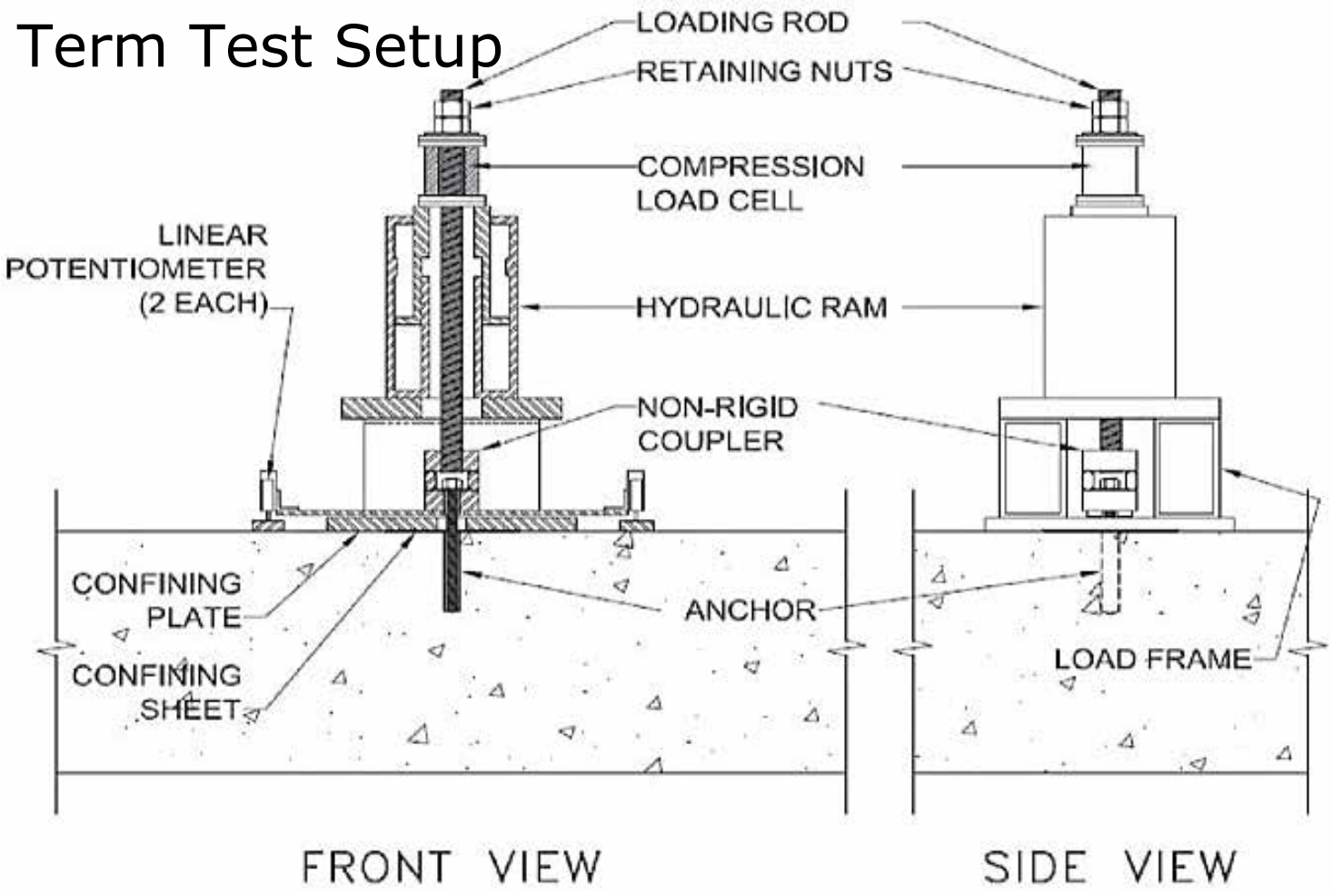
Florida Testing per NCHRP 639 and 757

Research Approach

- 16″x16″x12″ Deep (406mm x 406mm x 304mm) Concrete Specimens of 4000psi concrete
- Anchors Installed in accordance with Manufacturer's Printed Instructions
- Short Term Tests Conducted to Establish Baseline Short Term Capacity
- Long Term Tests Conducted at Elevated Temperature in Environmental Chamber (to be built)

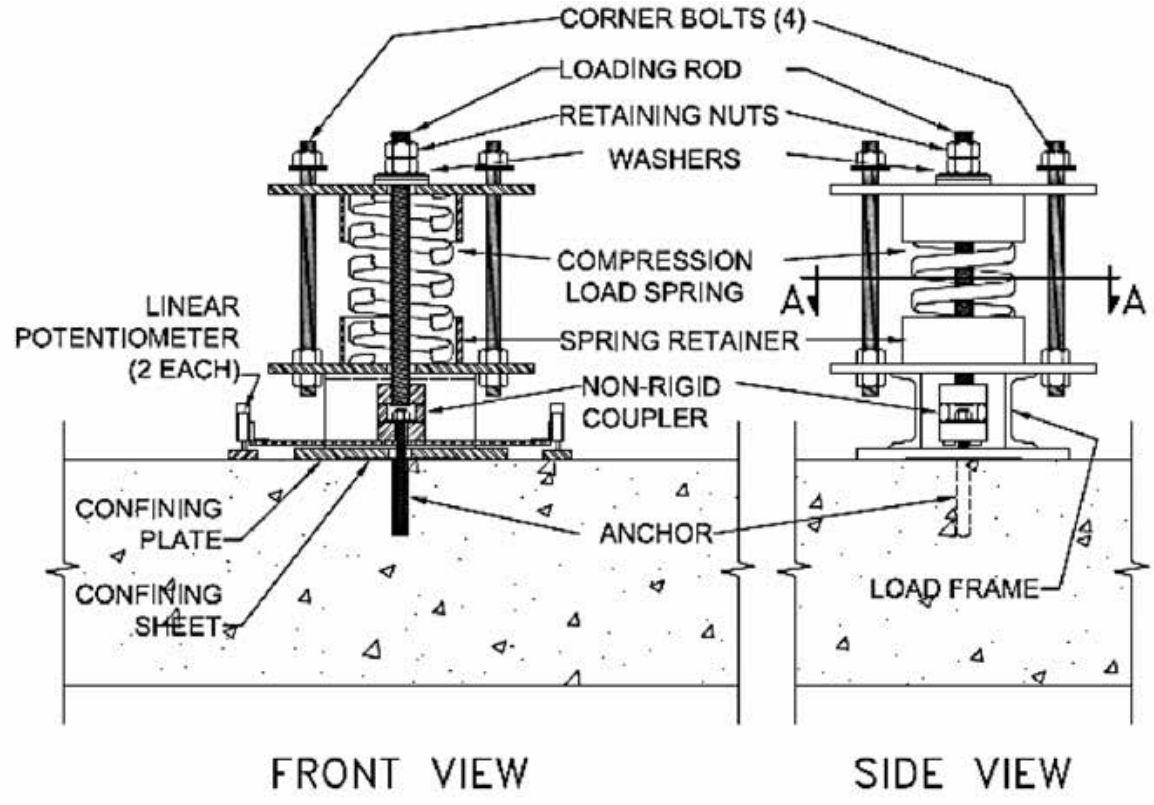
Research Approach

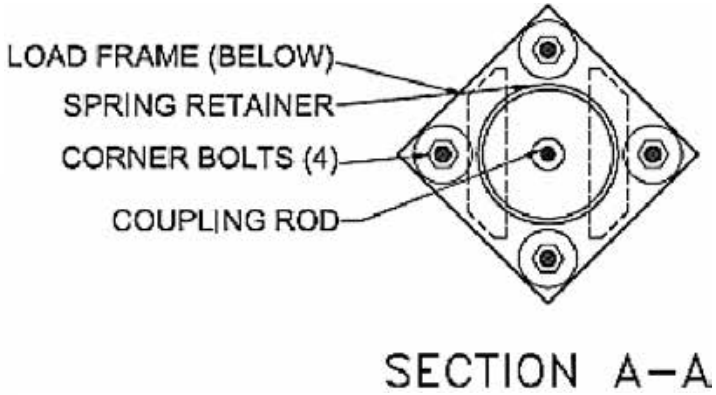
- Short Term Test Setup



Research Approach

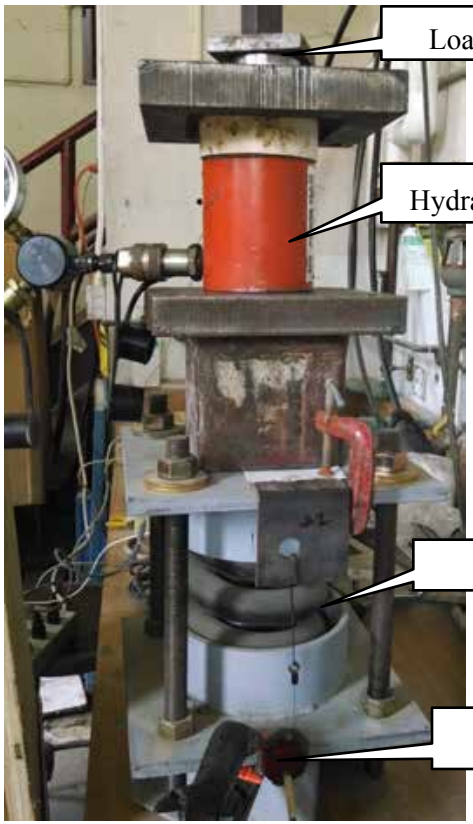
- Long Term Test Setup

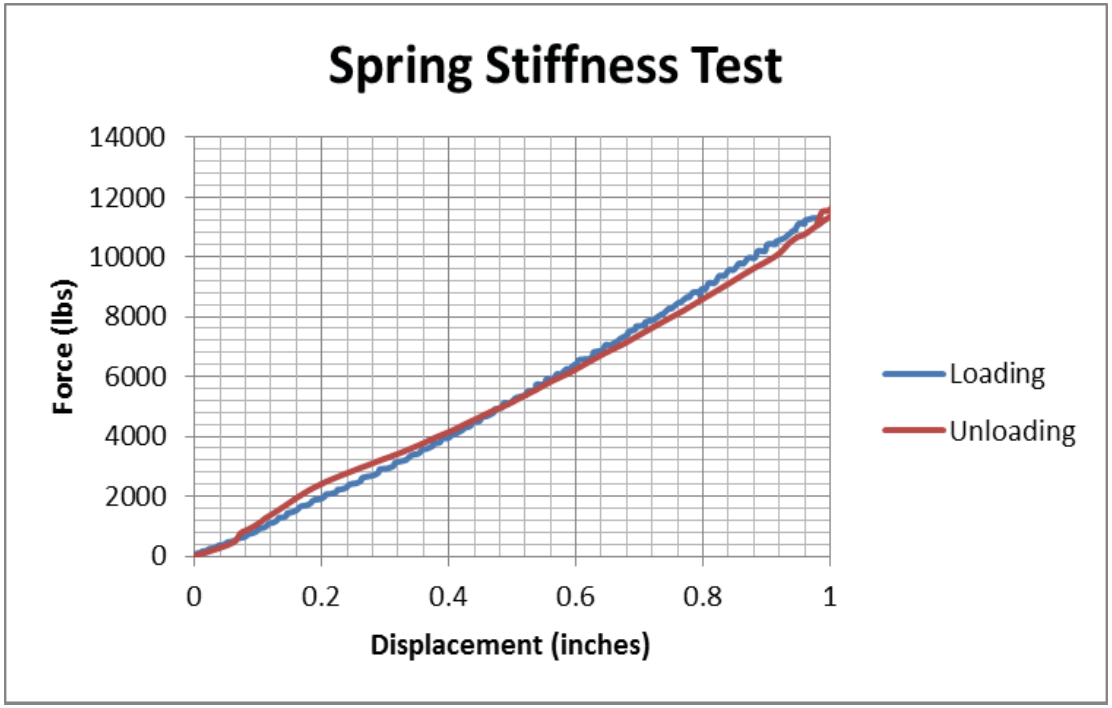




Spring Calibration

- Spring Stiffness 11.5 kips/in (14 kN/m)





Purpose

- Develop Test Capabilities to Meet AASHTO TP-84 testing methods at UMass Amherst
- Identify Gaps in Research and Standards Regarding Definitions and Testing Methods of Bonded Anchors
- Recommend Qualification Criterion for Bonded Anchors

MassDOT Project

- Contracting in place from MassDOT – 2 year project
- Project Kick-Off Meeting 9/18/14
- Initial approval requested to begin purchase of materials
- Year 1 – Focus initially on three previously approved anchor systems; AASHTO TP-84 methodology

QUESTIONS?

MassDOT Project

- Contracting in place from MassDOT – 2 year project
- Project Kick-Off Meeting 9/18/14
- Initial approval requested to begin purchase of materials
- Year 1 – Focus initially on Hilti HIT-RE 500-SD, Simpson Strong-Tie SET-XP, and Chemofast C-RE 385; AASHTO TP-84 methodology

Presentation

- Purpose
- Introduction
  - Cast in Place Anchor Systems
  - Mechanical Post Installed Anchor Systems
  - Bonded Post Installed Anchor Systems
- Bonded Anchor Systems
  - Installation Procedures
  - Failure Modes/Behavior Models
  - Parameters That Affect Capacity
  - Test Standards
- Research Approach/Future Work

Adhesive Anchors (Hole Diameters Less Than 1.5 x Anchor Diameter)

Adhesive *– Any adhesive comprised of chemical components that cure when blended together. Adhesives are formulated from organic polymers, or a combination of organic polymers and inorganic materials. Organic polymers used in adhesives can include, but are not limited to, epoxies, polyurethanes, polyesters, methyl methacrylates and vinyl esters. – ACI 355.4*

Preliminary Concrete Specimens

- Three Specimens were cast on June 4th using 4000psi Sakrete

- Specimens will be used to validate pullout test methods and anchor installation procedures