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ATTACHMENT A
ATTACHMENT B
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1.0 Introduction

This design guide applies to cast-in-place, cementitious grouted, post-installed mechanical and post-installed adhesive steel anchors and reinforcing bars. This guide does not apply to specialty inserts, through-bolts, multiple anchors connected to a single plate, or direct fasteners such as powder or pneumatic actuated nails or bolts. It has been prepared for use by Parsons Brinckerhoff (PB) engineering staff and may not be distributed to or used by others without written approval of PB.

This guide is applicable to steel anchors used in transportation structures, including but not limited to buildings; fixed and movable highway bridges, pedestrian bridges and viaducts; light and heavy rail structures; below-grade structures including tunnels and open approaches; and ancillary structures such as ladders, railings, platforms, barriers, fences, sign structures and luminaries.

While this guide is referenced to US standards and specifications, it is recognized that it may need to be modified for specific projects where additional codes and criteria may also apply. It is a guide, not a standard or a specification, and it may not apply to certain applications; thus, its use shall be under the supervision of a licensed professional engineer with relevant applicable experience.

This guide is an outgrowth of the collapse of a portion of the Central Artery tunnel ceiling support system in 2006. While those involved at the time believed that they had followed appropriate materials and procedures, an investigation by the National Transportation Safety Board identified problems in the materials, design and installation of the adhesive anchors used in the tunnel ceiling support system as the cause of the collapse. In response, PB has prepared this design guide. In preparing this guide, it was recognized that there was a need for a guide that considered all types of anchors used in transportation structures. Thus, the intent is to make available to PB staff a guide that can be used for the design and installation of anchors in the various types of transportation structures that are designed and/or inspected by PB.

With regard to adhesive anchors in particular, this guide reflects what is believed to be the current state of the art. However, studies and code development for adhesive anchors are currently underway by both the National Cooperative Highway Research Board and the American Concrete Institute Committee 355, Anchorage to Concrete. It is anticipated that these efforts will revise the current criteria used in this guide. Thus, this guide will be revised as those new criteria/codes are developed. It is very important that those professionals using anchors and in particular adhesive anchors, stay abreast of the technical literature when considering, designing or installing adhesive anchors.

This guide was prepared, under the supervision of Tony Lancellotti, P.E., by Michael J. Abrahams, P.E. and Julio Valvezan, P.E., and they request that any comments or errors be sent to either Abrahams@pbworld.com or Valvezan@pbworld.com.
2.0 General Considerations

2.1 TYPES OF ANCHORS

Cast-in-Place Anchors

Grouted Anchor

Anchor Sleeves
Post-Installed Mechanical Anchors

Undercut Mechanical Anchor

Screw Anchor

Wedge Expansion Anchor

Undercut Anchor

Sleeve Anchor
2.2. GLOSSARY OF TERMS

**Adhesive Anchor** – A device for transferring tension and shear loads to structural concrete, consisting of an anchor element embedded with an adhesive compound in a hole that has been drilled in hardened concrete. These are typically referred to as epoxy, chemical, acrylic, or polyester anchors.

**Mechanical Anchor** – An anchor inserted into hardened concrete that transfers loads to or from the concrete by direct bearing or friction or both. The anchor may be torque-controlled or displacement-controlled. Mechanical anchors include expansion anchors, sleeve anchors undercut anchors, and screw anchors.

**Post-Installed Anchors** – Anchors installed in hardened concrete.


**Cast-In-Place Embedded Anchors** – Anchors that are positioned before the concrete is cast.

**Cementitious Grouted Anchors** – Mechanical anchors that are installed in a large diameter preformed or drilled hole. Once the anchor is placed, the hole is filled with cementitious grout.

**Undercut Anchors** – A post-installed mechanical anchor that develops its tensile strength from the mechanical interlock provided by undercutting of the concrete at the embedded end of the anchor. The undercutting is achieved with a special drill before installing the anchor or alternatively by the anchor itself during its installation.

**Aggressive Exposure Condition** – Any anchor environmental exposure that may be characterized as equivalent to that produced by exposure of an adhesive compound to high alkalinity (pH 13) and a high sulfur dioxide concentration (0.7%).

### 2.3. ANCHOR SELECTION

In selecting the type of anchor to be used, there are many factors to be considered that affect long-term performance and strength including but not limited to the following:

- Environmental exposure can affect not only the anchor steel, but can also affect the adhesive and the substrate that supports the anchor. Over time, materials such as concrete can degrade in the vicinity of the anchor and affect its performance.

- Adhesive anchors are particularly sensitive to temperature. Unless otherwise qualified by testing, adhesive anchors shall not be used when they will be exposed to sustained temperatures above 110°F or short-term temperatures above 180°F. Unpredictable events, such as fires, can significantly affect the adhesive’s ability to carry the required load.

- The type of load, whether static or dynamic can affect the performance of the anchors. Anchors can vibrate loose depending on the type and cyclic nature of the load. Testing must follow a program that matches the in-service load conditions.

- The direction of the load can also affect the ability of the anchor to perform as designed. Some anchors perform well in tension but not in compression.

- The load duration can also affect performance. Adhesive anchors can creep under sustained loads. The amount of creep that will occur must be determined by testing and compared to acceptable levels.

- Loads on anchors close to edges of supporting members and loads toward the edges can significantly reduce the maximum load that an anchor can withstand.

- The strength of many anchors is limited, not by the anchor, but by the substrate that supports the anchor. Concrete, hollow block walls, bricks and stone have very different strengths that can limit the maximum load that an anchor can carry.

- Anchor capacities are reduced when they are installed in concrete that is cracked at service loads. Under recent codes, cracking is assumed to occur when, under service load or imposed deformation, the tensile stress in the concrete exceeds the modulus of rupture. Anchors need to have been tested to demonstrate that they can be used in cracked concrete.

- Anchor embedment affects the depth of concrete that is mobilized and how far the load spreads through the concrete.
• For anchor groups, the anchor spacing and embedment depth affect the influence of one anchor on another and the group pattern determines how much of the concrete participates in resisting the anchor loads.

• Installation and drill hole preparation, including the type of drill and condition of the hole must conform to the anchor manufacturer’s recommendation. On-site quality control and inspection is required to verify that the installation is being performed properly and that the anchor can carry the required loads. Post-installed anchors have only been tested for holes prepared by a carbide drill bit unless specific testing for core-drilled holes has been performed.

The ability of anchors to carry the required loads and perform as designed over the life of the structure depends on the proper selection, installation, hole preparation and the substrate supporting the anchor. Anchors may fail because of many factors including the following:

• **Adhesive anchors in sustained tension.** The adhesive will flow (creep) under the sustained tensile load and the anchor may pull out. The only indication that is visible is that the nut appears to have loosened or one may conclude that it has not been tightened properly. If a loose nut is observed, the cause should be investigated. Retightening the nut will only cause the nut to loosen more. The FHWA and this guide do not allow adhesive anchors to be used in sustained tension, including overhead applications.

• **The hole for a post-installed anchor is not drilled with a carbide tipped bit using a rotary hammer drill.** Other bits may damage the concrete during drilling and affect the mechanical interlock of the anchor or it may create a hole whose surface is too smooth for the adhesive to develop a proper bond. Only post-installed anchors that have been specifically tested for other types of bits or drills would be acceptable.

• **The post-installed anchor hole is not drilled with the manufacturer’s recommended drill bit diameter.** The diameter of the hole is tightly controlled during qualification testing. Larger hole diameters may cause the adhesive to flow when the anchor is tightened and the nut may appear loose. Smaller hole diameters may not allow sufficient adhesive to be inserted. Post-installed mechanical anchors may also not perform well with larger or smaller hole diameters than used in the test report.

• **Corrosion due to galvanic action between dissimilar metals in contact.** Some materials are not compatible with each other and when they are in contact, a corrosion process begins. This corrosion may be prevented if the two materials are isolated using neoprene, coal tar or other materials. Materials such a stainless steel, aluminum or galvanized coatings are susceptible to dissimilar metal corrosion.

• **Hole preparation affecting post-installed anchor adhesive bond.** Adhesives are sensitive to the hole preparation. If the hole is dirty or in some cases, wet, the adhesive may not bond properly. The installation must follow the tests used to qualify the anchor to ensure that the anchor hole is in accordance with the test report.

• **Type of adhesive used.** Not all adhesives are the same. Cure times and shelf life for adhesives are all different. Installation temperatures, substrate temperatures, and service temperatures can affect the performance. The adhesive selected must be compatible for the load and environment where the anchor will be used. Their suitability must be demonstrated by testing performed in accordance with AC308.
• **Overtightening of the anchor.** If the anchor nut is over tightened, the anchor, adhesive or substrate may fail. The AC308 test report must be followed to ensure proper performance of the anchor.

• **High temperatures on anchors.** Adhesive anchors do not perform well when exposed to elevated temperatures. A fire can cause an adhesive anchor to fail. Fires can also cause the concrete cover to spall so mechanical anchors should extend below the reinforcement. Only adhesive anchors that have been tested per AC308 for higher temperature, i.e., sustained temperatures above 110°F or short-term temperatures above 180°F shall be used in this application.

• **Post-installed expansion anchors in compression.** Expansion anchors that derive their strength by maintaining tension on the expansion mechanism can pull out of the hole if they are loaded in compression and then again in tension. These anchors must never be loaded in compression.
3.0 Design Criteria

3.1 GENERAL

While steel anchor bolts have been used extensively for over 100 years, their design criteria was not well documented until more recently when an anchor bolt design guide was prepared as part of ACI 349 Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary. More recently this guide has been modified and adopted by ACI 318, Building Code Requirements for Structural Concrete and Commentary, Appendix D for Strength Design Method. The ACI 318 Appendix D code requirements form the basis of PB’s guide for the design of cast-in-place, cementitious grouted, and post-installed mechanical anchors. However, the ACI 318 Appendix D and ACI 349 are not the same and both should not be used for a design. This guide may be used for the design of cementitious grouted anchors with due consideration for the loads at the grout/concrete interface. The failure modes described in ACI 318 Appendix D apply to cementitious grouted anchors as well. The forces at the interface between the grout and concrete shall be analyzed as in accordance with ACI 318.

These ACI code requirements do not currently include post-installed adhesive anchors, which are covered in the International Code Council Evaluation Service Approved Criteria (ICC-ES AC) 308 - Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements. However, ACI Committee 355, Anchorage to Concrete is currently developing ACI 355.XR Design Examples and ACI 355.YR Qualifications of Post-Installed Adhesive Anchors in Concrete, which, when available, will likely supersede ICC-ES AC308. It is also noted that the Transportation Research Board’s National Cooperative Highway Research Program (NCHRP) has issued a request for proposals to develop proposed standard test methods and specifications, design guide and specifications, and quality assurance guide and construction specifications for the use of epoxy adhesive anchor systems in transportation structures. This will be a three-year undertaking.

Currently, the Federal Highway Administration (FHWA) has indicated in Technical Advisory T 5140.30 that adhesive anchors shall not be used in sustained tension nor in overhead applications.

It is no longer appropriate to rely on published anchor capacities shown in the manufacturer’s web site or catalogs for post-installed mechanical or adhesive anchors. Designers should consult the most recent published test results in the ICC-ES web site for the specific anchor selected. ICC-ES is a non-profit, public benefit corporation that evaluates products for conformance with code. ICC-ES is the leading testing organization in the United States and is commonly used by anchor manufacturers to test their products. Prior to incorporation of an anchor into a design or construction, one needs to check that the design and testing have been performed in accordance with the latest version of ACI 355.2 or AC193 for post-installed mechanical anchors and AC308 for post-installed adhesive anchors. Currently there are no recognized test methods for post-installed anchors for vibration/fatigue, shock/impact or blast loading in ACI 355.2, AC193 or AC308. Anchors subject to seismic, fatigue, or shock shall be tested in accordance with ASTM E488. Specific test procedures will need to be developed for blast loading. (Refer to Section 5.0, References for additional information.)
There have been major recent revisions to the requirements for the design and testing of anchors that now need to be taken into consideration during design and installation. These considerations include the design of anchors for cracked concrete. The design of anchors also needs to consider, where applicable, seismic loading, vibration/fatigue, shock/impact and blast loading – and all three are different so an anchor that has been tested for seismic loading may not be suitable for vibration loading, and an anchor that has been tested for vibration loading may not be suitable for shock or blast loading.

3.2. CRITERIA

Anchors and anchor groups shall be designed using Strength Design Method (Load Factor Design) based on the critical effects of factored loads as determined by elastic analysis. Figure 1 shows failure modes of anchors based on ACI 318 Appendix D.

ACI 318 Appendix D does not apply to specialty inserts, through–bolts, multiple anchors connected to a single steel plate at the embedded end of the anchors or direct anchors such as powder or pneumatic actuated nails or bolts. For these, one will need to utilize other relevant codes or test results.

All anchors for use in exterior exposure or damp environments shall be mechanically galvanized or stainless steel. For aggressive applications, only Type 316 stainless steel anchors shall be used. Proper consideration should be given to contact between galvanically dissimilar metals.
Figure 1
Failure Modes of Anchors Based on ACI 318 Appendix D
3.3. CAST-IN-PLACE AND CEMENTITIOUS GROUTED ANCHORS

Cast-in-place anchors and cementitious grouted anchors shall be designed in accordance with ACI 318 Appendix D.

ACI 318 Appendix D does not apply to reinforcement used as part of embedment. Reinforcement used as part of embedment shall be designed in accordance with the relevant code: ACI or IBC for buildings; AASHTO for highway bridges; and AREMA railway bridges.

For seismic loads, one needs to follow the specific requirements in ACI 318 Appendix D. ACI 318 Appendix D does not apply to loads that are predominantly high-cycle vibration/fatigue, shock/impact or blast loads. Seismic conditions are not considered to be high-cycle fatigue.

The provisions of ACI 318 Appendix D do not apply to plastic hinge zones of concrete structures under earthquake loads.

The design requirements in ACI 318 Appendix D are based on anchors with a maximum diameter of 2 inches and an embedment depth not greater than 25 inches.

ACI 318 Appendix D is limited to $f'c = 10,000$ psi for cast-in-place anchors.

Cementitious grouted anchors shall use cementitious grout. In no instance shall any type of organic/epoxy grout be used. The grouted anchors shall be placed in a corrugated sleeve or an internally roughened hole that fully develops the tensile strength of the anchor. The strength of the grout shall match or exceed the strength of the adjacent cast-in-place concrete.

When designed for fire exposure, it shall be assumed that all concrete outside of the reinforcing has spalled. Therefore, embed the anchor behind the reinforcing mat.

3.4. POST-INSTALLED MECHANICAL ANCHORS

Post-installed mechanical anchors shall be designed in accordance with ACI 318 Appendix D.

Post-installed mechanical anchors shall be qualified in accordance with ACI 355.2 or ICC-ES AC193.

ACI 318 Appendix D is limited to $f'c = 8,000$ psi for post-installed anchors.

Post-installed mechanical anchors with a maximum diameter of 2 inches and an embedment depth not greater than 25 inches, in seismic zones shall be designed in accordance with ACI 355.2-07.

The provisions of ACI 318 Appendix D do not apply to plastic hinge zones of concrete structures under earthquake loads.

ACI 355.2 does not apply to post-installed mechanical anchors loaded in compression when the expansion mechanism is also loaded in compression.

Post-installed mechanical anchors subject to seismic loads shall be tested per ACI 355.2.
ACI 355.2 or AC193 do not apply to post-installed mechanical anchors subjected to vibration/fatigue/shock/impact or blast loading. For the design of post-installed anchors for vibration/fatigue/shock/impact or blast loads, one needs to utilize a specific testing regime, such as found in ASTM E488, which provides test methods for seismic, fatigue, and shock loads, or as found elsewhere in the engineering literature for the applicable loading. If no testing regime exists, for example for blast loads, one may need to conduct testing for the specific application being considered. Post-installed anchors that have been tested for seismic loads shall not be used as anchors subject to vibration/fatigue/shock/impact or blast loads. Post-installed anchors that have been tested for vibration loads have not been qualified for impact for shock or blast loads.

Post-installed expansion type anchors shall not be used as hold-down anchor bolts.

When designed for fire exposure, it shall be assumed that all concrete outside of the reinforcing has spalled. Therefore, embed the anchor behind the reinforcing mat.

For post-installed mechanical anchors consideration needs to be given to the specific tests that have been used to qualify the anchors, drill hole conditions, exposure and inspection regimen.

3.5. **POST-INSTALLED ADHESIVE ANCHORS**

One needs to be aware that there have been several revisions to adhesive anchor testing requirements within the last year, and manufacturers may not have tested their products to the more recent revisions. At the time of the preparation of this guide, only a few manufacturers are believed to meet current AC308 standards. Use only the most recent test results.

Post-installed adhesive anchors shall be designed in accordance with ACI 318 Appendix D as modified by ICC-ES AC308 Article 3.0 Design Requirements. Strength Design values may be converted to Allowable Stress Design values. The latest test results from ICC-ES are needed for design. Do not rely on manufacturer’s literature for test results.

Post-installed adhesive anchors shall be tested in accordance with ICC-ES AC308. AC308 applies to anchors with a minimum diameter of ¼ inch.

Adhesive anchors shall not be used in any permanent sustained tension application or in any overhead application. Adhesive anchors shall not be used in wall brackets where they would be in sustained tension (e.g., a pipe support bracket). They could be used in a handrail bracket.

Adhesive anchors shall not be used in any application where they will be exposed to sustained temperatures above 110°F unless they have been tested for higher temperatures in accordance with ICC-ES AC308.

Adhesive anchors shall not be used in any application where they will be exposed to short-term temperatures above 180°F unless they have been tested for higher temperatures in accordance with ICC-ES AC308.

Adhesive anchors shall not be used in any application where they may be exposed to fire.

For post-installed adhesive anchors, consideration needs to be given to the specific tests that have been used to qualify the anchors, drill hole conditions, exposure and inspection regimen. Post-installed adhesive anchor designs need to also consider if the anchor is loaded in permanent
tension (including but not limited to overhead anchors), creep, installation temperature, short-term temperature and long-term temperature, including but not limited to fire.

For the design of post-installed anchors for vibration/fatigue, shock/impact or blast loads one needs to utilize a specific testing regime, as found in the engineering literature, or if no testing regime exists, one may need to conduct testing for the specific application being considered. Post-installed anchors that have been tested for seismic loads shall not be used as anchors subject to vibration/fatigue, shock/impact or blast loads. Post-installed anchors that have been tested for vibration loads shall not be used for impact or shock loads.

Post-installed adhesive anchors installed in seismic zones shall be tested in accordance with Article 9.12 of AC308.

3.6. ANCHOR REINFORCEMENT OR SUPPLEMENTARY REINFORCEMENT

Anchor reinforcement, as defined in ACI 318 Appendix D, is reinforcement designed and detailed specifically to transfer the full anchor load from the anchor into the structural member. For conditions in which the anchor force exceeds the concrete breakout design strength, the design strength of anchor reinforcement (typically installed before the concrete is cast) may be used instead. The reinforcement may be detailed to resist tension or shear as shown below.

Supplementary reinforcement has a similar configuration and placement to that of anchor reinforcement, and therefore acts to restrain the potential concrete breakout. However, it is not specifically designed to transfer the full anchor load into the structural member, and is used only to justify an increase in the strength reduction factors (φ-factor) applied to the concrete breakout or side-face blowout strengths, but not replace those failure modes, as considered with anchor reinforcement. Stirrups, as used for shear reinforcement, may fall into the category of supplementary reinforcement. The reinforcement is typically installed before the concrete is cast.

Adapted from ACI 318 Fig. RD.5.2.9
Adapted from ACI 318 Fig. RD.6.2.9
4.0 Design Examples

4.1. CAST-IN-PLACE AND CEMENTITIOUS GROUTED ANCHORS

See Attachment A:

- Cast-in-place anchor bolt with sustained tension
- Cast-in-place anchor bolt in shear
- Cast-in-place anchor bolt in combined shear and sustained tension due to moment

4.2. POST-INSTALLED MECHANICAL ANCHORS

See Attachment B:

- Post-installed mechanical anchor with sustained tension
- Post-installed mechanical anchor in shear
- Post-installed mechanical anchor in combined shear and sustained tension due to moment

4.3. POST-INSTALLED ADHESIVE ANCHORS

See Attachment C:

- Post-installed adhesive anchor with temporary tension
- Post-installed adhesive anchor in shear
- Post-installed adhesive anchor in combined shear and sustained tension due to moment – sustained tension is not permitted.
5.0 References


AASHTO LRFD Bridge Design Specifications Article 14.5.3.6 Anchors and 14.5.3.7 bolts, 4th Edition, 2008 I


ACI 318-08 Building Code Requirements for Structural Concrete Article 12.6 and Appendix D – Anchoring to Concrete with 1st and 2nd printing Errata.

ACI 349-06 Code Requirements for Nuclear Safety Related Concrete Structures, Appendix B

ACI 349.2R-07 Embedment Design Examples Concrete Capacity Design Method

ACI 351.1R-99 Grouting between Foundations and Bases for Support for Equipment and Machinery Article 6.2

ACI 355.1R-91 (Reapproved 1997) State-of-the-Art Report on Anchorage to Concrete

ACI 355.2-07 Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary

AREMA Chapter 15 Article 10.3.7 Anchor Bolts and Rods, 2007

ASTM E488. Standard test methods for strength of anchors in concrete and masonry elements


FHWA Technical Advisory T 5140.30, Use and Inspection of Adhesive Anchors in Federal-Aid Projects

International Building Code (IBC), 2006

ICC-ES AC193 - Acceptance Criteria for Mechanical Anchors in Concrete Elements


Salim et al, Shock Capacity of Concrete Anchoring Systems in Uncracked Concrete, ASCE Journal of Structural Engineering, August 2005, Volume 131, Number 8,


Note: PB staff may access many of these codes via PB’s intranet IHS standards website at: http://www.pbworldnet.com/applications/ihs/PB_Standards_Expert.htm
6.0 Guide Specifications
Guide Specification

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Notes to Specifier: This Guide Specification is available in electronic format (MS Word) on PB WorldNet/Hub. Specification Section numbers are based on CSI Masterformat 1995. Edit this Guide Specification for project-specific requirements. For bracketed italic items, choose applicable item(s).

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PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Requirements for furnishing all labor, materials, tools, and equipment, and performing all operations necessary for cast-in-place anchors, cementitious grouted anchors, post-installed (drilled-in) mechanical anchors, and post-installed (drilled-in) adhesive anchors for as indicated on the Contract Drawings and specified herein.

1.02 REFERENCED SECTIONS

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Notes to Specifier: Referenced Section numbers based on CSI Masterformat 1995, applicable to most Contract Document sets. Revise as applicable to Project scope.

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A. Section 01330 - Submittal Procedures

B. Section 01780 - Closeout Submittals

1.03 CITED STANDARDS

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Notes to Specifier: Standards shall be cited based on specific cross-reference elsewhere in the Section. Use AASHTO for highway work and AREMA for rail work; choose applicable standards. Latest edition of standards at time of construction shall apply. During preparation of this Specification the latest standards are indicated, however, the Design Engineer must investigate the latest editions as they may have been updated.

************************************************************************
A. American Association of State Highway and Transportation Officials (AASHTO)
   1. {LRFD Bridge Design Specifications}
      a. {Article 14.5.3.7 - Bolts}
      b. {Article 14.8.4 - Anchorage and Anchor Bolts}
   2. M31 - Deformed and Plain Billet Steel Bars for Concrete Reinforcement
   3. M314 - Steel Anchor Bolts

B. American Concrete Institute (ACI) {Additional ACI standards, as applicable}
   1. 318-08 - Building Code Requirements for Structural Concrete, Appendix D - Anchoring to Concrete
   2. {349 - Code Requirements for Nuclear Safety Related Concrete Structures, Appendix B}
   3. {349.2R - Guide to the Concrete Capacity Design (CCD) Method - Embedment Design Examples}
   4. 355.2-07 - Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary

C. American National Standards Institute (ANSI)
   1. Cutting Tools - Carbide-Tipped Masonry Drills and Blanks for Carbide-Tipped Masonry Drills

D. {American Railway Engineering and Maintenance-of-Way Association (AREMA)}
   1. {Chapter 15 - Bridge Bearings, Article 10.3.7 - Anchor Bolts and Rods}

E. ASTM International (ASTM)
   1. A153 - Zinc Coating (Hot-Dip) on Iron and Steel Hardware
   2. A615 - Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
   3. A706 - Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
   4. B695 - Coatings of Zinc Mechanically Deposited on Iron and Steel
Section 03155 Concrete Anchors

5. C824 - Practice for Specimen Preparation for Determination of Linear Thermal Expansion of Vitreous Glass Enamels and Glass Enamel Frits for the Dilatometer Method

6. C1107 - Packaged Dry, Hydraulic-Cement Grout (Nonshrink)

7. E488 - Test Methods for Strength of Anchors in Concrete and Masonry Elements

8. F593 - Stainless Steel Bolts, Hex Cap Screws, and Studs

9. F594 - Stainless Steel Nuts

10. F1554 - Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength \{and Supplements S1, S4, and S5\}

F. International Code Council Evaluation Service (ICC-ES)

1. AC193 - Acceptance Criteria for Mechanical Anchors in Concrete Elements, \{Effective June 1, 2008\}

2. AC308 - Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements, \{Effective June 1, 2008\}

1.04 NOTED RESTRICTIONS

A. For bridge joints and bearings, only cast-in-place or cementitious grouted anchors shall be used. Anchor bolts may be swedged or threaded. Expansion (post-installed) anchors and countersunk anchor bolts shall not be used for bridge joints and bearings \{(AASHTO)\}.

B. The capacities of post-installed anchors shall be determined per independent testing laboratory in accordance with ACI 355.2 or ICC-ES AC193 for post-installed mechanical anchors, or ICC-ES AC308 for post-installed adhesive anchors. In no case shall manufacturer’s literature be relied upon to determine capacities.

C. Post-installed, torque-controlled expansion anchors and undercut anchors where not otherwise prohibited by ICC-ES AC193 are permitted for use in fire-resistant rated construction provided they conform to ICC-ES AC193 Article 6.2.2.

D. Adhesive anchors shall not be used in overhead applications or connections where anchors must resist sustained tension.

E. Adhesive anchors shall not be used where they will be exposed to sustained temperatures above 110-degrees Fahrenheit or short-term temperatures above 180-degrees Fahrenheit unless tested per ICC-ES AC308 for higher temperature.
F. Adhesive anchors shall not be installed if substrate temperature is below 40-degrees Fahrenheit unless tested per ICC-ES AC308 for lower installation temperature.

G. Anchors shall not be used for seismic, vibration, fatigue, shock, or impact loadings unless specifically tested in accordance with ASTM E488 for the loading to which they will be subjected. Anchors shall not be used for blast loadings unless specifically tested for the loading to which they will be subjected.

H. Post-installed anchors shall not be used with lightweight concrete unless specifically tested per ICC-ES AC193, ICC-ES AC308, or ACI 355.2

1.05 QUALITY CONTROL

A. An on-site Quality Control Program shall be provided for all post-installed adhesive anchors in accordance with ICC-ES AC308 Articles 14.3 and 14.4 and Annex A.

B. Full-time special inspection is required for all adhesive anchor systems together with proof load testing. Proof load testing alone is not recognized as meeting special inspection requirements.

C. Installer Qualifications: Post-installed anchors shall be installed by an installer with a minimum of five years experience performing similar installations.

D. Installer Training: Conduct thorough training with the manufacturer or the manufacturer’s representative for the installer on the Project. Training shall consist of a review of the complete installation process for drilled-in anchors including, but not limited to, the following:

   1. hole drilling procedure
   2. hole preparation and cleaning technique
   3. adhesive injection technique and dispenser training/maintenance
   4. anchor element type, material, diameter, and length
   5. proof loading/torquing

E. Certifications: Unless otherwise directed by the Engineer, anchors shall have one of the following certifications:

   1. ACI 355.2 Evaluation Report
   2. ASTM Certification
   3. ICC-ES Evaluation Report indicating conformance with applicable ICC-ES AC193 or ICC-ES AC308
F. Acceptance Criteria: A post-installed anchor is acceptable if the test load specified herein is attained without:

1. Slippage of more than:
   a. 1/16-inch for adhesive anchors
   b. 2.5-percent of the embedded length, rounded to the nearest 1/16-inch for mechanical anchors

2. Bolt failure

3. A sign of damage in the surrounding concrete

1.06 SUBMITTALS

A. General: Submit in accordance with Conditions of Contract and Section 01330.

B. Product Specifications: Include recommended design values and physical characteristics for post-installed anchors including anchor embedment, test load and torque, and manufacturer’s installation instructions.

C. Samples: Representative length and diameters of each type anchor shown on the Contract Drawings.

D. Test Reports: Certified test reports showing compliance with specified performance characteristics and physical properties.

E. Installer Qualifications and procedures: Submit installer qualifications as specified herein. Submit a letter of procedure stating method of drilling, the product proposed for use, the complete installation procedure, manufacturer’s training date, and a list of the personnel to be trained on anchor installation.

F. Installation and Field Quality Control methods, including method of locating embedded reinforcing steel.

1.07 DELIVERABLES

A. Certificates:
   1. ACI Evaluation Reports
   2. ASTM Certifications
   3. ICC-ES Evaluation Reports

B. Record Documents: Provide Project Record Documents for installed materials in accordance with Section 01780.

C. Installation and testing methods

D. Documentation:
1. Installation Inspection Record

2. Test Inspection Record: The test inspection record shall include, but not be limited to, the following information:
   a. General location of anchor and group represented
   b. Method of test or verification
   c. Test results, accepted or rejected
   d. Inspector’s name
   e. Date of test
   f. Identification number of testing tool

3. Failed Anchor Documentation: Documentation for anchors is required for an anchor that does not pass the test acceptance criteria specified herein. Failed anchor documentation shall be submitted to the Engineer. The documentation shall include, but not be limited to, the following:
   a. Exact location of failed anchor
   b. Reason for failure
   c. Repair steps taken
   d. Inspector’s name
   e. Date of test

1.08 DELIVERY, STORAGE, AND HANDLING

A. Store anchors in accordance with manufacturer’s recommendations.

PART 2 - PRODUCTS

2.01 MATERIALS

A. Fasteners and Anchors:

1. Bolts and Studs: ASTM F1554 {Grade 36/55/105} {AASHTO M314}. {Where Grade 55 bolts are welded, ASTM F1554 S1 shall be required.} {Where bolts are designed for seismic, fatigue, vibration, shock, or impact, forces, Charpy V-Notch testing per ASTM F1554 S1, S4, and S5 shall be required.}

2. Stainless Steel Bolts, Hex Cap Screws, and Studs: ASTM F593

3. Stainless Steel Nuts: ASTM F594
4. Zinc Coating: ASTM B695, Class 65
5. Hot-Dip Galvanizing: ASTM A153, Class C  \{or D\}
6. Reinforcing Bars: ASTM A615, deformed Grade 60, \{ASTM A706, deformed Grade 60\}

2.02 CAST-IN-PLACE BOLTS

A. {Bolts and studs, nuts, and washers shall conform to ASTM F1554, hot-dip galvanized including associated nuts and washers in accordance with ASTM A153.} or {Stainless steel anchor bolts, studs, nuts, and washers shall conform to ASTM F593 and ASTM F594.}
B. Grout shall conform to ASTM C1107 with no shrinkage and tested in accordance with ASTM C824. {Grout shall be non-metallic.}
C. Sleeves shall be corrugated, galvanized steel or corrugated high-density polyethylene.

2.03 POST-INSTALLED ANCHORS

A. Anchors for exterior, damp, or aggressive environment shall be Type 316 stainless steel.
B. Anchors for all other installations shall be hot-dip galvanized per ASTM A153 Class C \{or D\}, or mechanically coated per ASTM B695, Class 65.
C. Post-installed mechanical anchors shall conform to ACI 355.2 or ICC-ES AC193.
D. Post-installed adhesive anchors shall conform to ICC-ES AC308.
E. {Post-installed adhesive anchors shall be tested for simulated seismic loads per ICC-ES AC308 and ASTM E488}
F. {Post-installed adhesive anchors shall be tested for installation temperature below 40-degrees Fahrenheit. Anchors that are installed in concrete with temperatures below 40-degrees Fahrenheit shall be tested to the minimum allowable installation temperature per ICC-ES AC308.}
G. {Post-installed adhesive shall be tested for long-term temperature exposure of 110-degrees Fahrenheit in accordance with ICC-ES AC308. Anchors that are subject to higher temperatures shall be tested for the temperature that is equal to or exceeds the maximum long-term service temperature per ICC-ES AC308.}
H. Post-installed adhesive anchors shall be tested for short-term temperature exposure of 180-degrees Fahrenheit in accordance with ICC-ES AC308. Anchors that are subject to higher temperatures shall be tested for the temperature that is recommended in the manufacturer’s printed literature.

I. Post-installed adhesive anchors shall be tested for installation in holes drilled with any method or drill other than a carbide-tipped bit using a rotary hammer drill per ICC-ES AC308.

J. Post-installed adhesive anchors shall be tested for installation in water-saturated concrete per ICC-ES AC308.

K. Post-installed adhesive anchors shall be tested for standing water in holes per ICC-ES AC308.

L. Post-installed adhesive anchors shall be tested for use in submerged concrete per ICC-ES AC308.

M. Post-installed mechanical anchors shall be tested for installation in holes drilled with any method or drill other than a carbide-tipped bit using a rotary hammer drill.

N. Post-installed mechanical anchors shall be tested for simulated seismic loads per ACI 355.2. and ASTM E488.

O. Anchors shall be tested for vibration or fatigue loading in accordance with ASTM E488. Suitable testing provisions shall be included in the Specifications to simulate the type of load that the anchor will be subjected to during its use.

P. Anchors shall be tested for impact or shock loading in accordance with ASTM E488. Suitable testing provisions shall be included in the Specifications to simulate the type of load that the anchor will be subjected to during its use.

PART 3 - EXECUTION

3.01 GENERAL

A. Training:
   1. Installer Training: Implement a training and/or qualification program for installers of post-installed anchors. Anchor installers shall be trained and made fully familiar with the manufacturer’s installation procedures including additional requirements as specified or as directed.

B. Examination/Site Verification of Conditions:
   1. The use of anchors shall be restricted to the applications and installations as indicated on the Contract Drawings.
2. Post-installed anchors may only be installed in sound concrete. Surfaces showing obvious distress by way of porosity, disintegration, carbonation, and cracks over 0.02-inch in width and 12-inches or longer and within the distance of the embedment length shall be reported to the Engineer for evaluation.

C. Preparation:

1. Existing reinforcement shall be exposed as indicated on the Contract Drawings to establish the reinforcement pattern before drilling.

2. No cutting of reinforcement will be permitted without prior written approval from the Engineer. Multi-cutting of the same bar is considered as one cut.

3. Reinforcement will be considered to be cut if:
   a. For No. 4 through No. 7: Cuts, nicks, or drill into bar body are greater than 1/16-inch
   b. For No. 8 and Larger: Cuts, nicks, or drill into bar body are greater than 1/8-inch

4. When installing anchors through cut reinforcement, the anchoring mechanism shall be located at least two anchor diameters beyond the cut reinforcement.

3.02 INSTALLATION

A. Cast-In-Place Anchors: Use templates to locate bolts accurately and securely in formwork.

B. Anchors shall be installed according to the location, spacing, and edge distances specified in the Contract Drawings.

C. Post-installed anchors shall be installed in accordance with the ICC-ES reports and manufacturer’s installation instructions. Where installation criteria differ, the order of precedence from highest to lowest is 1) this Specification; 2) the ICC-ES reports; 3) the manufacturer’s installation instructions.

D. Holes for post-installed anchors shall be drilled with carbide-tipped bits using rotary hammer drills meeting the requirements of ANSI B212.15 unless ICC-ES AC193 or ICC-ES AC308 testing demonstrates that using percussive drilling or another type(s) of bit, including core drills, is acceptable. Drilled holes shall be cleaned of chips, dust, loose material, and water prior to anchor installation. The hole diameters and depths shall be as recommended in the manufacturer’s instructions. The hole diameter shall be checked every ten holes for conformance to the hole tolerances specified in ICC-ES AC308 for adhesive anchors, ICC-ES AC193 or ACI 335.2 for mechanical anchors. Verify depth of the concrete
member before drilling holes. The embedment depth of the post-installed anchor shall not exceed the greater of 2/3 of the concrete member thickness or the concrete member thickness minus 4-inches. Contact the Engineer if these requirements cannot be met based on the actual member thickness.

E. Anchors shall be installed perpendicular to the concrete surface within a plus or minus 5-degree tolerance. Post-installation verification of this criterion may be satisfied by visual inspection to verify proper seating of the nut and washer.

F. In areas where concrete has been removed, the minimum anchor embedment shall be measured from the surface of sound concrete.

G. Unless otherwise noted on the Contract Drawings, the spacing requirements indicated in the applicable ICC ES report shall be used.

H. Bending and welding of post-installed anchors is not permitted.

I. The nut thread engagement for the anchors (studs) shall be such that the bolt threads project past the outside face of the nut when completely installed.

J. The length identification code on the head of the anchor shall not be damaged during installation. Anchor projection may be cut-off subject to the approval of the Engineer and documentation of the location, embedment, and length code.

K. Unused anchors shall be driven in and cut-off flush. Cut-off anchors shall be considered an abandoned ungrouted hole for future anchor spacing requirements.

L. Care shall be exercised to avoid bending anchors to match base plate holes, or loosening of anchors by prying sideways after tightening. Care shall also be exercised to ensure that the cone nut of an undercut anchors does not become loose from the stud during the setting or tensioning operation.

M. Non-grouted base plates may have a maximum 1/8-inch gap as evidenced under exterior edges around the plate provided that 1) the plate exhibits bearing contact within its interior against the concrete surface; and 2) the uneven bearing does not prevent application of the prescribed torque. If an unacceptable bearing contact condition exists, one of the following procedures shall apply:

1. The concrete surface shall be reworked to obtain a proper fit.

2. For gaps of up to 1-inch, the base plate may be grouted instead using the following technique:
   a. Insert post-installed anchors and set the base plate.
   b. Insert nuts to finger-tight condition.
   c. Install shims positioned no more than 1/2-inch away from the anchors to reduce gaps between base plate shims to 1/8-inch or less at anchor locations.
d. Apply tightening torque. The bolt tightening shall not be performed when interior shims under the base plates have been placed away from anchors so that downward bending of the base plate would result upon tightening. Shims shall be moved as close as possible to the anchors before applying the installation torque.

e. Fill the gap with non-shrink grout leaving the shims in place. For base plates on walls where grouting is not feasible, the gap may be filled with shim plates. The shims may be stacked but no more than four shims shall be stacked.

N. Relocating Holes Within Base Plates: The base plate with bolts may be relocated no more than 1-inch in any direction with respect to the attachment principal axis unless otherwise noted on the Contract Drawings.

3.03 INSPECTION

A. All anchors shall be visually inspected in order to verify and document that they have been installed as specified herein. As a minimum, inspection attributes for post-installed anchors shall comply with the special inspection section of the applicable ICC-ES report (with the exception of validating the strength of existing concrete) plus additional attributes imposed by this Specification. These attributes of inspection shall be identified in the inspection report documentation.

B. If visual inspection reveals that the installed anchor does not meet the specified requirements, the anchor shall be relocated as permitted by this Specification, or shall be removed and replaced by another anchor, or referred to the Engineer for evaluation.

3.04 FIELD QUALITY CONTROL

A. Minimum anchor embedments, test (proof) loads, and torques shall be as shown on the approved shop drawings.

B. Testing of post-installed anchors shall be witnessed by the Inspector. Test of post-installed anchors is mandatory.

C. Testing Method: Post-installed anchors shall be tested by the direct tension method as follows:

1. Direct Tension Method: A tensile load as defined herein below is applied. If the tension load is applied by jacking against the concrete, the jacking pressure is to be distributed outside of an area having its center at the post-installed anchor and its diameter, or least dimension, equal to the required anchor spacing as given in the ICC ES report. Post-installed anchors tested by this method shall be retightened by applying the installation torques.
2. Testing shall be in accordance with \{ICC-ES AC308 Figure 5-1\} or \{ACI 355.2 and ASTM E488\}.

D. Test (Proof) Load: Tension test (proof) load shall be as indicated on the approved shop drawings.
   1. For post-installed adhesive anchors, the test shall be equal to the lesser of:
      a. A tensile load equal to 80-percent of the specified nominal yield strength of the anchor bolt material times the tensile area of the bolt; or
      b. A tensile load equal to twice the design load and at least 50-percent of the expected ultimate load based on the adhesive bond strength shown in the ICC-ES report, whichever is greater.
   2. For post-installed mechanical anchors, the test load shall be a tensile load equal to 80-percent of the specified nominal yield strength of the anchor bolt material times the tensile area of the bolt.

E. Test Frequency: Unless otherwise specified, the following test frequencies shall apply:
   1. Post-Installed Mechanical Anchors: All anchors shall be tension-tested.
   2. Post-Installed Adhesive Anchors: All anchors shall be tension-tested.

3.05 REPAIR AND RESTORATION OF DEFECTIVE WORK

A. Remove and replace misplaced or malfunctioning anchors. Fill empty anchor holes and patch failed anchor locations with high-strength non-shrink, nonmetallic grout. Anchors that fail to meet proof load or installation torque requirements shall be regarded as malfunctioning.

B. Abandoned holes shall be grouted with non-shrink grout. When post-installed anchors fail to meet the acceptance criteria under inspection and testing, the following repairs may be undertaken:
   1. When failure is due to excessive anchorage pullout, contact the Engineer to evaluate the damage and approve a repair method. If approved, the anchor may be reset once prior to redrilling the hole and installing an anchor of equal size. Use the minimum spacing embedment depth, and installation torque required for the original anchor.
   2. When failure is due to breaking of the anchor, slippage or loosening, bending, improper installation or poor attachment, remove the defective anchor, redrill the hole, and install the same diameter anchor if the integrity of surrounding concrete has not been disturbed.
3. For cases where excessive slippage upon torquing is experienced, or usage of the same hole is not possible, fill the existing hole with non-shrink grout and relocate the anchor location.

4. When failure is due to breakout of concrete around the anchor, the Engineer will develop an appropriate repair. Contact the Engineer to evaluate the damage and repair method. Local spalling of the concrete around the anchor, up to a maximum depth of 1/4-inch, is not considered a concrete breakout failure.

5. Mislocated anchors may be cut flush with concrete surface, and need not be removed if they do not interfere with subsequent installations.

6. Mislocated anchors or anchors installed for temporary applications may be left in place. Those anchors that must be removed to accommodate other attachments, aesthetics, or safety of personnel may be removed completely or abandoned in place by cutting off beneath the surface after chipping the concrete 1-inch minimum and patching with epoxy grout. Mislocated anchors that will be covered by a base plate or an attachment may be cut-off flush with the concrete. In the event that an anchor must be removed from the hole and a new anchor installed, the removal and installation of the new anchor shall be in accordance with the manufacturer’s specifications. The abandoned hole or removed concrete shall be filled with non-shrink grout.

7. Removal of installed anchors for inspection or replacement may be performed by using a bolt extractor as manufactured by Drillco Devices, Ltd., or approved equal.

8. Retest all replaced anchors as specified herein.

END OF SECTION
Attachment A

Cast-in-Place and Cementitious Grouted Anchors
CAST-IN-PLACE ANCHOR BOLT WITH SUSTAINED TENSION
Single Anchor Tension

Determine capacity of a single cast-in-place headed anchor rod in cracked concrete subject to tension only. No eccentricity (i.e. load is centered on anchor).

Assumptions:

* All references are to ACI 318-08 unless otherwise noted.
* Concrete is considered cracked, as controlled by flexural reinforcement design.
* \( \phi \)-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.

Given:

Concrete Edge Distances

\[ c_{el} = 12 \text{ in} \]
\[ c_{eg} = 12 \text{ in} \]
\[ h_b = 18 \text{ in} \] Depth of concrete

Concrete

\[ f_c' = 4000 \text{ psi} \] Compressive strength

Anchor Bolt Material:

\[ f_{yB} = 36 \text{ ksi} \] Yield strength
\[ f_{ubs} = 58 \text{ ksi} \] Tensile strength

Note: This is a ductile steel element per the definition of D.1, which requires that the element have a tensile test elongation of at least 14 percent, and a reduction in area of at least 30 percent.

\[ h_{ef} = 4.5 \text{ in} \] Effective embedment depth

Loads

\[ N_{ub} = 8 \text{ kips} \] (no shear, no moment)

Where: \( N_{ub} \) is the applied factored external tension using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors (\( \phi \)) for nominal strengths:

Tension of ductile steel element: \( \phi = 0.75 \) (D.4.4 (a) (i))
Concrete breakout or pullout for cast-in: \( \phi = 0.7 \) (Condition B: no supplementary reinforcement) (D.4.4 (c) (iii))
4.1.1: Example of cast-in-place anchor subject to tension only per ACI 318-08 Appendix D, Factored Loads

Solution:

Determine anchor area required to resist loads shown above.

Calculate required strengths such that \( \phi N_a \geq N_{ua} \) \( \text{Eq D-1} \)

where \( \phi N_a \) is the minimum design strength of all appropriate failure modes. \( \text{D.4.1.2} \)

In this example, failure modes are:
- Steel anchor strength
- Concrete breakout
- Anchor pullout

For a ductile failure mode, the steel anchor must fail before the concrete breakout and anchor pullout.

Steel Anchor Strength \( \text{(D.5.1)} \)

Nominal tension strength of steel anchor given by:

\[
N_{sa} = n A_{se,N} f_{ulta} \quad \text{Eq D-3}
\]

where:
- \( n = 1 \) number of anchor bolts

To calculate >>>

\[
A_{se,N} = \frac{\text{[in}^2\text{] effective anchor bolt cross sectional area}}{\text{ksi}} \quad 58 \text{ksi}
\]

shall not exceed the following:

1.9\( f_{ya} \) = 68.4 ksi

or 125 ksi

Use \( f_{ulta} = 58 \) ksi

from Eq's (D-1) and (D-3), determine \( A_{se,\text{reqd}} \):

\[
A_{se,\text{reqd}} \geq N_{ua} / n \phi f_{ulta} = \frac{[8 \text{ kips}]/[(1)(0.75)(58\text{ksi})]}{0.184 \text{ in}^2}
\]

\[
A_{se,\text{reqd}} = (\pi/4) (d_a - 0.9743/n_t)^2 \text{ where: } d_a \text{ is the anchor rod diameter}
\]

\[
r_t \text{ is the no. of threads per in., per ANSI/ASME B1.1.}
\]

Use anchor rod diameter of: \( d_a = 0.625 \text{ in} \)

\[
A_{se,\text{provided}} = 0.226 \text{ in}^2 \text{ (ACI 349.2R-07, App. A, Table 2)}
\]

Provided Steel Tension Strength:

\[
N_{sa} = A_{se,\text{prov}} f_{ulta} = [(0.226 \text{ in}^2)(58\text{ksi})]
\]

\[
N_{sa} = 13.11 \text{ kips}
\]
Concrete Breakout Strength of Anchor in Tension (D.5.2)

Nominal tension strength of concrete against breakout for a single anchor is given by:

$$N_{cb} = (A_{Nc}/A_{Nco}) \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b$$  \hspace{1cm} (Eq D-4)

where:

- Modification factor for edge effects:
  $$\Psi_{ed,N} = 1.0 \hspace{1cm} \text{when } c_{a,min} \geq 1.5 h_{ef}$$  \hspace{1cm} (D.5.2.5)

- Modification factor for cracking:
  $$\Psi_{c,N} = 1.0 \hspace{1cm} \text{cracking assumed at service loads}$$  \hspace{1cm} (D.5.2.6)

- Modification factor for splitting:
  $$\Psi_{cp,N} = 1.0 \hspace{1cm} \text{for cast-in anchors}$$  \hspace{1cm} (D.5.2.7)

$$A_{Nco} = 9 h_{ef}^2 \hspace{1cm} [\text{in}^2] \hspace{1cm} \text{Projected concrete failure area of a single anchor with an edge distance equal to or greater than } 1.5 h_{ef}$$  \hspace{1cm} (Eq D-6)

$$A_{Nc} = \hspace{1cm} [\text{in}^2] \hspace{1cm} \text{Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward } 1.5 h_{ef} \text{ from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).}$$

In this example of a single anchor without concern for edge effects:

$$A_{Nco} = A_{Nc} = 9 h_{ef}^2 \hspace{1cm} \triangleright \triangleright \triangleright A_{Nc}/A_{Nco} = 1.00$$

Basic concrete breakout strength of a single anchor in tension in cracked concrete given by:

$$N_b = k_c \lambda (f'c)^{1.5} h_{ef}^{1.5} \hspace{1cm} (Eq D-7)$$

where:

- $$k_c = 24 \hspace{1cm} \text{(Cast-in anchor)}$$  \hspace{1cm} (D.5.2.2)
- $$\lambda = 1.0 \hspace{1cm} \text{(Normal weight concrete)}$$  \hspace{1cm} (8.6.1)
- $$h_{ef} = 4.5 \hspace{1cm} \text{in} \hspace{1cm} \text{Effective embedment depth of anchor}$$

Provided basic concrete breakout strength of single anchor:

$$N_b = k_c \lambda (f'c)^{1.5} h_{ef}^{1.5} = (24)(1) (4000 \text{ psi})^{1.5} (4.5 \text{ in})^{1.5} = 14.49 \text{ kips}$$

Provided nominal concrete breakout strength of single anchor:

$$N_{cb} = (A_{Nc}/A_{Nco}) \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b = [(1)(1)(1)(1)[14.49 \text{ kips}]]$$

$$N_{cb} = 14.49 \text{ kips}$$
Pullout Strength of Anchor in Tension (D.5.3)

Nominal pullout strength of single anchor is given by:
\[ N_{pn} = \Psi_{c,p} N_p \]  \hspace{1cm} (Eq D-14)

where:
Modification factor for cracking: \[ \Psi_{c,p} = 1.0 \]  \hspace{1cm} (D.5.3.6)

Maximum pullout strength in tension of single headed stud or headed bolt:
\[ N_p = 8 A_{brg} f_c' \]  \hspace{1cm} (Eq D-15)

For bolt diameter of: \[ d_b = 0.625 \text{ in} \]
Bearing area of hex head nut: \[ A_{brg} = 0.45 \text{ in}^2 \]  \hspace{1cm} (ACI 349.2R-07, App. A, Table 4(b))

\[ N_p = 8 A_{brg} f_c' = (8)(0.45 \text{ in}^2)(4000 \text{ psi}) \]
\[ N_p = 14.40 \text{ kips} \]

Provided nominal pullout strength of single anchor is given by:
\[ N_{pn} = \Psi_{c,p} N_p = (1)(14.4 \text{ kips}) \]
\[ N_{pn} = 14.40 \text{ kips} \]

Summary of Design Strengths:
- Steel anchor strength : \[ \phi N_{sa} = (0.75)(13.11 \text{ kips}) = 9.83 \text{ kips} \]
- Concrete breakout strength : \[ \phi N_{cb} = (0.7)(14.49 \text{ kips}) = 10.14 \text{ kips} \]
- Anchor pullout strength : \[ \phi N_{pn} = (0.7)(14.4 \text{ kips}) = 10.08 \text{ kips} \]

\[ \phi N_n = \min(\phi N_{sa}, \phi N_{cb}, \phi N_{pn}) = 9.83 \text{ kips} \]  \hspace{1cm} (D.4.1.2)
\[ \phi N_n \geq N_{ca} ? : \text{OK} \]  \hspace{1cm} (Eq D-1)

- Anchor bolt fails first.
- Capacity greater than factored loads.
CAST-IN-PLACE ANCHOR BOLT IN SHEAR
4.1.2: Example of cast-in-place anchor subject to shear only per ACI 318-08 Appendix D, Factored Loads

Single Anchor Shear
Determine capacity of a single cast-in-place headed anchor rod in cracked concrete subject to shear only. No eccentricity (i.e. load is centered on anchor).

Assumptions:
* All references are to ACI 318-08 unless otherwise noted.
* Concrete is considered cracked, as controlled by flexural reinforcement design.
* φ-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided)
* Edge distances are considered large such that there are no edge effects.

Given:
Concrete Edge Distances
- \( c_{af} = 10 \) in Distance to free edge in direction of load
- \( c_{as} = 18 \) in Distance to edges perpendicular to direction of load
- \( h_a = 18 \) in Depth of concrete

Concrete
- \( f_c' = 4000 \) psi Compressive strength

Anchor Bolt Material:
- \( f_y = 36 \) ksi Yield strength
- \( f_{uta} = 58 \) ksi Tensile strength

Note: This is a ductile steel element per the definition of D.1, which requires that the element have a tensile test elongation of at least 14 percent, and a reduction in area of at least 30 percent.
- \( h_{et} = 2.5 \) in Effective embedment depth

Loads
- \( V_{wa} = 8 \) kips (no axial, no moment)

Where: \( V_{wa} \) is the applied factored shear using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors (φ) for nominal strengths:
- Shear of ductile steel element: \( \phi = 0.65 \) (D.4.4 (a) (ii))
- Concrete breakout, pullout, or ptyout for cast-in: \( \phi = 0.7 \) (Condition B: no supplementary reinforcement) (D.4.4 (c) (i))
Solution:

Determine anchor area required to resist loads shown above.

Calculate required strengths such that \( \phi V_n \geq V_{ua} \)  

(Eq D-2)

where \( \phi V_n \) is the minimum design strength of all appropriate failure modes.  

(D.4.1.2)

In this example, failure modes are:

- Steel anchor shear strength
- Concrete side breakout failure
- Concrete pryout failure

For a ductile failure mode, the steel anchor must fail before the concrete breakout and anchor pullout.

Steel Anchor Strength  (D.6.1)

Nominal shear strength of steel cast-in headed anchor bolt given by:

\[
V_{sa} = n A_{sa,V} f_{ulta} 
\]  

(Eq D-19)

where:

\[
n = 1 \quad \text{number of anchor bolts}
\]

To calculate >>>

\[
A_{sa,V} = \frac{[\text{in}^2]}{\text{effective anchor bolt cross sectional area}}
\]

\[
f_{ulta} = 58 \quad \text{ksi}
\]

shall not exceed the following:

\[
1.9f_{ya} = 68.4 \quad \text{ksi}
\]

or \( 125 \quad \text{ksi} \)

Use \( f_{ulta} = 58 \quad \text{ksi} \)

from Eq's (D-2) and (D-19), determine \( A_{sa,required} \):

\[
A_{sa,reqd} \geq V_{ua} / n \phi f_{ulta} = \frac{[6 \text{ kips}] / [(1)(0.65)(58 \text{ksi})]}{0.159 \text{ in}^2}
\]

\[
A_{sa,reqd} = 0.159 \quad \text{in}^2
\]

\[
A_{sa,reqd} = \frac{\pi}{4} \left(d_a - 0.9743/n_t\right)^2 \quad \text{where:}
\]

\[
d_a \quad \text{is the anchor rod diameter}
\]

\[
n_t \quad \text{is the no. of threads per in., per ANSI/ASME B1.1.}
\]

Use anchor rod diameter of: \( d_a = 0.625 \quad \text{in} \)

\[
A_{sa,provided} = 0.226 \quad \text{in}^2
\]  

(ACI 349.2R-07, App. A, Table 2)

Nominal steel shear strength:

\[
V_{sa} = n A_{sa,prov} f_{ulta} = [(1)(0.226 \text{ in}^2)(58 \text{ksi})]
\]

\[
V_{sa} = 13.11 \quad \text{kips}
\]
Concrete Breakout Strength of Anchor in shear (D.6.2)

Nominal shear strength of concrete against breakout of a single anchor is given by:

\[ V_{cb} = (A_{Vc} / A_{Vco}) \Psi_{ed,v} \Psi_{c,v} \Psi_{h,v} V_b \]  

(Eq D-21)

where:

Modification factor for edge effects:
\[ \Psi_{ed,v} = \begin{cases} 1.0 & \text{if } c_{at} \geq 1.5c_{at} \\ \text{cracking assumed at service loads} & \text{if } h_a \geq 1.5c_{at} \end{cases} \]  

(D 6.2.6)  

(D 6.2.7)  

Mod. factor for member thickness:
\[ \Psi_{h,v} = \begin{cases} 1.0 & \text{if } c_{at} \geq 1.5c_{at} \end{cases} \]  

(D 6.2.8)

\[ A_{Vco} = 4.5 \ c_{at}^2 \ [in^2] \]  

Projected area for a single anchor in a deep member with a distance from edges \( \geq 1.5c_{at} \) in the direction perpendicular to the shear force.

\[ A_{Vc} = \ [in^2] \]  

Projected area of the failure surface on the side of the concrete member at its edge for a single anchor (or group). It shall be permitted to evaluate \( A_{Vc} \) as the base of a truncated half pyramid projected on the side face of the member where the top of the half pyramid is given by the axis of the anchor row selected as critical. The value of \( c_{at} \) shall be taken as the distance from the edge to this axis.

In this example of a single anchor without concern for edge effects:

\[ A_{Vco} = A_{Vc} = 4.5 \ c_{at}^2 \]  

\[ \text{>>>AAA}_{Vc}/A_{Vco} = 1.00 \]

Basic concrete breakout strength of a single anchor in shear in cracked concrete given by:

\[ V_b = (7 \ (l_e/d_a)^{0.2} \ (d_a)^{1/2}) \lambda \ {f_c}^{1/2} \ c_{at}^{1.5} \]  

(Eq D-24)

where:

\[ l_e \] is the load bearing length of the anchor for shear

\[ = 2.50 \ in = hef = 2.5 \ in \leq 8 \ da = 5 \ in \]  

(D.6.2.2)

\[ \lambda = 1.0 \] (Normal weight concrete)

Provided basic concrete breakout strength in shear of single anchor:

\[ V_b = (7 \ (l_e/d_a)^{0.2} \ (d_a)^{1/2}) \lambda \ {f_c}^{1/2} \ c_{at}^{1.5} \]  

[\( (7)(2.5\ in / 0.625\ in)^{0.2} \ (0.625\ in)^{1/2} \ (1) \ (4000\ psi)^{0.5} \ (0.5 \ [10\ in])^{1.5} \]  

\[ V_b = 14.6 \ \text{kips} \]

Provided nominal concrete breakout strength in shear of single anchor:

\[ V_{cb} = (A_{Vc}/A_{Vco}) \Psi_{ed,v} \Psi_{c,v} \Psi_{h,v} V_b = [(1)(1)(1)\ [14.6 \ \text{kips}]] \]  

\[ V_{cb} = 14.6 \ \text{kips} \]
Pryout Strength of Anchor in Shear (D.6.3)

Nominal concrete pryout strength of single anchor is given by:

\[ V_{cp} = k_{cp} N_{cb} \]  

(Eq D-30)

where:

\[ k_{cp} = \begin{cases} 2.0 & \text{for } h_{ef} \geq 2.5\text{in} \\ N_{cb} &= \text{concrete breakout strength of anchor in tension as calculated below} \end{cases} \]  

Nominal tension strength of concrete against breakout given by:

\[ N_{cb} = (A_{Nc}/A_{Nco}) \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b \]  

(Eq D-4)

where:

Modification factor for edge effects:

\[ \psi_{ed,N} = \begin{cases} 1.0 & \text{when } c_{a,min} \geq 1.5h_{ef} \\ \text{cracking assumed at service loads} & \end{cases} \]  

(D.5.2.5)

Modification factor for cracking:

\[ \psi_{c,N} = 1.0 \]  

(D.5.2.6)

Modification factor for splitting:

\[ \psi_{cp,N} = 1.0 \]  

(D.5.2.7)

\[ A_{Nco} = 9 \, h_{ef}^2 \quad \text{[in}^3]\]  

Projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5h_{ef}  

\[ A_{Nc} = \quad \text{[in}^3]\]  

Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectangular geometrical figure that results from projecting the failure surface outward 1.5h_{ef} from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).

In this example of a single anchor without concern for edge effects:

\[ A_{Nco} = A_{Nc} = 9 \, h_{ef}^2 \]

\[ \boxed{A_{Nc}/A_{Nco} = 1.00} \]

Basic concrete breakout strength of a single anchor in tension in cracked concrete given by:

\[ N_b = k_c \lambda \sigma_{f}^{1/2} h_{ef}^{1.5} \]  

(Eq D-7)

where:

\[ k_c = \begin{cases} 24 & \text{(Cast-in anchor)} \\ 1.0 & \text{(Normal weight concrete)} \end{cases} \]  

(D.5.2.2)

Assumed embedment depth:

\[ h_{ef} = 2.50 \quad \text{in} \]  

Effective embedment depth of anchor (min 2.5" based on assumption for k_{cp} above)

for bolt diameter of:

\[ d_s = 0.625 \quad \text{in} \]

Hex head nut thickness:

\[ H = 0.438 \quad \text{in} \]  

(ACI 349.2R-07, App. A, Table 4(b))

\[ L_{reqd} = h_{ef,reqd} + H = 2.94 \quad \text{in} \]

Use anchor bolt length of:

\[ L_{prov} = 3.00 \quad \text{in} \]

Provided embedment depth of:

\[ h_{ef,prov} = L_{prov} - H = 2.56 \quad \text{in} \]  

(min 2.5" based on assumption for k_{cp} above)
Provided basic concrete breakout strength of single anchor:
\[ N_b = k_c \lambda \left( f_c' \right)^{1/2} (2.56 \text{ in})^{1.5} = (24)(1)(4000 \text{ psi})^{1/2} \left[ 2.56 \text{ in} \right]^{1.5} = 6.22 \text{ kips} \]

Provided nominal concrete breakout strength in tension of single anchor:
\[ N_{cb} = (A_{nc}/A_{Ncb}) \gamma_{ed, N} \lambda \Psi_{c, N} \Psi_{cp, N} N_b = [(1)(1)(1)(1)(6.22 \text{ kips})] \]
\[ N_{cb} = 6.22 \text{ kips} \]

Provided nominal concrete pryout strength in shear of single anchor:
\[ V_{cp} = k_{cp} N_{cb} = [(2)(6.22 \text{ kips})] \]
\[ V_{cp} = 12.45 \text{ kips} \]

**Summary of Design Strengths:**

- **Steel anchor shear strength:** \( \phi V_{sa} = (0.65)(13.11 \text{ kips}) = 8.52 \text{ kips} \)  
- **Concrete side breakout strength:** \( \phi V_{cb} = (0.7)(14.6 \text{ kips}) = 10.22 \text{ kips} \)
- **Concrete pryout strength:** \( \phi V_{cp} = (0.7)(12.45 \text{ kips}) = 8.71 \text{ kips} \)

\[ \phi V_n = \min(\phi V_{sa}, \phi V_{cb}, \phi V_{cp}) = 8.52 \text{ kips} \]  
(D.4.1.2)  
(Eq D-1)

- Anchor bolt fails first.
- Capacity greater than factored loads.
CAST-IN-PLACE ANCHOR BOLT IN COMBINED SHEAR AND SUSTAINED TENSION DUE TO MOMENT
4.1.3: Example of cast-in-place anchor subject to combined shear and tension per ACI 318-08 Appendix D, Factored Loads

Determine capacity of cast-in-place group of four headed anchors in cracked concrete subject to combined shear and uniaxial moment. Shear and moment transmitted to anchor group via a 3" square structural steel tube welded to a steel base plate.

Assumptions:
* All references are to ACI 318-08 unless otherwise noted.
* Concrete is considered cracked, as controlled by flexural reinforcement design.
* $\psi$-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.
* No eccentricity with respect to anchor tensile loads.

Given:
Concrete Edge Distances, per preceding sketch
- $c_{a1} = 23$ in: Distance from rear anchor row to free edge in direction of load
- $c_{a2} = 35$ in: Distance to edge normal to direction of load, from nearest anchor in group
- $h_a = 18$ in: Depth of concrete
- $s = 5$ in: Spacing between anchors in group

Concrete
- $f_c' = 4000$ psi: Compressive strength

Anchor Rod Material:
- $f_ya = 105$ ksi: Yield strength
- $f_uoa = 120$ ksi: Tensile strength

Note: This is a ductile steel element per the definition of D.1, which requires that the element have a tensile test elongation of at least 14 percent, and a reduction in area of at least 30 percent.

- $n_a = 4$: Number of anchors in group
- $h_{ef} = 10.5$ in: Effective embedment depth

Loads
- $V_{ua} = 12.4$ kips: (no axial force)
- $M_{ua} = 70$ kip-in

Where: $V_{ua}$ and $M_{ua}$ are the applied factored shear and uniaxial moments using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors ($\psi$) for nominal strengths:
- Tension of ductile steel element: $\psi = 0.75$ (D.4.4 (a) (i))
- Shear of ductile steel element: $\psi = 0.65$ (D.4.4 (a) (ii))
- Shear in concrete for cast-in anchor: $\psi = 0.7$ (Condition B: no supplementary reinforcement) (D.4.4 (c) (i))
- Tension in concrete for cast-in anchor: $\psi = 0.7$ (D.4.4 (c) (ii))
Solution:

Determine anchor area required to resist loads shown above.

Calculate required strengths for tension loads (due to moment) such that:  \( \phi N_t \geq N_{ua} \)  
where:  
\( N_{ua} \) is the tensile force imposed on the anchors by the moment  
\( \phi N_t \) is the minimum design strength of all appropriate failure modes.

In this example, tension failure modes are: Steel anchor tension strength  
Concrete breakout  
Anchor pullout

Calculate required strengths for shear loads such that:  \( \phi V_s \geq V_{ua} \)  
where \( \phi V_s \) is the minimum design strength of all appropriate failure modes.

In this example, shear failure modes are: Steel anchor shear strength  
Concrete side breakout failure  
Concrete pryout failure

Steel Anchor Tension Strength (D.5.1)
Nominal tension strength of steel anchor given by:

\[ N_{sa} = n A_{se,N} f_{uta} \]  
(Eq D-3)

where:
\( n = 2 \) number of bolts in tension  
(one side tension / one side compression)

To calculate >>>

\[ A_{se,N} = \frac{\text{in}^2}{\text{ksi}} \] effective anchor cross sectional area

\( f_{uta} = 120 \)ksi

shall not exceed the following:

\( 1.9 f_{ya} = 199.5 \)ksi  
or  \( 125 \)ksi

Use \( f_{uta} = 120 \)ksi

Tension demand due to moment:

\[ N_u = M_{ud}/d = \frac{[70 \text{ kip-in}]}{[4 \text{ in}]} = \frac{17.5 \text{ kips}}{\text{on two anchors}} \]

from Eq's (D-1) and (D-3), determine \( A_{se,reqd} \):

\[ A_{se,reqd} \geq N_u/\phi f_{uta} = \frac{[17.5 \text{ kips}])(2)(0.75)(120 \text{ksi})}{2} \]

\[ 0.097 \text{ in}^2 \]

\[ A_{se,reqd} = (\pi/4) \{d_a - 0.9743/n_i\}^2 \]

where:  
\( d_a \) is the anchor rod diameter  
n_i \( \) is the no. of threads per in., per ANSI/ASME B1.1.

Use anchor diameter of:  
\( d_a = 0.625 \) in

\[ A_{se,provided} = 0.226 \text{ in}^2 \]  
(ACI 349.2R-07, App. A, Table 2)

Provided Steel Tension Strength of single anchor:

\[ N_{sa} = A_{se,provided} f_{uta} = [(0.226 \text{ in}^2)(120\text{ksi})] \]

\[ N_{sa} = 27.12 \text{ kips} \]

Note: Anchor pullout must be also checked. Please see example for tension only on a single anchor.
Concrete Breakout Strength of Anchors in Tension (D.5.2)
Nominal concrete breakout strength of a group of anchors is given by:

\[ N_{cbg} = (A_{Ne}/A_{Nco}) \Psi_{ec,N} \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} \ N_b \]  
(Eq D-5)

where the following are modification factors for:

- Eccentricity effects: \( \Psi_{ec,N} = 1.0 \)  
- Edge effects: \( \Psi_{ed,N} = 1.0 \) when \( c_{a,min} \geq 1.5h_{ef} \)  
- Concrete cracking: \( \Psi_{c,N} = 1.0 \) cracking assumed at service loads  
- Concrete splitting: \( \Psi_{cp,N} = 1.0 \) for cast-in anchors

\[ A_{Nco} = 9 \ h_{ef}^2 \ [\text{in}^2] \]  
Projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5\( h_{ef} \)  
(Eq D-6)

\[ A_{NC} = 3 \ h_{ef} \{2(1.5h_{ef}) + s\} \]  
Projected concrete failure area of a group of anchors that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward 1.5\( h_{ef} \) from the centerlines through a row of adjacent anchors.

In this example, two anchors are in tension, while the other two are in compression.

\[ A_{Nco} = 9 \ h_{ef}^2 = 9*(10.5 \text{ in})^2 = 992.25 \text{ in}^2 \]

\[ A_{NC} = 3 \ h_{ef} \{2(1.5h_{ef}) + s\} = 3(10.5 \text{ in})(2(1.5[10.5 \text{ in}]) + 5 \text{ in}) = 1149.75 \text{ in}^2 \]

\[ A_{NC} / A_{Nco} = \frac{1149.75 \text{ in}^2}{992.25 \text{ in}^2} = 1.16 \]

\[ A_{NC} \leq n A_{Nco} ?: \ (1149.75 \text{ in}^2) \leq (2)(992.25 \text{ in}^2) \ ?: \text{OK} \]  
(D.5.2.1)

Basic concrete breakout strength of a single anchor in tension in cracked concrete given by:

\[ N_b = k_c \lambda \left(\frac{f_{et}}{f_{ck}}\right)^{1.5} \ h_{ef} \]  
(Eq D-7)

where:

\[ k_c = \frac{24}{24} \] (Cast-in anchor)  
(D.5.2.2)

\[ \lambda = 1.0 \] (Normal weight concrete)  
(8.6.1)

from Eq's (D-4) and (D-7) determine \( N_{cbg} \):

\[ N_{cbg} = (A_{Ne}/A_{Nco}) \Psi_{ec,N} \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} [k_c \lambda \left(\frac{f_{et}}{f_{ck}}\right)^{1.5}] \]

\[ = \left[(1.16)(1)(1)(1)(24)(1) \{4000 \text{ psi}\}^{0.5}(10.5 \text{ in}^2)^{1.5}\right] \]

\[ = 59.91 \text{ kips} \]

**Design Strengths - Tension**

Concrete breakout - group \( \phi \ N_{cbg} = (0.7)(59.91 \text{ kips}) \)

\[ \phi \ N_{cbg} = \text{41.94 kips} \]

Anchor tensile strength - group \( \phi \ n N_{sa} = (0.75)(2)(27.12 \text{ kips}) \)

Anchor tensile strength - group \( \phi \ n N_{sa} = \text{40.68 kips} \)

Anchor tensile demand - group \( N_{ua} = 17.50 \text{ kips} \)
Steel Anchor Shear Strength (D.6.1)

Nominal shear strength of steel cast-in headed bolt anchor given by:

\[ V_{sa} = n \cdot 0.6 \cdot A_{se,V} \cdot f_{ula} \]  

(Eq D-20)

where:

\[
\begin{align*}
    n &= 4 \text{ bolts} \quad \text{all bolts participate in shear} \\
    A_{se,V \text{ provided}} &= 0.226 \text{ in}^2 \quad \text{effective anchor cross sectional area for single bolt} \\
    f_{ula} &= 120 \text{ ksi}
\end{align*}
\]

from Eq's (D-2) and (D-20), determine \( A_{se,V \text{ required}} \):

\[
\begin{align*}
    A_{se,V \text{ reqd}} &\geq V_{ula} / n \cdot 0.6 \cdot f_{ula} = [12.4 \text{ kips}]/[(4)(0.6)(0.65)(120\text{ksi})] \\
    A_{se,V \text{ reqd}} &= 0.066 \text{ in}^2 \\
    A_{se,V \text{ provided}} &\geq A_{se,V \text{ reqd}}? \quad \text{OK}
\end{align*}
\]

Nominal steel shear strength:

\[ V_{sa} = n \cdot 0.6 \cdot A_{se,prov'd} \cdot f_{ula} = [(4)(0.6)(0.226 \text{ in}^2)(120\text{ksi})] \]

\[ V_{sa} = 65.09 \text{ kips} \quad \text{(for entire group of anchors)} \]

Friction between concrete and steel base plate

(only consider if normal force always present to develop friction)

Assume friction coefficient of:

\[ \mu = 0.4 \]

Compression force equal to tension

from moment calculated above:

\[ CF = 17.5 \text{ kips} \]

\[ V_f = \mu \cdot CF = (0.4)(17.5 \text{ kips}) \]

\[ V_f = 7.00 \text{ kips} \]

Design shear strength for 4 anchors:

\[ \phi \cdot V_{sa} + \phi \cdot V_f = (0.65)(65.09 \text{ kips}) + (0.65)(7 \text{ kips}) \]

\[ = 42.31 \text{ kips} + 4.55 \text{ kips} \]

\[ \phi \cdot V_{sa} + \phi \cdot V_f = 46.86 \text{ kips} \]
Concrete Breakout Strength of Anchor in shear (D.6.2)

Note: The example calculation below for concrete breakout strength considers the failure surface for the row of anchors furthest from the edge ("Mode 1" as shown in the preceding sketch). This failure mode assumes that this row of anchors alone resists the entire shear force as the group concrete breakout strength is developed.

Nominal concrete shear breakout strength of a group of anchors is given by:

\[ V_{cbg} = (A_{VC}/A_{Vco}) \Psi_{ec,V} \Psi_{ed,V} \Psi_{c,V} \Psi_{h,V} V_b \]  

(Eq D-22)

where the following are modification factors for:

- Eccentricity effects: \( \Psi_{ec,V} = 1.0 \) (shear acts through center of group)  
- Edge effects: \( \Psi_{ed,V} = 1.0 \) if \( c_{st} \geq 1.5 c_{st1} \)  
- Concrete cracking: \( \Psi_{c,V} = 1.0 \) cracking assumed at service loads  
- Member thickness: \( \Psi_{h,V} = \begin{cases} 1.38 & \text{if } h_a \geq 1.5 c_{st1}, \text{ else:} \left(1.5 c_{st1}/h_a\right)^{1/2} \end{cases} \)  

\( h_a = 18 \text{ in} \) \( (1.5 c_{st1} = 34.5 \text{ in}) \)

\( h_a \geq 1.5 c_{st1}? \) : FALSE

\[ A_{Vco} = 4.5 \left(c_{st1}\right)^2 \]  

Projected area for a single anchor in a deep member with a distance from edges \( \geq 1.5 c_{st1} \) in the direction perpendicular to the shear force  

\[ = (4.5)(23 \text{ in})^2 \]  

\[ = 2380.5 \text{ in}^2 \]

\[ A_{VC} = h_a \left(3c_{st1} + s\right) \]  

Projected area of the failure surface on the side of the concrete member at its edge for a group. It shall be permitted to evaluate \( A_{VC} \) as the base of a truncated half pyramid projected on the side face of the member where the top of the half pyramid is given by the axis of the anchor row selected as critical. The value of \( c_{st1} \) shall be taken as the distance from the edge to this axis.

\[ = (18 \text{ in}) \left(3(23 \text{ in}) + 5 \text{ in}\right) \]  

\[ = 1332 \text{ in}^2 \]

see Fig. RD.6.2.1(b)

Ratio of these areas: \( A_{VC} / A_{Vco} = (1332 \text{ in}^2) / (2380.5 \text{ in}^2) = 0.56 \)

The projected concrete failure area of the group shall not exceed the sum of the individual concrete failure areas:

\[ A_{VC} \leq n A_{Vco}? : (1332 \text{ in}^2) \leq (2)(2380.5 \text{ in}^2)? : OK \]  

(D.6.2.1)

Basic concrete breakout strength of a single anchor in shear in cracked concrete given by:

\[ V_b = (7 \left(l_c/d_{st}\right)^{0.2} (d_{st})^{1.2}) \lambda \left(t_c\right)^{1/2} c_{st1}^{1.5} \]  

(Eq D-24)

where:

- \( l_c \) is the load bearing length of the anchor for shear
- \( \lambda = \begin{cases} 5.00 & \text{in} = hcf = 10.5 \text{ in} \leq 8 d_a = 5 \text{ in} \\ 1.0 & \text{(Normal weight concrete)} \end{cases} \) (8.6.1)

Provided basic single anchor concrete breakout strength in shear:

\[ V_b = \{(7)(5 \text{ in} / 0.625 \text{ in})^{0.2} (0.625 \text{ in})^{0.5} (1) (4000 \text{ psi})^{0.5} (23 \text{ in})^{1.5} \} \]  

\[ = 58.52 \text{ kips} \]

Provided nominal concrete breakout strength in shear on anchor group (for given failure mode):

\[ V_{cbg} = (A_{VC}/A_{Vco}) \Psi_{ec,V} \Psi_{ed,V} \Psi_{c,V} \Psi_{h,V} V_b \]  

\[ = [(0.56)(1)(1)(1.38)[58.52 \text{ kips}]] \]  

\[ V_{cbg} = 45.37 \text{ kips} \]

Note: This strength is for failure mode "1", as described above and shown the preceding sketch. Complete design calculations should also consider failure mode "2", as pictured on the sketch, due to half the shear acting on the row closest to the edge. See Fig. RD.6.2.1(b).
4.1.3: Example of cast-in-place anchor subject to combined shear and tension per ACI 318-08 Appendix D, Factored Loads

Pryout Strength of Anchor in Shear (D.6.3)

Nominal concrete pryout strength of anchor group is given by:

\[ V_{cpg} = k_{cp} \cdot N_{cbg} \]  \hspace{1cm} (Eq D-31)

where:

\[ k_{cp} = 2.0 \] for \( h_{ef} \geq 2.5\text{in} \]  \hspace{1cm} (D.6.3.1)

\[ N_{cbg} = 59.91 \text{ kips} \] as calculated above by (Eq D-5)

Provided nominal concrete pryout strength in shear of single anchor:

\[ V_{cpg} = k_{cp} \cdot N_{cbg} = [2](59.91 \text{ kips}) \]

\[ V_{cpg} = 119.82 \text{ kips} \]

Design Steel Base Plate

Design steel base plate thickness for flexure per applicable code.

This step is not covered in this example.

Tension Design Strengths:

Steel anchor tensile strength (2)  
\[ \phi_n \cdot N_{sa} = (0.75) \cdot (2)(27 \text{ kips}) = 40.7 \text{ kips} \]  \hspace{1cm} CONTROLS

Concrete breakout failure  
\[ \phi \cdot N_{cbg} = (0.7)(59.9 \text{ kips}) = 41.9 \text{ kips} \]

Anchor pullout failure  
\[ \phi \cdot N_{cpq} = \text{not considered in this example} \text{ kips} \]

\[ \phi \cdot N_{n} = \min(\phi \cdot N_{sa}, \phi \cdot N_{cbg}, \phi \cdot N_{cpq}) = 40.7 \text{ kips} \]  \hspace{1cm} (D.4.1.2)

\[ N_{ua} = 17.5 \text{ kips (2 anchors)} \]  \hspace{1cm} (Eq D-1)

\[ \phi \cdot N_{n} \geq N_{ua} \? : \text{OK} \]

\[ N_{ua} / \phi \cdot N_{n} = 0.43 \]

Shear Design Strengths:

Steel anchor shear strength (2)  
\[ \phi \cdot V_{sa} = (0.65)(32.5 \text{ kips}) = 21.2 \text{ kips} \]  \hspace{1cm} CONTROLS

Concrete breakout failure  
\[ \phi \cdot V_{cbg} = (0.7)(45.4 \text{ kips}) = 31.8 \text{ kips} \]

Concrete pryout failure  
\[ \phi \cdot V_{cpq} = (0.7)(119.8 \text{ kips}) = 83.9 \text{ kips} \]

\[ \phi \cdot V_{n} = \min(\phi \cdot V_{sa}, \phi \cdot V_{cbg}, \phi \cdot V_{cpq}) = 21.2 \text{ kips} \]  \hspace{1cm} (D.4.1.2)

\[ V_{ua} = 12.40 \text{ kips} \]

\[ \phi \cdot V_{n} \geq V_{ua} \? : \text{OK} \]  \hspace{1cm} (Eq D-2)

\[ V_{ua} / \phi \cdot V_{n} = 0.59 \]

Interaction of tensile and shear forces (D.7)

Since \( V_{ua} \geq 0.2 \phi \cdot V_{n} \) and \( N_{ua} \geq 0.2 \phi \cdot V_{n} \):

\[ \left( N_{ua} / \phi \cdot N_{n} \right) + \left( V_{ua} / \phi \cdot V_{n} \right) = 1.02 \leq 1.2, \text{ OK} \]  \hspace{1cm} (Eq D-32)

- Anchor bolt failure controls design for tension due to applied moment. (ductile)
- Anchor bolt failure controls design for shear due to applied shear. (ductile)
- Capacity greater than factored loads, per interaction equation.
Attachment B

Post-Installed Mechanical Anchors
PROJECTED CONCRETE FAILURE AREA IN TENSION
Anc, Anco

PLAN

SECTION

POST-INSTALLED MECHANICAL ANCHOR WITH SUSTAINED TENSION
Single Post-Installed Mechanical Anchor in Tension

Determine capacity of single headed post-installed mechanical anchor in cracked concrete subject to tension only. No eccentricity (i.e. load is centered on anchor).

Assumptions:
* All references are to ACI 318-08 unless otherwise noted.
* Product testing per ICC-ES AC193 or ACI 355.2.
* Concrete is considered cracked, as controlled by flexural reinforcement design.
* $\phi$-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.

Notes to designer:
* Obtain the most recent ICC-ES Report (ESR) for the anchor from: http://www.icc-es.org.
* Do not use an ESR obtained from the manufacturer's website for design.
* Check that the date of the ESR is consistent with that of the design code.

Given:
Concrete Properties
\[
\begin{align*}
c_{at} &= 18 \text{ in} & \text{Edge Distance in direction 1} \\
c_{at} &= 18 \text{ in} & \text{Edge Distance in direction 2} \\
h_c &= 18 \text{ in} & \text{Depth of concrete} \\
 f'_c &= 7000 \text{ psi} & \text{Compressive strength}
\end{align*}
\]

Anchor Properties (Input below and check design)
HILTI HDA Undercut Anchor, Size M12. Data from ICC-ES Report ESR-1546, Reissued 2008 March 1
\[
\begin{align*}
f_{ya} &= 92.8 \text{ ksi} & \text{Yield strength} & \text{(ESR-1546 - Table 5)} \\
f_{uas} &= 116 \text{ ksi} & \text{Tensile strength} & \text{(ESR-1546 - Table 5)}
\end{align*}
\]
Note: This is a ductile steel element per the definition of D.1.
\[
\begin{align*}
h_{ef} &= 4.92 \text{ in} & \text{Effective embedment depth} & \text{(ESR-1546 - Table 5)} \\
d_a &= 0.830 \text{ in} & \text{Anchor diameter} & \text{(ESR-1546 - Table 5)} \\
A_{se} &= 0.131 \text{ in}^2 & \text{Effective Tensile Area} & \text{(ESR-1546 - Table 5)} \\
k_{c,cr} &= 24 & \text{effectiveness factor for cracked concrete} & \text{(ESR-1546 - Table 5)} \\
k_{c,uncr} &= 30 & \text{effectiveness factor for uncracked concrete} & \text{(ESR-1546 - Table 5)}
\end{align*}
\]

Loads
\[
N_{ua} = 8 \text{ kips} & \text{(no shear, no moment)}
\]

Where: $N_{ua}$ is the applied factored external tension using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors ($\phi$) for nominal strengths:
\[
\begin{align*}
\text{Tension of ductile steel element} & : & \phi = 0.75 & \text{(ESR-1546 - Table 5)} \\
\text{Concrete breakout or pullout} & : & \phi = 0.65 & \text{(ESR-1546 - Table 5)}
\end{align*}
\]
\text{Condition B: no supplementary reinforcement}
4.2.1: Example of post-installed mechanical anchor subject to tension only per ACI 318-08 Appendix D, Factored Loads

Solution:

Determine anchor suitability to resist loads as shown above.

Calculate required strengths such that \( 4N_r \geq N_{ua} \)  \hspace{1cm} (Eq D-1)

where \( 4N_r \) is the minimum design strength of all appropriate failure modes.  \hspace{1cm} (D.4.1.2)

In this example, failure modes are: Steel anchor strength
Concrete breakout
Anchor pullout

For a ductile failure mode, the steel anchor must fail before the concrete breakout and anchor pullout.

Steel Anchor Strength  \hspace{1cm} (D.5.1)

Nominal tension strength of steel anchor given by:
\[
N_{ea} = n A_{se,N} f_{uta}
\]  \hspace{1cm} (Eq D-3)

where:
\[
n = \boxed{1} \text{ number of mechanical anchors}
\]

To check:
\[
A_{se,N} = \text{[in}^2\text{]} \text{ effective anchor cross sectional area in tension}
\]
\[
f_{uta} = 116 \text{ ksi}
\]

shall not exceed the following:
\[
1.9f_{ya} = 176.32 \text{ ksi}
\]
or
\[
125 \text{ ksi}
\]

Use \( f_{uta} = 116 \text{ ksi} \)

from Eq's (D-1) and (D-3), determine \( A_{se,reqd} \):
\[
A_{se,reqd} = \frac{N_{ea}}{n f_{uta}} = \frac{[8 \text{ kips}]/[(1)(0.75)(116\text{ksi})]}{0.092 \text{ in}^2}
\]
\[
A_{se} = 0.131 \text{ in}^2
\]

CHECK: Is \( A_{se} \geq A_{use,reqd} \)?: **OK**

Provided Steel Tension Strength:
\[
N_{ea} = A_{se,prov} f_{uta} = [(0.131 \text{ in}^2)(116\text{ksi})]
\]
\[
N_{ea} = 15.196 \text{ kips}
\]
Concrete Breakout Strength of Anchor in Tension (D.5.2)

Nominal tension strength of concrete against breakout given by:
\[ N_{cb} = \left( \frac{A_{nc}}{A_{Nco}} \right) \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b \]  
(Eq D-4)

where:
- Modification factor for edge effects: \[ \Psi_{ed,N} = 1.00 \quad \text{when } c_{a,\text{min}} \geq 1.5 h_{ef} \]  
  (D.5.2.5)
- Modification factor for cracking: \[ \Psi_{c,N} = 1.25 \]  
  (ESR-1546 - Table 5)
- Modification factor for splitting: \[ \Psi_{cp,N} = 1.00 \quad (=1.0 \text{ for cracking under service loads}) \]  
  (D.5.2.7)

\[ A_{Nco} = 9 \ h_{ef}^2 \quad [\text{in}^2] \]  
Projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5\( h_{ef} \)  
(Eq D-6)

\[ A_{nc} = \quad [\text{in}^2] \]  
Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward 1.5\( h_{ef} \) from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).

In this example of a single anchor without concern for edge effects:
\[ A_{Nco} = A_{nc} = 9 \ h_{ef}^2 \]  
\[ >>>>> A_{Nco}/A_{Nco} = 1.00 \]

Basic concrete breakout strength of a single anchor in tension in cracked concrete given by:
\[ N_b = k_c \lambda \left( f_{c}' \right)^{1/2} h_{ef}^{1.5} \]  
(Eq D-7)

where:
- \[ k_c = k_{c,cr} = 24 \]  
  (ESR-1546 - Table 5)
- \[ \lambda = 1.0 \]  
  (Normal weight concrete)  
  (8.6.1)
- \[ h_{ef} = 4.92 \text{ in} \]  
  Effective embedment depth of anchor

Provided basic concrete breakout strength of single anchor:
\[ N_b = k_c \lambda \left( f_{c}' \right)^{1/2} h_{ef}^{1.5} = (24)(1) \{7000 \text{ psi}\}^{1/2} \{4.92 \text{ in}\}^{1.5} \]
\[ N_b = 21.91 \text{ kips} \]

Provided nominal concrete breakout strength of single anchor:
\[ N_{cb} = (A_{nc}/A_{Nco}) \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b = [(1)(1)(1.25)(1)[21.91 \text{ kips}]] \]
\[ N_{cb} = 27.39 \text{ kips} \]
Pullout Strength of Anchor in Tension (D.5.3)

Nominal pullout strength of a single post-installed anchor in tension is determined by product testing according to ACI 355.2, or ICC-ES AC193. For the anchor considered it is given by:

\[ N_{p,rc} = N_{p,cr} \left( \frac{f'_c}{2500} \right)^{1/2} \]

where:
- \( N_{p,cr} = 11,240 \text{ lb} \) (ESR-1546 - Table 5)
- \( f'_c = 7000 \text{ psi} \) given above

Provided nominal pullout strength of single post-installed mechanical anchor is given by:

\[ N_{p,rc} = N_{p,cr} \left( \frac{f'_c}{2500} \right)^{1/2} = \left( \frac{11240 \text{ lb}}{1000 \text{ lb/kip}} \right) \left( \frac{7000 \text{ psi}}{2500 \text{ psi}} \right)^{0.5} \]

\[ N_{p,rc} = 18.81 \text{ kips} \]

Summary of Design Strengths:

- Steel anchor strength:
  - \( \phi N_{sa} = (0.75) (15.2 \text{ kips}) = 11.40 \text{ kips} \) CONTROLS

- Concrete breakout strength:
  - \( \phi N_{cb} = (0.65) (27.4 \text{ kips}) = 17.80 \text{ kips} \)

- Anchor pullout strength:
  - \( \phi N_n = \min(\phi N_{sa}, \phi N_{cb}, \phi N_{pn}) = 11.40 \text{ kips} \) (D.4.1.2)

  \[ N_{ua} = 8.00 \text{ kips} \]

\[ \phi N_n \geq N_{ua} ? : \text{OK} \] (Eq D-1)

- Anchor fails first.
- Capacity greater than factored loads.
POST-INSTALLED MECHANICAL ANCHOR IN SHEAR
4.2.2: Example of post-installed mechanical anchor subject to shear only per ACI 318-08 Appendix D, Factored Loads

Single Post-Installed Mechanical Anchor in Shear

Determine capacity of single post-installed mechanical anchor in cracked concrete subject to shear only. No eccentricity (i.e. load is centered on anchor).

Assumptions:

* All references are to ACI 318-08 unless otherwise noted.
* Product testing per ICC-ES AC193 or ACI 355.2.
* Concrete is considered cracked, as controlled by flexural reinforcement design.
* $\phi$-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.

Notes to designer:

* Obtain the most recent ICC-ES Report (ESR) for the anchor from: http://www.icc-es.org.
* Do not use an ESR obtained from the manufacturer's website for design.
* Check that the date of the ESR is consistent with that of the design code.

Given:

Concrete Properties

- $c_{sl} = 10$ in, Distance to free edge in direction of load
- $c_{se} = 18$ in, Distance to edges perpendicular to direction of load
- $h_o = 18$ in, Depth of concrete
- $f'_c = 4000$ psi, Compressive strength

Anchor Properties (Input below and check design)

HILTI HSL-3 Expansion Anchor, Size M-10. Data from ICC-ES Report ESR-1545, Reissued 2008 March 1

- $f_y = 92.8$ ksi, Yield strength
- $f_u = 116$ ksi, Tensile strength

Note: This is a ductile steel element per the definition of D.1.

- $h_{ef} = 2.76$ in, Effective embedment depth
- $d_o = 0.59$ in, Anchor diameter
- $A_{se} = 0.090$ in$^2$, Effective cross-sectional area
- $k_{cr} = 24$, effectiveness factor for cracked concrete
- $k_{uncr} = 24$, effectiveness factor for uncracked concrete

Loads

- $V_{ua} = 6$ kips, (no axial, no moment)

Where: $V_{ua}$ is the applied factored shear using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors ($\phi$) for nominal strengths:

- Shear of ductile steel element: $\phi = 0.65$
- Concrete breakout or pryout: $\phi = 0.70$

Condition B: no supplementary reinforcement
Solution:

Determine anchor suitability to resist loads as shown above.

Calculate required strengths such that $\phi V_n \geq V_{ua}$ 

where $\phi V_n$ is the minimum design strength of all appropriate failure modes. 

In this example, failure modes are: Steel anchor shear strength
Concrete side breakout failure
Concrete pryout failure

For a ductile failure mode, the steel anchor must fail before the concrete breakout and anchor pullout.

Steel Anchor Strength (D.6.1)

Nominal shear strength of steel anchor is given in the ICC-ES report:

$V_{sa} = \text{10.229 kips}$

Concrete Breakout Strength of Anchor in shear (D.6.2)

Nominal shear strength of concrete against breakout of a single anchor is given by:

$V_{cb} = (A_{Vc}/A_{Vco}) \Psi_{ed,V} \Psi_{c,V} \Psi_{h,V} V_0$

where:

Modification factor for edge effects: $\Psi_{ed,V} = 1.0$ if $c_{a2} \geq 1.5c_{a1}$

Modification factor for cracking: $\Psi_{c,V} = 1.0$ cracking assumed at service loads

Modif. factor for member thickness: $\Psi_{h,V} = 1.0$ if $h_a \geq 1.5c_{a1}$

$A_{Vco} = 4.5 c_{a1}^2$ [in$^2$] Projected area for a single anchor in a deep member with a distance from edges $\geq 1.5c_{a1}$ in the direction perpendicular to the shear force

$A_{Vc} = \ldots$ [in$^2$] Projected area of the failure surface on the side of the concrete member at its edge for a single anchor (or group). It shall be permitted to evaluate $A_{Vc}$ as the base of a truncated half pyramid projected on the side face of the member where the top of the half pyramid is given by the axis of the anchor row selected as critical. The value of $c_{a1}$ shall be taken as the distance from the edge to this axis.

In this example of a single anchor without concern for edge effects:

$A_{Vco} = A_{Vc} = 4.5 c_{a1}^2$

$\ldots A_{Vc}/A_{Vco} = 1.00$
4.2.2: Example of post-installed mechanical anchor subject to shear only per ACI 318-08 Appendix D, Factored Loads

Basic concrete breakout strength of a single anchor in shear in cracked concrete given by:

\[
V_b = (7 \frac{l_c}{d_a})^{0.2} \left( d_a \right)^{0.8} \left\{ f_{c_t} \right\}^{0.12} N_{ca}^{1.5}
\]  

(Eq D-24)

where:

\[
l_c = \text{the load bearing length of the anchor for shear} = 1.18 \text{ in} = 2da = 1.18 \text{ in} \tag{D.6.2.2}
\]

(Torque-controlled anchor with separate distance and expansion sleeves)

\[
\lambda = \frac{1.0}{10 \text{ in}} \text{ (normal weight concrete)} \tag{8.6.1}
\]

Provided basic concrete breakout strength in shear of single anchor:

\[
V_b = (7 \frac{l_c}{d_a})^{0.2} \left( d_a \right)^{0.8} \left\{ f_{c_t} \right\}^{0.12} N_{ca}^{1.5} = \left[ (7)(1.18 \text{ in} / 0.59 \text{ in})^{0.2} (0.59 \text{ in})^{0.8} (0.5 \text{ in})^{0.12} \right] (1) (4000 \text{ psi})^{0.5} [10 \text{ in}]^{1.5} \]

\[
V_b = 12.4 \text{ kips} 
\]

Provided nominal concrete breakout strength in shear of single anchor:

\[
V_{cb} = (A_{Vc} / A_{Vco}) \Psi_{ed,V} \Psi_{e,V} \Psi_{h,V} V_b = [(1)(1)(1)(1)[12.35 \text{ kips}] \]

\[
V_{cb} = 12.4 \text{ kips} 
\]

Pryout Strength of Anchor in Shear (D.6.3)

Nominal concrete pryout strength of single anchor is given by:

\[
V_{cp} = k_{cp} N_{cb}
\]  

(Eq D-30)

where:

\[
k_{cp} = 2.0 \text{ for } h_{ef} \geq 2.5 \text{ in} \tag{D.6.3.1}
\]

\[
N_{cb} = \text{concrete breakout strength of anchor in tension}
\]

Nominal tension strength of concrete against breakout given by:

\[
N_{cb} = (A_{nc} / A_{Nco}) \Psi_{ed,N} \Psi_{e,N} \Psi_{h,N} N_b
\]  

(Eq D-4)

where:

Modification factor for edge effects:

\[
\Psi_{ed,N} = 1.0 \text{ when } c_{a,min} \geq 1.5 h_{ef}
\]  

(EQ D-5.2.5)

Modification factor for cracking:

\[
\Psi_{e,N} = 1.0
\]

(ESR-1545 - Table 3)

Modification factor for splitting:

\[
\Psi_{h,N} = 1.0 \text{ (=1.0 for cracking under service loads)}
\]  

\[A_{Nco} = 9 h_{ef}^2 \text{ [in}^2] \text{ Projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5h}_{ef} \]  

(Eq D-6)

\[A_{nc} = \text{ Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward 1.5h}_{ef} \text{ from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors)}\]

In this example of a single anchor without concern for edge effects:

\[
A_{Nco} = A_{nc} = 9 h_{ef}^2
\]

\[
A_{Nco}/A_{nc} = 1.00
\]
4.2.2: Example of post-installed mechanical anchor subject to shear only per ACI 318-08 Appendix D, Factored Loads

Basic concrete breakout strength of a single anchor in tension in cracked concrete given by:

$$ N_b = k_c \cdot \lambda \cdot \{f_c\}^{1/2} \cdot h_{ef}^{1.5} $$  \hspace{1cm} (Eq D-7)

where:

$$ k_c = k_{c,cr} = \text{24} $$  \hspace{1cm} (ESR-1545 - Table 3)

$$ \lambda = \boxed{1.0} \hspace{1cm} \text{(Normal weight concrete)} $$  \hspace{1cm} (8.6.1)

Assumed embedment depth: \hspace{0.5cm} h_{ef} = 2.76 \text{ in} \hspace{1cm} \text{Effective embedment depth of anchor (min 2.5" based on assumption for } k_{cp} \text{ above (D.6.3.1))}

Provided basic concrete breakout strength of single anchor:

$$ N_b = k_c \cdot \lambda \cdot \{f_c\}^{1/2} \cdot h_{ef}^{1.5} = (24)(1) \{4000 \text{ psi}\}^{1/2} \cdot [2.76 \text{ in}]^{1.5} $$

$$ N_b = 6.96 \hspace{0.5cm} \text{kips} $$

Provided nominal concrete breakout strength in tension of single anchor:

$$ N_{cb} = (A_{nc}/A_{ncb}) \cdot \Psi_{ed,N} \cdot \Psi_{c,N} \cdot \Psi_{cp,N} \cdot N_b = [(1)(1)(1)(6.96 \text{ kips})] $$

$$ N_{cb} = 6.96 \hspace{0.5cm} \text{kips} $$

Provided nominal concrete pryout strength in shear of single anchor:

$$ V_{cp} = k_{cp} \cdot N_{cb} = [(2)(6.96 \text{ kips})] $$

$$ V_{cp} = 13.92 \hspace{0.5cm} \text{kips} $$

Summary of Design Strengths:

| Steel anchor shear strength : | $\phi \cdot V_{sa}$ | (0.65) (10.2 kips) | 6.65 kips | CONTROLS |
| Concrete breakout strength : | $\phi \cdot V_{cb}$ | (0.7) (12.4 kips) | 8.65 kips |
| Concrete pryout strength : | $\phi \cdot V_{cp}$ | (0.7) (13.9 kips) | 9.74 kips |
| $\phi \cdot V_n = \min(\phi \cdot V_{sa}, \phi \cdot V_{cb}, \phi \cdot V_{cp})$ | | 6.65 kips | |
| $V_{sa}$ | | 6.00 kips | |

- Anchor fails first.
- Capacity greater than factored loads.
PROJECTED CONCRETE FAILURE
AREA IN TENSION, Anc

TENSION ANCHORS

S

1.5 hcf

1.5 hcf

1.5 hcf

1.5 hcf

PLAN - MOMENT

REAR BOLT ROW
SHEAR FAILURE
PLANE "MODE 1"
(AS SHOWN IN EXAMPLE)

PLAN - SHEAR FORCE

POST-INSTALLED MECHANICAL ANCHOR IN COMBINED SHEAR
AND SUSTAINED TENSION DUE TO MOMENT
4.2.3: Example of post-installed mechanical anchor subject to combined shear and tension, per ACI 318-08 Appendix D, Factored Loads

Post-Installed Mechanical Anchor Four-Anchor Group under combined shear and uniaxial moment

Determine capacity of post-installed group of four mechanicals anchors in cracked concrete subject to combined shear and uniaxial moment. Shear and moment transmitted to anchor group via a 3" square structural steel tube welded to a steel base plate.

Assumptions:
* All references are to ACI 318-08 unless otherwise noted.
* Product testing per ICC-ES AC193 or ACI 355.2.
* Concrete is considered cracked, as controlled by flexural reinforcement design.
* ε-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.
* No eccentricity with respect to anchor tensile loads.

Notes to designer:
* Obtain the most recent ICC-ES Report (ESR) for the anchor from: http://www.icc-es.org.
* Do not use an ESR obtained from the manufacturer's website for design.
* Check that the date of the ESR is consistent with that of the design code.

Given:
Concrete Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>c_a1</td>
<td>23 in</td>
</tr>
<tr>
<td>c_a1'</td>
<td>18 in</td>
</tr>
<tr>
<td>c_a2</td>
<td>35 in</td>
</tr>
<tr>
<td>h_a</td>
<td>18 in</td>
</tr>
<tr>
<td>s</td>
<td>5 in</td>
</tr>
<tr>
<td>f_c'</td>
<td>7000 psi</td>
</tr>
</tbody>
</table>

Edge distance from rear anchor row to free edge in direction of load
Edge distance from front anchor row to free edge in direction of load
Edge distance to edge normal to direction of load, from nearest anchor in group
Depth of concrete
Spacing between anchors in group

Compressive strength

Anchor Properties (Input below and check design)

**HILTI HDA Undercut Anchor, Size M12.** Data from ICC-ES Report ESR-1546, Reissued 2008 March 1

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_ya</td>
<td>92.8 ksi</td>
</tr>
<tr>
<td>f_uha</td>
<td>116 ksi</td>
</tr>
</tbody>
</table>

Yield strength
Tensile strength

Note: This is a ductile steel element per the definition of D.1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n_a</td>
<td>4</td>
</tr>
<tr>
<td>h_eff</td>
<td>4.92 in</td>
</tr>
<tr>
<td>d_a</td>
<td>0.830 in</td>
</tr>
<tr>
<td>A_eff</td>
<td>0.131 in²</td>
</tr>
<tr>
<td>k_eff</td>
<td>24</td>
</tr>
</tbody>
</table>

Number of anchors in group
Effective embedment depth
Anchor diameter
Effective cross-sectional area
Effectiveness factor - cracked
Effectiveness factor - uncracked

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_uas</td>
<td>10 kips</td>
</tr>
<tr>
<td>M_uas</td>
<td>60 kip-in</td>
</tr>
</tbody>
</table>

Loads

Where: \( V_{uas} \) and \( M_{uas} \) are the applied factored shear and uniaxial moments using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors (φ) for nominal strengths:

<table>
<thead>
<tr>
<th>Element</th>
<th>φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension of ductile steel element</td>
<td>0.75</td>
</tr>
<tr>
<td>Shear of ductile steel element</td>
<td>0.65</td>
</tr>
<tr>
<td>Concrete shear breakout, pullout, or pryout</td>
<td>0.70</td>
</tr>
<tr>
<td>Concrete tension breakout or pullout</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Condition B: no supplementary reinforcement
4.2.3: Example of post-installed mechanical anchor subject to combined shear and tension, per ACI 318-08 Appendix D, Factored Loads

Solution:
Determine anchor suitability to resist loads as shown above.

Calculate required strengths for tension loads (due to moment) such that:
\[ \phi N_t \geq N_{u,a} \]  \hspace{1cm} (Eq D-1)
where:
- \( N_{u,a} \) is the tensile force imposed on the anchors by the moment
- \( \phi N_t \) is the minimum design strength of all appropriate failure modes.  \hspace{1cm} (D.4.1.2)

In this example, tension failure modes are:
- Steel anchor tension strength
- Concrete breakout
- Anchor pullout

Calculate required strengths for shear loads such that:
\[ \phi V_s \geq V_{u,a} \]  \hspace{1cm} (Eq D-2)
where:
- \( V_{u,a} \) is the minimum design strength of all appropriate failure modes.  \hspace{1cm} (D.4.1.2)

In this example, shear failure modes are:
- Steel anchor shear strength
- Concrete side breakout
- Concrete pryout

Steel Anchor Tension Strength (D.5.1)

Nominal tension strength of steel anchor given by:
\[ N_{u,a} = n A_{sa,N} f_{us} \]  \hspace{1cm} (Eq D-3)
where:
- \( n = 2 \) number of bolts in tension
  (one side tension / one side compression)

To calculate >>>
- \[ A_{sa,N} = \frac{[\text{in}^2]}{116 \text{ ksi}} \] effective anchor cross sectional area
- \( f_{us} = 116 \text{ ksi} \)

shall not exceed the following:
- \( 1.9 f_{ys} = 176.32 \text{ ksi} \)
- or \( 125 \text{ ksi} \)

Use \( f_{us} = 116 \text{ ksi} \)

Tension demand due to moment:
\[ N_t = M_{ub}/d = \frac{[60 \text{ kip-in}]}{[4 \text{ in}]} \]  \hspace{1cm} Assume \( d = 4'' \)
= 15 kips  \hspace{1cm} (on two anchors)

from Eq's (D-1) and (D-3), determine \( A_{sa,reqd} \):
- \[ A_{sa,reqd} = \frac{N_t}{\phi f_{us}} = \frac{[15 \text{ kips}]\left/[2\left(0.75\right)(116\text{ksi})]\right.}{0.086 \text{ in}^2} \]
- \[ A_{sa,reqd} = 0.131 \text{ in}^2 \]
- \[ A_{sa} = 0.131 \text{ in}^2 \]

CHECK: Is \( A_{sa} \geq A_{sa,reqd} \)?: \hspace{0.1cm} OK

Provided Steel Tension Strength of single anchor:
\[ N_{u,a} = A_{sa,provid} f_{us} = \left((0.131 \text{ in}^2)(116\text{ksi})\right) \]
\[ N_{u,a} = 15.196 \text{ kips} \]

Note: Anchor pullout must be also checked. Please see example for tension only on a single anchor.
Concrete Breakout Strength of Anchors in Tension (D.5.2)

Nominal concrete breakout strength of a group of anchors is given by:

\[ N_{\text{cog}} = \frac{A_{\text{NC}}}{A_{\text{NCg}}} \Psi_{\text{ec,N}} \Psi_{\text{ed,N}} \Psi_{\text{c,N}} \Psi_{\text{cp,N}} N_0 \]  

(Eq D-5)

where the following are modification factors for:

- Eccentricity effects: \( \Psi_{\text{ec,N}} = \begin{cases} 1.0 & \text{no eccentricity} \\ \text{when } c_{\text{a,min}} \geq 1.5 h_{\text{ef}} \end{cases} \)  

  \( \text{D.5.2.4} \)

- Edge effects: \( \Psi_{\text{ed,N}} = \begin{cases} 1.0 & \text{when } c_{\text{a,min}} \geq 1.5 h_{\text{ef}} \end{cases} \)  

  \( \text{D.5.2.5} \)

- Concrete cracking: \( \Psi_{\text{c,N}} = 1.25 \)  

  \( \text{ESR-1546 - Table 5} \)

- Concrete corner splitting: \( \Psi_{\text{cp,N}} = 1.0 \) (N/A)  

  \( \text{D.5.2.7} \)

\[ A_{\text{NC}} = 9 \ h_{\text{ef}}^2 \ \text{[in}^2] \]  

Projected concrete failure area of a single anchor with an edge distance equal to or greater than \( 1.5 h_{\text{ef}} \)  

(Eq D-6)

\[ A_{\text{NC}} = 3 \ h_{\text{ef}} (2 \ (1.5 h_{\text{ef}}) + s) \]  

Projected concrete failure area of a group of anchors that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward \( 1.5 h_{\text{ef}} \) from the centerlines through a row of adjacent anchors.

In this example, two anchors are in tension, while the other two are in compression.

\[ A_{\text{NCg}} = 9 \ h_{\text{ef}}^2 = 9 \times (4.92 \text{ in})^2 = 217.86 \ \text{in}^2 \]

\[ A_{\text{NC}} = 3 \ h_{\text{ef}} (2 \ (1.5 h_{\text{ef}}) + s) = 3 \times (4.92 \text{ in})(2 \times (1.5 \times 4.92 \text{ in})) + 5 \text{ in} = 291.56 \ \text{in}^2 \]

\[ \frac{A_{\text{NC}}}{A_{\text{NCg}}} = \frac{291.6576 \text{ in}^2}{217.8576 \text{ in}^2} = 1.34 \]

\[ A_{\text{NC}} \leq n \ A_{\text{NCg}}? = (291.6576 \text{ in}^2) <= (2)(217.8576 \text{ in}^2) \ : \ OK \]  

(\text{D.5.2.1})

Basic concrete breakout strength of a single anchor in tension in cracked concrete given by:

\[ N_p = k_c \lambda \left( \frac{f_{ct}}{1.0} \right)^{1.5} h_{\text{ef}} \]  

(Eq D-7)

where:

\[ k_c = k_{c,cr} = 24 \]  

(Normal weight concrete)  

(ESR-1546 - Table 5)

\[ \lambda = 1.0 \]  

(ESR-1546 - Table 5)

\[ N_{\text{cog}} = (A_{\text{NCg}}/A_{\text{NC}}) \Psi_{\text{ec,N}} \Psi_{\text{ed,N}} \Psi_{\text{c,N}} \Psi_{\text{cp,N}} k_c \lambda \left( \frac{f_{ct}}{1.0} \right)^{1.5} h_{\text{ef}} \]

\[ = [(1.34)(1)/(1.0)(1.25)(1)(24)(1)(7000 \text{ psi})]^{0.5} (4.92 \text{ in}^2)^{1.5} \]

\[ = 35.70 \ \text{kips} \]

**Design Strengths - Tension**

Concrete breakout - group  
\[ \phi N_{\text{cog}} = (0.85)(36.7 \text{ kips}) = 30.64 \text{ kips} \]

Anchor tensile strength - group  
\[ \phi n N_{\text{sat}} = (0.75)(2)(15.2 \text{ kips}) = 22.80 \text{ kips} \]

Anchor tensile demand - group  
\[ N_{\text{sat}} = 15.00 \text{ kips} \]
Steel Anchor Shear Strength (D.6.1)

Nominal shear strength of a single steel anchor is:

\[ V_{sa} = 7.284 \text{ kips} \]  

(ESR-1546 - Table 5)

Friction between concrete and steel base plate
(only consider if normal force always present to develop friction)

Assume friction coefficient of: \[ \mu = 0.4 \]

Compression force equal to tension from moment calculated above:

\[ CF = 15 \text{ kips} \]

\[ V_t = \mu CF = (0.4)(15 \text{ kips}) \]

\[ V_t = 6.00 \text{ kips} \]

Design shear strength for 4 anchors:

\[ f V_{sa} + f V_t = (0.65)(4)(7.284 \text{ kips}) + (0.65)(6 \text{ kips}) \]

\[ = 18.94 \text{ kips} + 3.9 \text{ kips} \]

\[ f V_{sa} + f V_t = 22.84 \text{ kips} \]
Concrete Breakout Strength of Anchor in shear (D.6.2)

Note: The example calculation below for concrete breakout strength considers the failure surface for the row of anchors furthest from the edge ("Mode 1" as shown in the preceding sketch). This failure mode assumes that this row of anchors alone resists the entire shear force as the group concrete breakout strength is developed.

Nominal concrete shear breakout strength of a group of anchors is given by:

\[ V_{bg} = \left( \frac{A_{vo}}{A_{voa}} \right) \Psi_{ac} \Psi_{ed} \Psi_{c, v} \Psi_{h, v} V_0 \]  

(Eq D-22)

where the following are modification factors for:

- Eccentricity effects: \( \Psi_{ac} = 1.0 \) (shear acts through center of group)
- Edge effects: \( \Psi_{ed} = 1.0 \) if \( c_{di} \geq 1.5c_{ai} \)
- Concrete cracking: \( \Psi_{c, v} = 1.0 \) cracking assumed at service loads
- Member thickness: \( \Psi_{h, v} = 1.38 \)

\[ h_x = 18 \text{ in} \] 
\[ (1.5c_{ai} = 34.5 \text{ in}) \]

\[ h_x \geq 1.5c_{ai}?: \] FALSE

\[ A_{voa} = 4.5 \left( \frac{c_{ai}}{c_{si}} \right)^2 \]  

Projected area for a single anchor in a deep member with a distance from edges \( \geq 1.5c_{ai} \) in the direction perpendicular to the shear force

\[ = (4.5)(23 \text{ in})^2 \]
\[ = 2380.5 \text{ in}^2 \]

\[ A_{vo} = h_a \left( \frac{3(c_{si})}{c_{ai}} \right) + 3 \]  

Projected area of the failure surface on the side of the concrete member at its edge for a group. It shall be permitted to evaluate \( A_{vo} \) as the base of a truncated half pyramid projected on the side face of the member where the top of the half pyramid is given by the axis of the anchor row selected as critical. The value of \( c_{ai} \) shall be taken as the distance from the edge to this axis

\[ = (18 \text{ in}) \left( \frac{3(23 \text{ in})}{5 \text{ in}} \right) \]
\[ = 1332 \text{ in}^2 \]

\[ \text{see Fig. RD.6.2.1(b)} \]

Ratio of these areas: \( \frac{A_{vo}}{A_{voa}} = \frac{(1332 \text{ in}^2)}{(2380.5 \text{ in}^2)} = 0.56 \)

The projected concrete failure area shall not exceed the sum of the individual concrete failure areas:

\[ A_{vo} \leq n A_{voa} \Rightarrow \frac{(1332 \text{ in}^2)}{(2)(2380.5 \text{ in}^2)} \Rightarrow \text{OK} \]  

(Eq D.6.2.1)

Basic concrete breakout strength of a single anchor in shear in cracked concrete given by:

\[ V_{s} = \left( \frac{T}{l_e} \right) \left( \frac{(d_a)^{0.5}}{(d_s)^{1.5}} \right) \lambda \left( \frac{f_e}{c_{ai}} \right)^{0.5} \]  

(Eq D-24)

where: \( l_e \) is the load bearing length of the anchor for shear
\[ = 4.92 \text{ in} \]
\[ = h_{ef} = 4.92 \text{ in} \leq 8 \text{ da} = 6.64 \text{ in} \]

(see also ESR-156 - Table 5, footnote 11)

\[ \lambda = 1.0 \]  

(Normal weight concrete)

(8.6.1)

Provided basic single anchor concrete breakout strength in shear:

\[ V_{b} = [(7)(4.92 \text{ in} / 0.83 \text{ in})^{0.2} (0.83 \text{ in})^{0.5} (1)(7000 \text{ psi})^{0.5} (23 \text{ in})^{1.5}] \]
\[ = 84.01 \text{ kips} \]

Provided nominal concrete breakout strength in shear on anchor group (for given failure mode):

\[ V_{bg} = \left( \frac{A_{vo}}{A_{voa}} \right) \Psi_{ac} \Psi_{ed} \Psi_{c, v} \Psi_{h, v} V_0 \]
\[ = [(0.56)(1)(1)(1)(1.38)(84.01 \text{ kips})] \]
\[ = 65.14 \text{ kips} \]

Note: This strength is for failure mode "1", as described above and shown on the sketch. Complete design calculations should also consider failure mode "2", as pictured on the sketch, due to half the shear acting on the row closest to the edge. See Fig. RD.6.2.1(b).
4.2.3: Example of post-installed mechanical anchor subject to combined shear and tension, per ACI 318-08 Appendix D, Factored Loads

Pryout Strength of Anchor in Shear (D.6.3)
Nominal concrete pryout strength of anchor group is given by:

\[ V_{cpg} = k_{cp} N_{cpg} \]  
(\text{Eq D-31})

where:

\[ k_{cp} = \begin{cases} 2.0 & \text{for } h_{af} \geq 2.5\text{in} \\ 36.70 & \text{kips as calculated above by (Eq D-5)} \end{cases} \]

Provided nominal concrete pryout strength in shear of single anchor:

\[ V_{cpg} = k_{cp} N_{cpg} = [(2)(36.7 \text{ kips})] = 73.41 \text{ kips} \]

Design Steel Base Plate
Design steel base plate thickness for flexure per applicable code.

This step is not covered in this example.

Tension Design Strengths:
Steel anchor tensile strength (2 anchors)
\[ \phi n N_{sa} = (0.75)(2)(15kips) = 22.8 \text{ kips} \]
Concrete breakout failure
\[ \phi N_{cbo} = (0.65)(36.7 \text{kips}) = 23.9 \text{ kips} \]
Anchor pullout failure
\[ \phi N_{cpg} = \text{not considered in this example} \text{ kips} \]
\[ \phi N_{p} = \min(\phi N_{sa}, \phi N_{cbo}, \phi N_{cpg}) = 22.8 \text{ kips} \]
\[ N_{ua} = 15.0 \text{ kips (2 anchors)} \]
\[ \phi N_{p} \geq N_{ua} ? : \text{OK} \]  
(\text{Eq D-1})
\[ N_{ua} / \phi N_{p} = 0.66 \]

Shear Design Strengths:
Steel anchor shear strength (2 anchors)
\[ \phi V_{sa} = (0.65)(2)(7kips) = 9.5 \text{ kips} \]
Concrete breakout failure
\[ \phi V_{cbo} = (0.7)(65.1 \text{kips}) = 45.6 \text{ kips} \]
Concrete pryout failure
\[ \phi V_{cpg} = (0.7)(73.4 \text{kips}) = 51.4 \text{ kips} \]
\[ \phi V_{p} = \min(\phi V_{sa}, \phi V_{cbo}, \phi V_{cpg}) = 9.5 \text{ kips} \]
(\text{D.4.1.2})

Shear load applied to anchors (frictional resistance considered):
\[ V_{ua} = V_{ua} - \phi V_{f} = 10 \text{ kips} - (0.4)(15 \text{ kips}) \]
\[ V_{ua} = 4.00 \text{ kips} \]
\[ \phi V_{p} \geq V_{ua} ? : \text{OK} \]  
(\text{Eq D-2})
\[ V_{ua} / \phi V_{p} = 0.42 \]

Interaction of tensile and shear forces (D.7)
Since \( V_{ua} \geq 0.2 \phi V_{p} \) and \( N_{ua} \geq 0.2 \phi V_{p} \):
\[ (N_{ua} / \phi N_{p}) + (V_{ua} / \phi V_{p}) = 1.08 \leq 1.2, \text{OK} \]  
(\text{Eq D-32})

- Anchor bolt failure controls design for tension due to applied moment. (ductile)
- Anchor bolt failure controls design for shear due to applied shear. (ductile)
- Capacity greater than factored loads, per interaction equation.
Attachment C

Post-Installed Adhesive Anchors
POST-INSTALLED ADHESIVE ANCHOR
WITH TEMPORARY TENSION
Single Adhesive Anchor Tension
Determine capacity of single post-installed adhesive anchor rod in uncracked concrete subject to tension only. No eccentricity (i.e. load is centered on anchor).

Assumptions:
* All references are to ACI 318 Appendix D, as modified by ICC-ES AC308, unless otherwise noted.
* Product testing per ICC-ES AC308.
* Concrete is considered uncracked, as controlled by flexural reinforcement design ($f_{x_{\text{max}}} < f_c$).
* $\phi$-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.

Notes to designer:
* Obtain the most recent ICC-ES Report (ESR) for the anchor from: http://www.icc-es.org.
* Do not use an ESR obtained from the manufacturer's website for design.
* Check that the date of the ESR is consistent with that of the design code.

Given:
Concrete Properties
- $c_{\text{ed}} = 20$ in, Edge Distance in direction 1
- $c_{\text{et}} = 20$ in, Edge Distance in direction 2
- $h_L = 18$ in, Depth of concrete
- $f_c = 4000$ psi, Compressive strength

Anchor Rod and Adhesive Properties
Input properties below and check design.

**Simpson Strong-Tie SET-XP Epoxy Adhesive Anchor for Uncracked Concrete**
- Design data from ICC-ES Report ESR-2508, Issued 2008 Aug 1 (This report contains modifications to ACI 318 App. D mirroring those of ICC-ES AC308, except that this anchor has been approved for use in uncracked concrete only).

Anchor Rod Properties (ASTM F1554, Gr. 36 (A307 Gr. C)):
- $f_y = 36$ ksi, Yield strength
- $f_{ut} = 58$ ksi, Tensile strength
- $d_a = 0.625$ in, Anchor diameter
- $A_{sa} = 0.2250$ in$^2$, Effective Tensile Area
- $h_d = 6.50$ in, Effective embedment depth

Adhesive Properties
For Temperature Range 1: Max short term temperature = 110°F, Max long term temperature = 75°F.
- $\tau_{\text{curv}} = 1.515$ psi, characteristic bond strength in uncracked concrete
- $k_{\text{curv}} = 24$, effectiveness factor for uncracked concrete
- $h_{\text{min}} = 3.125$ in, min and max effective embedment depths
- $h_{\text{min}} = 14.625$ in, minimum concrete thickness (= $2.25 \times h_d$)
- $c_{\text{ac}} = 19.5$ in, Critical edge distance (= 3 $h_d$)

Loads
- $N_{\text{es}} = 8$ kips, (no shear, no moment)

Where: $N_{\text{es}}$ is the applied factored external tension using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors ($\phi$) for nominal strengths:
- Tension of ductile steel element: $\phi = 0.75$ (ESR-2508 - Table 2)
- Concrete breakout: $\phi = 0.65$ (ESR-2508 - Table 4)
- Adhesive Bond Strength: $\phi = 0.55$ (ESR-2508 - Table 5)

Dry concrete installation, periodic inspection
Solution:

Determine anchor suitability to resist loads as shown above.

Calculate required strengths such that $\phi N_r \geq N_{ua}$  (Eq D-1)

where $\phi N_r$ is the minimum design strength of all appropriate failure modes. (D.4.1.2) and (D.4.1.2)

In this example, failure modes are:

- Steel anchor strength
- Tension limited by adhesive bond/concrete failure
- Tension limited by concrete cone breakout failure

For a ductile failure mode, the steel anchor must fail before the concrete breakout and adhesive failure.

**Steel Anchor Strength (D.5.1)**

Nominal tension strength of steel anchor given by:

$$ N_{sa} = n \cdot A_{sa,N} \cdot f_{uts} $$  (Eq D-3)

where:

- $n = 1$ number of anchor bolts
- $A_{sa,N} = \ldots$ effective anchor bolt cross sectional area
- $f_{uts} = 58$ ksi

To calculate >>>

$A_{sa,N} = \ldots$ [in$^2$]

shall not exceed the following: (D.5.1.2)

- $1.9f_{ya} = 68.4$ ksi
- or $125$ ksi

Use $f_{uts} = 58$ ksi

from Eq's (D-1) and (D-3), determine $A_{sa,required}$:

$$ A_{sa,reqd} = \frac{N_{sa}}{n \cdot f_{uts}} = \frac{[8 \text{ kips}] \cdot [(1)(0.75)(58\text{ksi})]}{0.184 \text{ in}^2} $$

$$ A_{sa} = 0.226 \text{ in}^2 $$

CHECK: Is $A_{sa} \geq A_{sa,reqd}$? : OK

Provided Steel Tension Strength:

$$ N_{sa} = A_{sa,prov} \cdot f_{uts} = [(0.226 \text{ in}^2)(58\text{ksi})] $$

$$ N_{sa} = 13.11 \text{ kips} $$
4.3.1: Example of post-installed adhesive anchor subject to tension only per ACI 318-08 App. D, as modified by ICC-ES AC308. Factored Loads

Tension limited by adhesive bond/concrete cone breakout (D.5.3) and (D.5.3.7 to D.5.3.14)

Nominal strength of an adhesive anchor in tension is given by:

\[ N_a = (A_{na}/A_{na0}) \Psi_{ed,Na} \Psi_{p,Na} N_{a0} \]  

(Eq D-16a)

where:

Modification factor for edge effects:

\[ \Psi_{ed,Na} = \begin{cases} 1.00 & \text{if } c_{u,min} \leq c_{cr,Na} \text{ else Eq. (D-16m)} \\ 1.00 & \text{if } c_{u,min} \geq c_{cr,Na} \text{ else Eq. (D-16p)} \end{cases} \]  

(D.5.3.12)

(D.5.3.14)

\[ A_{Na0} = (s_{cr,Na})^2 \text{ [in}^2\text{]} \]  

Projected concrete failure area of a single anchor with an edge distance \( \geq \) critical value, \( c_{cr,Na} \)

(Eq D-16c)

where:

Critical spacing:

\[ s_{cr,Na} = 20 \{\tau_{uncr}/1450\}^{1/2} \leq h_{ef} \]  

\[ = 20 \times (0.625) \times (1515 \text{ psi} / 1450) \times 0.5 \leq 3 \times 6.5 \text{ in} \]  

\[ s_{cr,Na} = 12.78 \text{ in} \leq 19.5 \text{ in} \]  

(Eq D-16d)

Critical edge distance:

\[ c_{u,Na} = s_{cr,Na} / 2 \]  

\[ = 6.39 \text{ in} \]  

(Eq D-16g)

\[ A_{Na0} = (12.78 \text{ in})^2 \]  

\[ = 163.25 \text{ in}^2 \]  

\[ A_{Na} = \]  

Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward \( c_{cr,Na} \) from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).

In this example of a single anchor without concern for edge effects:

\[ A_{Na} = A_{Na0} = (s_{cr,Na})^2 \]  

\[ >>>>>> A_{Na}/A_{Na0} = 1.00 \]

Basic strength of a single adhesive anchor in tension in uncracked concrete is given by:

\[ N_{a0} = \tau_{uncr} \pi d h_{ef} \]  

(Eq D-16f)

\[ N_{a0} = \tau_{uncr} \pi d h_{ef} = (1515 \text{ psi}) \times (3.14159 \times 0.625 \text{ in}) \times (6.5 \text{ in}) / (1000 \text{ lb} / \text{kip}) \]  

\[ N_{a0} = 19.34 \text{ kips} \]

 Provided nominal strength of single adhesive anchor in uncracked concrete:

\[ N_a = (A_{Na}/A_{Na0}) \Psi_{ed,Na} \Psi_{p,Na} N_{a0} = [(1/1)(1/1)(19.34 \text{ kips})] \]

\[ N_a = 19.34 \text{ kips} \]
Concrete Breakout Strength of Anchor in Tension (D.5.2)

Nominal tension strength of concrete against breakout given by:

\[ N_{cb} = \left( A_{nc}/A_{nco} \right) \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b \]  

(Eq D-4)

where:

- Modification factor for edge effects: \( \Psi_{ed,N} = 1.00 \) when \( c_{e,min} \geq 1.5h_{ef} \)  
  \( \text{(D.5.2.5)} \)
- Modification factor for cracking: \( \Psi_{c,N} = 1.00 \) no cracking assumed at service loads  
  \( \text{(D.5.2.6)} \)
- Modification factor for splitting: \( \Psi_{cp,N} = 1.00 \) when \( c_{e,max} \geq c_{co} \), else Eq. (D-13)  
  \( \text{(D.5.2.7)} \)

\[ A_{nco} = 9 \ h_{ef}^2 \text{ [in}^2]\]  

Projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5\( h_{ef} \).  

\[ A_{nc} = \]  

Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectangular geometrical figure that results from projecting the failure surface outward 1.5\( h_{ef} \) from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).

In this example of a single anchor without concern for edge effects:

\[ A_{nco} = A_{nc} = 9 \ h_{ef}^2 \]

\[ A_{nco}/A_{nc} = 1.00 \]

Basic concrete breakout strength of a single anchor in tension in uncracked concrete given by:

\[ N_b = k_c \lambda \left( f'_c \right)^{1/2} h_{ef}^{1.5} \]  

(Eq D-7)

where:

- \( k_c = k_c,\text{uncr} = 24 \)  
  \( \text{(ESR-2508 - Table 4)} \)

- \( \lambda = 1.0 \) (Normal weight concrete)  
  \( \text{(8.6.1)} \)

Assumed above:

\[ h_{ef} = 6.50 \text{ in} \]  

Effective embedment depth of anchor

Provided basic concrete breakout strength of single anchor:

\[ N_b = k_c \lambda \left( f'_c \right)^{1/2} h_{ef}^{1.5} = (24)(1) \{4000 \text{ psi}\}^{1/2} \{6.5 \text{ in}\}^{1.5} / (1000 \text{ lb/kip}) = 25.15 \text{ kips} \]

Provided nominal concrete breakout strength of single anchor:

\[ N_{cb} = (A_{nc}/A_{nco}) \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b = [(1)(1)(1)(25.15 \text{ kips})] = 25.15 \text{ kips} \]

Summary of Design Strengths:

- Steel anchor strength:\n  \( \phi N_{ss} = \)  
  \( (0.75) (13.1 \text{ kips}) = 9.83 \text{ kips} \)  
  \( \text{CONTROLS} \)

- Adhesive bond strength:\n  \( \phi N_{ab} = \)  
  \( (0.55) (19.3 \text{ kips}) = 10.64 \text{ kips} \)

- Concrete breakout:\n  \( \phi N_{cb} = \)  
  \( (0.65) (25.2 \text{ kips}) = 16.35 \text{ kips} \)

\[ \phi N_b = \min(\phi N_{ss}, \phi N_{ab}, \phi N_{cb}) = 9.83 \text{ kips} \]  

\( N_{ua} = 8.00 \text{ kips} \)  

\( \phi N_b \geq N_{ua} \) :  \( \text{OK} \)  

(Eq D-1)

- Anchor fails first.
- Capacity greater than factored loads.
POST-INSTALLED ADHESIVE ANCHOR IN SHEAR
Single Adhesive Anchor Shear

Determine capacity of single post-installed adhesive anchor rod in uncracked concrete subject to shear only.
No eccentricity (i.e. load is centered on anchor).

Assumptions:
* All references are to ACI 318 Appendix D, as modified by ICC-ES AC308, unless otherwise noted.
* Product testing per ICC-ES AC308.
* Concrete is considered uncracked, as controlled by flexural reinforcement design \( (f_{lim} < f) \).
* \( \phi \)-factors are based on Condition B in D.4.4 (supplementary reinforcement is not provided).
* Edge distances are considered large such that there are no edge effects.

Notes to designer:
* Obtain the most recent ICC-ES Report (ESR) for the anchor from: http://www.icc-es.org.
* Do not use an ESR obtained from the manufacturer’s website for design.
* Check that the date of the ESR is consistent with that of the design code.

Given:
Concrete Properties
\[
\begin{align*}
\sigma_{s1} &= 10 \text{ in} & & \text{Distance to free edge in direction of load} \\
\sigma_{s2} &= 18 \text{ in} & & \text{Distance to edges perpendicular to direction of load} \\
h_s &= 18 \text{ in} & & \text{Depth of concrete} \\
f_c &= 4000 \text{ psi} & & \text{Compressive strength}
\end{align*}
\]

Anchor Rod and Adhesive Properties
Input properties below and check design.

Simpson Strong-Tie SET-XP Epoxy Adhesive Anchor for Uncracked Concrete
- Design data from ICC-ES Report ESR-2508, Issued 2008 Aug 1 (This report contains modifications to ACI 318 App. D mirroring those of ICC-ES AC308, except that this anchor has been approved for use in uncracked concrete only).

Anchor Rod Properties (ASTM F1554, Gr. 36 (A307 Gr. C)):
\[
\begin{align*}
f_y &= 36 \text{ ksi} & & \text{Yield strength} \\
f_u &= 58 \text{ ksi} & & \text{Tensile strength} \\
d_a &= 0.75 \text{ in} & & \text{Anchor diameter} \\
A_{te} &= 0.334 \text{ in}^2 & & \text{Effective Tensile Area} \\
h_{ef} &= 3.50 \text{ in} & & \text{Effective embedment depth}
\end{align*}
\]

Adhesive Properties
- For Temperature Range 1: Max short term temperature = 110°F; Max long term temperature = 75°F.
\[
\begin{align*}
\tau_{k,uncr} &= 1,300 \text{ psi} & & \text{characteristic bond strength in uncracked concrete} \\
k_{c,uncr} &= 24 & & \text{effectiveness factor for uncracked concrete} \\
h_{ef,limits} &= 3.5 \text{ in} \quad 15 & & \text{min and max effective embedment depths} \\
h_{min} &= 7.675 \text{ in} & & \text{minimum concrete thickness (= 2.25 h_{ef})} \\
c_{ac} &= 10.5 \text{ in} & & \text{Critical edge distance (= 3 h_{ef})}
\end{align*}
\]

Loads
\[
V_{u} = 6 \text{ kips} & & \text{(no axial, no moment)}
\]
Where: \( V_{u} \) is the applied factored shear using load factors from ACI 318 Section 9.2 (consistent with AISC LRFD Specifications).

Resistance factors (\( \phi \)) for nominal strengths:
Shear of ductile steel element: \( \phi = 0.65 \) (ESR-2508 - Table 2)
Concrete breakout or pryout: \( \phi = 0.7 \) (ESR-2508 - Table 4)
4.3.2: Example of post-installed adhesive anchor subject to shear only per ACI 318-08 App. D, as modified by ICC-ES AC308. Factored Loads

Solution:

Determine anchor suitability to resist loads as shown above.

Calculate required strengths such that $\phi V_n \geq V_{ua}$  

(Eq D-2)

where $\phi V_n$ is the minimum design strength of all appropriate failure modes.  

(D.4.1.2) and (D.4.1.2)

In this example, failure modes are:

- Steel anchor shear strength
- Concrete breakout strength in shear
- Concrete pryout failure

For a ductile failure mode, the steel anchor must fail before concrete breakout or pryout.

Steel Anchor Strength (D.6.1)

Nominal shear strength of steel anchor given by:

$$V_{sa} = n \cdot 0.6 \cdot A_{se} \cdot f_{ula}$$

(Eq D-20)

where:

- $n$ = number of anchor bolts
- $A_{se}$ = effective anchor cross sectional area
- $f_{ula}$ = ksi

To calculate $A_{se}$:

$$f_{ula} = 58 \text{ ksi}$$

shall not exceed the following:

- $1.9f_{ya} = 68.4 \text{ ksi}$
- or $125 \text{ ksi}$

Use $f_{ula} = 58 \text{ ksi}$

from Eq's (D-2) and (D-20), determine $A_{se, \text{ required}}$:

$$A_{se, \text{reqd}} \geq \frac{V_{ua}}{\phi n 0.6 f_{ula}} = \frac{[8 \text{ kips}] / [(0.65)(1)(0.6)(58 \text{ ksi})]}{0.265 \text{ in}^2}$$

$$A_{se} = 0.334 \text{ in}^2$$

CHECK: Is $A_{se} \geq A_{se, \text{reqd}}$? : OK

Nominal steel shear strength:

$$V_{sa} = n \cdot 0.6 \cdot A_{se, \text{provd}} \cdot f_{ula} = [(1)(0.6)(0.334 \text{ in}^2)(58 \text{ ksi})]$$

$$V_{sa} = 11.62 \text{ kips}$$
Concrete Breakout Strength of Anchor in shear (D.6.2)

Nominal shear strength of concrete against breakout of a single anchor is given by:

\[ V_{cb} = \left( \frac{A_{Vc}}{A_{Vco}} \right) \Psi_{ed,V} \Psi_{e,V} \Psi_{h,V} V_b \]  

(Eq D-21)

where:

\[ \Psi_{ed,V} = \begin{cases} 1.0 & \text{if } c_{oa} \geq 1.5 c_{oa1}, \text{ else Eq. (D-28)} \end{cases} \]

(D.6.2.6)

\[ \Psi_{e,V} = \begin{cases} 1.4 & \text{no cracking assumed at service loads} \end{cases} \]

(D.6.2.7)

\[ \Psi_{h,V} = \begin{cases} 1.0 & \text{if } h_v \geq 1.5 c_{oa1}, \text{ else Eq. (D-29)} \end{cases} \]

(D.6.2.8)

\[ A_{Vco} = 4.5 c_{oa}^2 \text{ [in}^2\text{]} \]

Projected area for a single anchor in a deep member with a distance from edges \( \geq 1.5 c_{oa1} \) in the direction perpendicular to the shear force

\[ A_{Vc} = \text{[in}^2\text{]} \]

Projected area of the failure surface on the side of the concrete member at its edge for a single anchor (or group). It shall be permitted to evaluate \( A_{Vc} \) as the base of a truncated half pyramid projected on the side face of the member where the top of the half pyramid is given by the axis of the anchor row selected as critical. The value of \( c_{oa1} \) shall be taken as the distance from the edge to this axis.

In this example of a single anchor without concern for edge effects:

\[ A_{Vco} = A_{Vc} = 4.5 c_{oa1}^2 \]

\[ \frac{A_{Vc}}{A_{Vco}} = 1.00 \]

Basic concrete breakout strength of a single anchor in shear in cracked concrete given by:

\[ V_b = \left( \frac{7}{5} \right) \left( \frac{l_e}{d_a} \right)^{0.2} (d_a)^{1/2} \lambda \sqrt[12]{f'_c} \frac{1}{12} c_{oa1}^{1.5} \]

(Eq D-24)

where:

\[ l_e = \text{the load bearing length of the anchor for shear} \]

\[ = \begin{cases} 3.50 \text{ in} & \text{if } h_e = 3.5 \text{ in} \leq 8 \text{ da} = 6 \text{ in} \end{cases} \]

(D.6.2.2)

\[ \lambda = 1.0 \text{ (Normal weight concrete)} \]

(8.6.1)

Provided basic concrete breakout strength in shear of single anchor:

\[ V_b = \left[ 7 \left( \frac{l_e}{d_a} \right)^{0.2} (d_a)^{1/2} \lambda \frac{1}{12} f'_c \frac{1}{12} c_{oa1}^{1.5} \right] \left( \frac{4000}{10 in} \right)^{0.5} \]

\[ V_b = 16.5 \text{ kips} \]

Provided nominal concrete breakout strength in shear of single anchor:

\[ V_{cb} = \left( \frac{A_{Vc}}{A_{Vco}} \right) \Psi_{ed,V} \Psi_{e,V} \Psi_{h,V} V_b = (1)(1)(1.4)(1)(16.5 \text{ kips}) \]

\[ V_{cb} = 23.1 \text{ kips} \]
Pryout Strength of Anchor in Shear (D.6.3) and (D.6.3.2)

Nominal concrete pryout strength of single adhesive anchor is given by:

\[ V_{cp} = \min(k_{cp} N_a; k_{cp} N_{ob}) \]  \hspace{2cm} \text{(Eq D-30a)}

where:

\[ k_{cp} = \begin{cases} 2.0 & \text{if } h_{ef} < 2.5 \text{in}, \text{ else } = 2.0 \end{cases} \]  \hspace{2cm} \text{(D.6.3.1)}

\[ N_a = \text{nominal strength of an adhesive anchor in tension} \]

\[ N_{ob} = \text{concrete breakout strength of anchor in tension} \]

Nominal strength of an adhesive anchor in tension is given by:

\[ N_a = (A_{Na}/A_{Na0}) \Psi_{ed,Na} \Psi_{p,Na} N_{a0} \]  \hspace{2cm} \text{(Eq D-16a)}

where:

Modification factor for edge effects:

\[ \Psi_{ed,Na} = \begin{cases} 1.00 & \text{if } c_{e,min} \geq c_{cr,Na}, \text{ else Eq. (D-16m)} \end{cases} \]  \hspace{2cm} \text{(D.5.3.12)}

Modification factor for cracking:

\[ \Psi_{p,Na} = \begin{cases} 0.95 & \text{if } c_{e,min} \geq c_{cr,Na}, \text{ else Eq. (D-16p)} \end{cases} \]  \hspace{2cm} \text{(D.5.3.14)}

\[ \Psi_{p,Na} = \max(c_{e,min}, c_{cr,Na})/c_{cr,Na} = \text{MAX}(10 \text{ in}, 5.25 \text{ in})/10.5 \text{ in} \]  \hspace{2cm} \text{(Eq D-16p)}

\[ A_{Na0} = (s_{cr,Na})^2 \text{ [in}^2\text{]} \text{ Projected concrete failure area of a single anchor with an edge distance \( c_{cr,Na} \)} \]

where:

Critical spacing:

\[ s_{cr,Na} = 20 \text{ d } (t_{u,uncr}/1450)^{1/2} \leq 3 \text{ h}_{ef} \]

\[ = 20 (0.75) [(1300 \text{ psi})/1450]^{1/2} \leq 3 (3.5 \text{ in}) \]

\[ s_{cr,Na} = 10.50 \text{ in} \leq 10.5 \text{ in} \]  \hspace{2cm} \text{(Eq D-16d)}

Critical edge distance:

\[ c_{cr,Na} = s_{cr,Na}/2 \]

\[ = 5.25 \text{ in} \]  \hspace{2cm} \text{(Eq D-16e)}

\[ A_{Na0} = (10.5 \text{ in})^2 \]

\[ = 110.25 \text{ in}^2 \]

\[ A_{Na} = \frac{10.25 \text{ in}^2}{110.25 \text{ in}^2} \]

\[ \text{Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectangular geometrical figure that results from projecting the failure surface outward } c_{cr,Na} \text{ from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).} \]

In this example of a single anchor without concern for edge effects:

\[ A_{Na} = A_{Na0} = (s_{cr,Na})^2 \]

\[ \ggggggg A_{Na}/A_{Na0} = 1.00 \]

Basic strength of a single adhesive anchor in tension in cracked concrete is given by:

\[ N_{a0} = \tau_{t.uncr} \pi d h_{ef} \]  \hspace{2cm} \text{(Eq D-16f)}

\[ N_{a0} = \tau_{t.uncr} \pi d h_{ef} = (1300 \text{ psi})(3.14159)(0.75 \text{ in})(3.5 \text{ in})/(1000 \text{ lb} / \text{kip}) \]

\[ N_{a0} = 10.72 \text{ kips} \]

Provided nominal strength of single adhesive anchor in cracked concrete:

\[ N_a = (A_{Na}/A_{Na0}) \Psi_{ed,Na} \Psi_{p,Na} N_{a0} = [(1)(1)(0.95)][10.72 \text{ kips}] \]  \hspace{2cm} \text{(Eq D-16a)}

\[ N_a = 10.21 \text{ kips} \]
Nominal tension strength of concrete against breakout given by:

\[ N_{cb} = \left( \frac{A_{nc}}{A_{Nco}} \right) \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b \]  

(Eq D-4)

where:

- Modification factor for edge effects: \( \psi_{ed,N} = 1.00 \) when \( c_{u,min} \geq 1.5h_{ef} \)  
  (D.5.2.5)

- Modification factor for cracking: \( \psi_{c,N} = 1.00 \) no cracking assumed at service loads  
  (D.5.2.6)

- Modification factor for splitting: \( \psi_{cp,N} = 0.95 \) when \( c_{u,min} \geq c_{u,cr} \), else Eq. (D-13)  
  (D.5.2.7)

\[ A_{Nco} = 9 \ h_{ef}^2 \text{ [in}^2] \]  

Projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5\( h_{ef} \)  
(Eq D-6)

\[ A_{nc} = \text{[in}^2] \]  

Projected concrete failure area of a single anchor (or group) that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward 1.5\( h_{ef} \) from the centerlines of the anchor (or for a group, from a line through a row of adjacent anchors).

In this example of a single anchor without concern for edge effects:

\[ A_{Nco} = A_{nc} = 9 \ h_{ef}^2 \]


**Basic concrete breakout strength of a single anchor in tension in uncracked concrete given by:**

\[ N_b = k_c \ \lambda \ \left( \frac{f_{ct}}{f_{ct}} \right)^{1/2} \ h_{ef}^{1.5} \]  

(Eq D-7)

\[ k_c = k_{c,uncr} = 24 \]  

(ESR-2508 - Table 4)

Assumed above:

\[ \lambda = 1.0 \]  

(Normal weight concrete)  
(8.6.1)

Effective embedment depth of anchor:

\[ h_{ef} = 3.50 \text{ in} \]

Provided basic concrete breakout strength of single anchor:

\[ N_b = k_c \ \lambda \ \left( \frac{f_{ct}}{f_{ct}} \right)^{1/2} \ h_{ef}^{1.5} = (24)(1) \ [4000 \text{ psi}] \ \lambda^{1/2} \ [3.5 \text{ in}]^{1.5} \]  

\[ N_b = 9.94 \text{ kips} \]  

Provided nominal concrete breakout strength in tension of single anchor:

\[ N_{cb} = A_{Nco}/A_{Nco} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b = \left[ (1)(1)(1)(0.95)[9.94 \text{ kips}] \right] \]  

\[ N_{cb} = 9.47 \text{ kips} \]  

Provided nominal concrete pryout strength in shear of single anchor:

\[ V_{cp} = \min[\{(k_{cp} \cdot N_b) \} ; \{(k_{c} \cdot N_b) \} \} = \min[[\{(2)(10.2 \text{ kips}) \} ; \{(2)(9.5 \text{ kips}) \} \} \]  

\[ V_{cp} = 18.93 \text{ kips} \]  

(Eq D-30a)

**Summary of Design Strengths:**

- Steel anchor shear strength:
  \[ \phi V_{sa} = 0.65 \ (11.62 \text{ kips}) = 7.56 \text{ kips} \]

- Concrete breakout strength shear:
  \[ \phi V_{cb} = 0.7 \ (23.1 \text{ kips}) = 16.17 \text{ kips} \]

- Concrete pryout failure:
  \[ \phi V_{cp} = 0.7 \ (18.93 \text{ kips}) = 13.25 \text{ kips} \]

\[ \phi V = \min(\phi V_{sa}, \phi V_{cb}, \phi V_{cp}) = 7.56 \text{ kips} \]  

\[ V_{us} = 6.00 \text{ kips} \]  

\[ \phi V \geq V_{us} \?: \text{ OK} \]  

- Anchor fails first.
- Capacity greater than factored loads.