TECHNICAL MANUAL FOR THE DESIGN PROFESSIONAL 6TH EDITION

Anchoring & Fastening Systems

Building Code Compliant Solutions

Powers
FASTENING INNOVATIONS

Introduction

Powers FASTENING INNOVATIONS

Powers Fasteners, Inc. has been a worldwide pioneer in the fastening industry since 1921 and today is the leading supplier of concrete and masonry anchors and fastening systems in North America. Powers has extensive engineering and manufacturing expertise in several product groups, including mechanical anchors, adhesive anchoring systems and powered forced-entry systems such as powder-actuated and gas fastening systems.

The 6th Edition of the Powers Technical Manual for the Design Professional:

This comprehensive technical manual was developed for the design professional and specifier. It is an update to our previous technical manual and is based on several decades of industry experience. The manual is the culmination of our efforts to include the latest in anchor technology, testing standards, performance data and product listings. It should be used as a reference for selecting and specifying the proper products for your anchoring and fastening applications.

Use of our website is strongly recommended (www.powers.com):

The Powers website contains our product information, documentation and updates. This includes product approvals and listings, MSDS sheets, general product information, software tools, contact information, newsletters and announcements. These program resources and supplements, combined with over twenty stocking locations throughout North America, provide one of the best engineering and field support systems available in the anchoring industry.

Powers Design Assist (PDA) real-time anchor design software is more powerful than ever:

Our PDA software provides code-compliant anchoring solutions in a dynamic environment with real-time results. It does more than just provide calculations. It is also a comprehensive digital library for mechanical anchors, adhesive anchoring systems and cast-in-place anchor products. Multiple products in the PDA software can be compared in seconds with utilization ratings using the innovative Anchor Tree feature.

We invite you to utilize our other services for design professionals:

Our engineering and field support teams can offer educational seminars/workshops, technical support and field-testing of Powers Fasteners products. We also offer our national Powers Training Vehicle (PTV) program for product installation demonstrations, instruction, and training for designers and contractors. We have a fully dedicated staff of customer support specialists and engineers to answer all of your technical needs. If you should have any questions or feedback, please contact customer service at (914) 235-6300 or toll free at (800) 524-3244 or by email at engineering@powers.com.

Individual help and specification tools are only minutes away:

Improve your firm's specifications by adding our code compliant products into your design documents. If you would like assistance writing our products into your specifications, please contact our engineering department toll free at (888) 745-2633 or by email at engineering@powers.com. We look forward to earning your specification and working with you.

Quality Policy

Powers Fasteners, Inc. is committed to meeting or exceeding our customer's expectations, for all our products and services, through continuous improvement of the Quality Management System.

Quality Statement

Powers Fasteners, Inc. is an ISO 9001:2008 certified anchoring products company and is dedicated to a quality leadership position in the design and manufacture of products for the construction industry. We strive to achieve this mission by seeking to achieve total customer satisfaction through high quality offerings in design and manufacturing. Powers Fasteners, Inc. values and promotes education and training, continuous product improvement through dedication and teamwork, environmental responsibility and a safe work place.

Powers Fasteners, Inc.

Frederic Powers III
President

Jeffrey Powers
CEO

Christopher Powers
Chairman

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It is the responsibility of the design professional in charge of the product installation and/or the Authority Having Jurisdiction (AHJ) to ensure that a suitable product is selected and is properly installed and used for the intended application. This includes their selection and use of a product that is compliant with the applicable building codes and other legal requirements and will satisfy durability and performance criteria and margins of safety which they determine are applicable.

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Powers Fasteners, Inc. will repair or replace, at its sole option, any product within 90 days after sale by Powers Fasteners, Inc. or its distributors, if it is found to be defective in material or workmanship, normal wear and tear excluded.

This warranty does not apply to products not used in compliance with published instructions, specific applications, installment procedures, modified products, defective substrate materials or deterioration due to environmental conditions, force majeure or other extraordinary events.

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In the event customer makes any modification to the product itself or deviates from proper product installation procedures, regardless of specific instructions to the user, the customer shall indemnify, defend, and hold harmless, Powers Fasteners, Inc. for any and all claimed loss or damage occasioned, in whole or in part, by the modified products or deviation in product installation procedures.

Post-Installed Anchor Systems

INTRODUCTION

Post-installed anchors have been used since the early 1900's to secure building components. At that time, the Anchor holes were manually drilled using a star type drill and a hammer. An anchor consisted of a wood or lead plug which was carved or molded to size and driven into the drilled hole. As a screw or nail was inserted in the plug, it expanded against the wall of the hole. Commercially manufactured anchors were first made from lead or fiber material in a variety of sizes to match a bolt or screw.

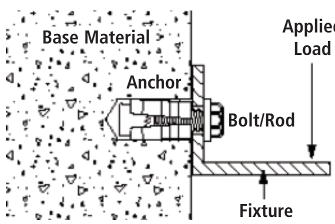
As the materials and techniques used in building construction changed, new anchors were developed to meet application needs. During the Second World War, powder-actuated fastening systems were developed for repairing damage to ships. After the war, use of powder-actuated fastening technology developed rapidly and became the standard method of attachment for many light duty applications in the construction industry. Today, a wide variety of anchors and fastening systems are available, including the use of gas fastening and adhesive technologies. Although the variety of choice provides the user with the opportunity to select the best product for a specific application, it also makes the selection process more difficult. For this reason, the load capacities and other criteria used to determine the type, size, and number of anchors or fasteners to be used for any given application need to be taken into consideration. As in all applications, the load capacity and other criteria used to determine an anchoring system's suitability should be reviewed and verified by the design professional responsible for the actual product installation.

The following is intended to guide the user of this information toward an anchor or fastening system that is best suited for the application.

SECTION CONTENTS

FASTENED ASSEMBLY

Before selection can take place, several factors should be considered and reviewed to determine their effect on the application. First, we need to consider the key components of the fastened assembly. The following diagram shows a typical fastened assembly using an anchor.



Some critical items to consider in the selection of a product include the following:

1. Base material in which the anchor or fastener will be installed.
2. Loads applied by the fixture or material to be fastened.
3. Anchor or fastener material and the bolt / threaded rod.
4. Installation procedures including the method of drilling, hole preparation, or the installation tool used.
5. Dimensions of the base material including the material thickness, anchor or fastener spacing, and edge distance.
6. Effects of corrosion and service environment.

BASE MATERIALS

The materials used in building construction vary widely. Although fastening can occur in many materials, the base materials are often the weak link in the assembly design. The base material is a critical factor in the selection of an anchor or fastener because it must be able to sustain the applied loads. Base material strength can vary widely, and is a key factor in the performance of an anchor or fastener. Generally, products installed in stone and dense concrete can withstand far greater loads than those installed in softer materials such as lightweight concrete, block, or brick. Medium to heavy loads cannot be safely applied to materials such as stucco, grout, shotcrete or plaster. Prior to product installation, base materials should be fully cured. The following sections provide a descriptive summary of typical base materials for reference purposes. Refer to the individual product sections for details on suitable base materials. Individual standards and local codes / jurisdictions having authority should be consulted for complete design details.

Concrete

Reinforced concrete is formed using concrete meeting a certain compressive strength combined with reinforcing steel (rebar). The function of the concrete is to resist compressive forces while the reinforcing steel resists the tensile forces. Two primary factors are workability and strength. For fresh concrete, it must have the proper consistency or workability to enable it to be properly placed. Hardened concrete must be able to achieve the specified performance factors including the required compressive strength. The design and construction requirements for reinforced concrete buildings are published by the American Concrete Institute (ACI) in document ACI 318, Building Code Requirements for Reinforced Concrete.

Concrete is a mixture of aggregate, cement, water, and additives. Its strength is achieved through the hydration of the cement component (usually Portland) which is used to bind the aggregate together. The type of cement used depends on the requirements of the structure into which the concrete will be placed. The requirements are outlined in ASTM C 150. A concrete mix design consists of both fine and coarse aggregates. Fine aggregate is usually particles of sand less than 3/16" in diameter while the coarse aggregate is crushed stone or gravel greater than 3/16" in diameter as outlined in ASTM C 33 for normal-weight concrete.

BASE MATERIALS (Continued)

The aggregate used in normal-weight concrete ranges in weight from 135 to 165 pcf. For structural lightweight concrete, the aggregate such as that manufactured from expanded shale, slate, clay, or slag has a weight range of 55 to 75 pcf as listed in ASTM C 330. The unit weight for normal-weight concrete ranges from 145 to 155 pcf while structural lightweight concrete ranges from 100 to 115 pcf. Structural lightweight concrete is used where it is desirable to decrease the weight of the building structure. It also has better fire resistance than normal-weight concrete. The strength and hardness of the aggregate will affect drilling speed, drill bit wear, and drill bit life. Anchors or fasteners installed in lightweight concrete may have load capacities which are up to 40% less than those installed in normal-weight. Job site tests are recommended if specific data is not available for this base material.

Another form of concrete is lightweight insulating concrete. This type of concrete is used for thermal insulating and should not be confused with structural lightweight concrete. ASTM C 332 lists the aggregates used in lightweight insulating concrete in two groups. Group I includes aggregates such as perlite or vermiculite. These aggregates generally produce concrete ranging in weight from 15 to 50 pcf. The aggregates in Group II are prepared by expanding, calcining, or sintering products such as blast furnace slag, fly ash, shale, or slate. Natural materials such as pumice, scoria, or tuff are also included in Group II and produce a concrete with a weight range of 45 to 90 pcf. Lightweight insulating concrete typically has compressive strengths ranging from 100 to 300 psi. Job site performance tests are always required for installations in lightweight insulating concrete.

Precast autoclaved aerated concrete (AAC) describes the lightweight concrete building material that is relatively new in the United States, but that has been used in other parts of the world for over 70 years. The raw materials used in the production of AAC are pulverized sand, water, cement, and lime – the same ingredients as conventional concrete, with the exception that there is no large aggregate in the mix. The raw materials are batched together to form a slurry. The slurry is cast into steel molds. Due to the chemical reactions that take place within the slurry, the material expands, encapsulating tiny air bubbles within the solid matrix. After setting, but before final hardening, the mass is machine cut into units of various sizes. The units are then steam-cured under pressure in autoclaves where the material is transformed into fully cured and hardened products.

AAC is available as block products in a multitude of combinations of thickness, height, length and compressive strength. AAC is also available as reinforced panels that can be used as non-load bearing vertical and horizontal exterior wall panels, load bearing vertical panels, and floor and roof panels. AAC products have been successfully used in various types of commercial and residential building construction as well as highway sound walls, mines, firewalls, and shaft wall construction. Product specifications for AAC can be found in ASTM C 1386 for unreinforced block elements and in ASTM C 1452 for reinforced panel elements. The range for minimum compressive strength is 300 psi to 1000 psi, with 580 psi being the most common value.

The range for dry bulk density is 25 pcf to 50 pcf, with most common products manufactured at approximately 31-37 pcf. Job site performance tests are always required for installations in AAC.

Admixtures are specified in a mix design to modify the concrete, either for placement characteristics or hardened properties. Air entraining admixtures which disperse tiny air bubbles throughout the concrete mix help to improve the freeze thaw resistance and increase workability. Examples of other admixtures are superplasticizers, which allow a reduction in the quantity of mixing water for much lower water-cement ratios, or products which accelerate or slow down the curing of the concrete.
While the type of cement, aggregate, and admixtures have an impact on the compressive strength of the concrete, the water-cement ratio is the primary factor affecting the strength. As the water-cement ratio decreases, the compressive strength of the concrete increases. In order to determine the compressive strength of concrete, test specimens are formed in cylinders approximately 6" in diameter and 12" in length according to ASTM C 31. The cylinders are broken according to ASTM C 39 at specified time intervals, usually 7 and 28 days, and the resulting strength is calculated to the nearest 10 psi increment.

The load capacities for installations in normal-weight concrete listed in this manual are for concrete which has achieved its designated 28 day compressive strength. Concrete is considered 'green' if less than 21 days old and can have an effect on performance of anchors and fasteners. It is recommended that anchors and fasteners not be made in concrete which has cured for less than 7 days. For concrete that has not cured at least 21 days, expected load capacities would be for the actual compressive strength at the time of installation. Job site tests are recommended for installations in concrete where the material strength or condition is unknown or questionable. In some sections, load capacities are also listed for installations in structural lightweight concrete. The load capacities listed in this manual were conducted in unreinforced test members to provide baseline data which is usable regardless of the possible benefit of reinforcement unless otherwise noted.

To resist tensile forces, steel reinforcement such as deformed reinforcing bars or welded wire fabric are placed in the forms prior to the pouring of concrete. For prestressed or post-tensioned concrete construction, bars, wire, or strands may be used as the reinforcement. Smooth dowel bars are also used primarily to resist shear loads. Steel reinforcement should not be drilled/cored through without authorization from the design professional resposible for the project. The following page contains tables that list the dimensions and strengths of standard Grade 40 and Grade 60 deformed reinforcing bars according to ASTM A 615 and the building codes.

BASE MATERIALS (Continued)

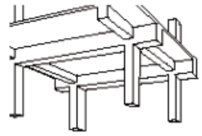
Rebar Size d	Rebar Area A_{br} in.^{2} (mm^2)	Grade 40 Rebar			Grade 60 Rebar		
		Allowable Tension lbs. (kN)	Yield Strength lbs. (kN)	Ultimate Strength lbs. (kN)	Allowable Tension lbs. (kN)	Yield Strength lbs. (kN)	Ultimate Strength lbs. (kN)
No. 3	0.110 (71.0)	2,200 (9.9)	4,400 (19.8)	7,700 (34.7)	2,640 (11.9)	6,600 (29.7)	9,900 (44.6)
No. 4	0.200 (129.0)	4,000 (18.0)	8,000 (36.0)	14,000 (63.0)	4,800 (21.6)	12,000 (54.0)	18,000 (81.0)
No. 5	0.310 (200.0)	6,200 (27.9)	12,400 (55.8)	21,700 (97.7)	7,440 (33.5)	18,600 (83.7)	27,900 (125.6)
No. 6	0.440 (283.9)	8,800 (39.6)	17,600 (79.2)	30,800 (138.6)	10,560 (47.5)	26,400 (118.8)	39,600 (178.2)
No. 7	0.600 (387.1)	12,000 (54.0)	24,000 (108.0)	42,000 (189.0)	14,400 (64.8)	36,000 (162.0)	54,000 (243.0)
No. 8	0.790 (509.7)	15,800 (71.1)	31,600 (142.2)	55,300 (248.9)	18,960 (85.3)	47,400 (213.3)	71,100 (320.0)
No. 9	1.000 (645.2)	20,000 (90.0)	40,000 (180.0)	70,000 (315.0)	24,000 (108.0)	60,000 (270.0)	90,000 (405.0)
No. 10	1.270 (819.4)	25,400 (114.3)	50,800 (228.6)	88,900 (400.1)	30,480 (137.2)	76,200 (342.9)	114,300 (514.4)
No. 11	1.560 (1,006.4)	31,200 (140.4)	62,400 (280.8)	109,200 (491.4)	37,440 (168.5)	93,600 (421.2)	140,400 (631.8)
No. 14	2.250 (1,451.6)	45,000 (202.5)	90,000 (405.0)	157,500 (708.8)	54,000 (243.0)	135,000 (607.5)	202,500 (911.3)
No. 18	4.000 (2,580.6)	80,000 (360.0)	160,000 (720.0)	280,000 (1,260.0)	96,000 (432.0)	240,000 (1,080.0)	360,000 (1,620.0)

The strengths listed in the table above are calculated based on the following stresses. The allowable tensile stress, f_S, for the reinforcing is based on the building code requirements.

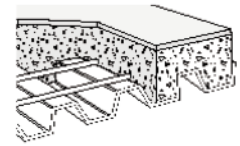
Grade 40 Rebar			Grade 60 Rebar		
Allowable Tension psi (MPa)	Yield Strength psi (MPa)	Ultimate Strength psi (MPa)	Allowable Tension psi (MPa)	Yield Strength psi (MPa)	Ultimate Strength psi (MPa)
20,000 (138.0)	40,000 (276.0)	60,000 (414.0)	24,000 (165.6)	60,000 (414.0)	90,000 (621.0)

Generally, concrete is capable of sustaining a higher load than brick or block. As the embedment depth of an anchor or fastener is increased, the tension load will increase up to a point at which either the capacity of the anchor is reached in pullout or steel strength or the capacity of the concrete is reached where the base material fails locally.

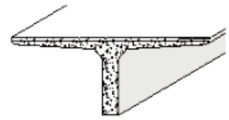
Common construction methods in which concrete can be used are shown in the following figures.



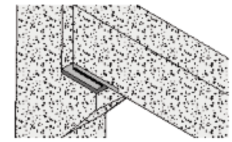
Poured in Place concrete using a form system



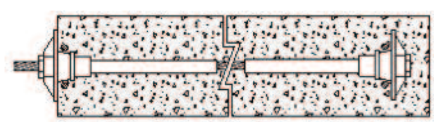
Composite slabs poured over steel deck



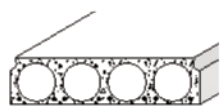
Precast tees



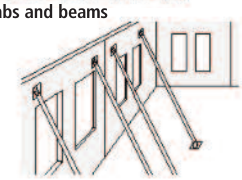
Precast beams and columns



Post-tensioned slabs and beams



Precast plank



Tilt-up wall panels

Masonry Materials

The strength of masonry walls is usually less than that of concrete and the consistency of these materials can vary on a regional basis. To form a wall, individual masonry units are bonded together with a cement mortar. A vertical row is called a course and a horizontal row is called a wythe. The strength of the mortar is often the critical factor in product performance. Anchors or fasteners may be installed in the horizontal mortar joint or directly into some types of masonry units. In field testing, products should be installed and loaded to simulate the actual placement. The reaction bridge used should span the joint or unit to provide an unrestrained test.

Note: Hollow base materials require special care as the anchor or fastener must be properly sized to coincide with the wall thickness or selected to properly expand in the void for toggle type anchors. When using anchors, spalling can occur during the drilling process, further decreasing the wall thickness. Manufacturers of hollow base materials often specify a maximum load that can be applied to the material. Since the strength of masonry materials varies widely, job site tests are recommended to determine actual load capacities for critical applications.

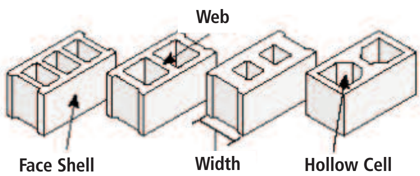
Concrete Block

Masonry block is found in a variety of sizes and shapes depending upon the age and location of a building. Both hollow and solid styles which can be classified as load-bearing or non-load bearing are used. Load-bearing block, known as a concrete masonry unit (CMU) is generally suitable for anchoring or fastening.

BASE MATERIALS (Continued)

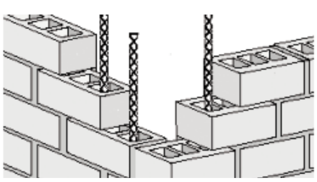
Job site tests are recommended for critical applications due to the wide variations in these materials unless otherwise noted. ASTM C 90 describes hollow and solid load-bearing concrete masonry units made from portland cement, water, and mineral aggregates, both normal, medium and lightweight.

Typical shapes for concrete masonry units are shown in the following diagrams. The term "face shell" refers to the outside face of the block while the term "web" refers to the interior portions between the hollow cells.



Typical CMU Shapes

The difference between hollow and solid block is based on the cross sectional bearing area of the block. Solid block is defined as having a cross sectional bearing area which is not less than 75% of the gross area of the block measured in the same plane. Typical minimum dimensions for the face shell and web thickness are given in ASTM C 90. One of the critical factors contributing to the strength of a masonry wall is the type of mortar used to bond the masonry units together. Mortar is made from a mixture of cement, very fine aggregate, and water. ASTM C 270 describes cement-lime and masonry cement mortars, each available in four types as summarized in the standard. To provide greater resistance to lateral loads, concrete masonry units are often strengthened with steel reinforcing bars. In this case, hollow units are grout filled to allow them to act together with the reinforcing bars.



Grout-filled Concrete Masonry

Experience has shown that the consistency of grout filled block varies widely. Voided areas are often a problem, therefore, job site performance tests are recommended.

In this manual, guide load capacities are published for some products installed in the face shell of hollow load-bearing concrete masonry units and at various embedments into grout filled units. The load capacities listed in this manual were conducted in unreinforced test members to provide baseline data which is usable regardless of the possible benefit of reinforcement unless otherwise noted.

For hollow units, most anchors were tested in walls constructed using normal-weight concrete block meeting the requirements of ASTM C 90, Grade N. Grade N signifies that it is suitable for use in exterior walls above or below grade which may or may not be exposed to moisture.

The minimum compressive strength from the ASTM specification is 1,900 psi. Typical dimensions are nominally 8" x 8" x 16" with a minimum face shell thickness of 1-1/4" to 1-1/2". For 75% solid block, typical face shell thickness is 2-1/4". For anchors, the face shell thickness may be decreased by as much as 1/2" during the drilling operation due to spalling on the back side of the face shell.

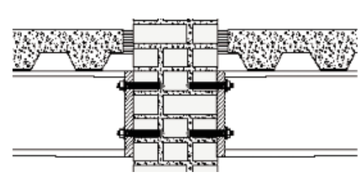
Grout filled block walls were constructed using the hollow block described above which was then filled with fine grout as described in ASTM C 476.

Brick

Brick units are found in a variety of shapes, sizes, and strengths depending upon the age and location of a building. Brick is manufactured from clay or shale which is extruded / wire-cut, machine molded, or handmade to shape then hardened through a firing process. In the natural state, a buff colored finish is obtained when using clay while shale produces a red shade. The addition of mineral pigments, glazes, or other compounds is used to change the visual impact of brick. Brick can be used to form a load bearing wall or used as a veneer or facade.

Brick is produced as a solid masonry unit or with cores during extrusion. The cores reduce the weight of the brick and help it to lay better. ASTM C 652 describes hollow brick masonry units. Hollow brick is defined as having a cross sectional bearing area which is less than 75% of the gross area of the brick measured in the same plane. Hollow brick units have stricter physical property requirements than those for structural clay tile. The cores often create a problem when attempting to install traditional expansion anchors because the resulting thin walls cannot sustain the high bearing stresses applied by the expansion mechanism. In this case, an alternative anchor, such as an adhesive anchor could be considered. Brick walls are generally not suitable for power-actuated fasteners.

ASTM C 62 describes solid building brick while C 216 describes solid facing brick. To provide greater resistance to lateral loads, walls are often strengthened with steel reinforcing bars. The wythes of brick are tied together and then grout filled to allow them to act together with the reinforcing bars.

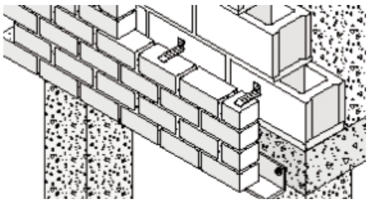


Typical brick bearing wall

When brick is used as a building facade, it is important to properly tie it to the backup wall and structure using anchors manufactured from a corrosion-resistant material such as stainless steel.

BASE MATERIALS (Continued)

Brick (continued)

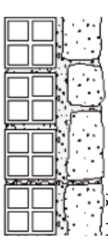


In this manual, guide load capacities are published for anchors installed in solid brick and in multiple wythe brick walls. Unless otherwise noted, anchors were tested in walls constructed using brick meeting the requirements of ASTM C 62, Grade SW. Grade SW signifies that it is suitable for use in exterior walls exposed to severe weathering. The minimum compressive strength from the ASTM specification is 1,250 to 3,000 psi, however, actual strengths typically can range as high as 6,000 to 8,000 psi. Both single and multiple wythe brick walls were constructed using a Type S cement-lime mortar meeting ASTM C 270.

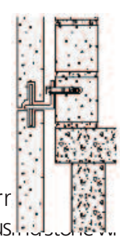
Stone

Natural stone is available in a variety of types, colors, and textures for use in many building applications. Naturally occurring rock which has been fabricated to a specific size and shape is referred to as dimension stone as opposed to broken or crushed stone such as that used for aggregate in concrete. The three common classes of rock used to fabricate dimension stone are igneous, metamorphic, and sedimentary. Granite is an igneous material while marble building stone is metamorphic. Both of these stones tend to be harder than limestone or sandstone which are sedimentary materials. The strength and the quality of stone can vary dramatically from each stone quarry and for different geological locations.

Generally, anchors installed in softer material such as limestone or sandstone will have capacities similar to those obtained in 2,000 psi concrete. In harder stone such as granite or marble, the capacities will be similar to 4,000 or 6,000 psi concrete. Job site tests are recommended because of the wide variation in the strengths of natural stone. Stone is not generally considered a suitable base material for power-actuated fasteners.



Stone with tile backup

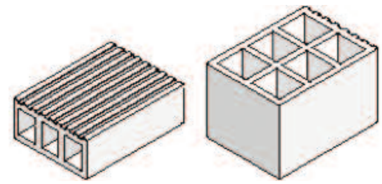


Stone facade

Dimensi… can be used to form … ring wall and as a veneer o… onry constructed us… th little or no sha… e whil… stone is called ashlar. When used as a building facade, it is important that the stone be properly tied to the backup wall using anchors manufactured from a corrosion-resistant material such as stainless steel. ASTM C 119 describes dimensional stone for use in building construction. Specifications for individual stone types include C 503 for marble, C 568 for limestone, C 615 for granite, and C 616 for quartz-based material.

Structural Clay Tile

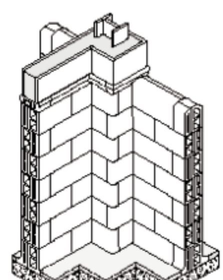
Structural clay tile units are found in a variety of shapes, sizes, and strengths for use primarily in walls. The tile units are manufactured from clay, shale, or fire clay which is extruded to shape then hardened through a firing process. Finished units may have a natural finish or may be glazed. During the extrusion process, several continuous cells or hollow spaces are formed within the exterior shell of the tile. The typical thickness of the outer shell is 3/4" with a 1/2" thick interior web. End-construction tile is designed to be placed in a wall with the axis of the cells vertical while side-construction tile is placed with the axis of the cells horizontal.



Typical clay tile shapes

These materials present a problem when attempting to install anchors because the resulting thin walls cannot sustain the high bearing stresses applied by a mechanical anchor. For light duty loads, a hollow wall anchor which opens behind the face shell may be used. For heavier loading, an adhesive anchor installed using a screen tube inserted through the face shell and interior web is suggested. In most cases, job site tests are recommended. Structural clay tile is not a suitable base material for power-actuated fasteners.

Structural clay tile units can be used to form a load bearing wall and as a veneer or facade. ASTM C 34 describes structural clay tile for load bearing walls. Tile of Grade LBX is suitable for exposure to weather while Grade LB is normally used in a protected environment. The minimum compressive strength for this type of unit ranges from 500 to 1400 psi depending upon the orientation and grade. Structural clay facing tile is described in ASTM C 212.



Structural clay partition

…le used primarily for partitions. This type of tile is sometimes referred to as architectural terra cotta although this term is more appropriately applied to ornamental building units. No minimum compressive strength is specified for this type of tile.

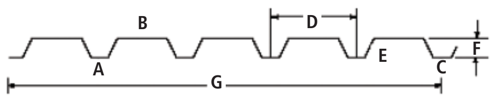
Steel Deck

Steel deck is available in many configurations for use as a floor deck (both composite and non-composite) or a roof deck. It is usually cold formed from steel sheet to provide the combination of deck type, depth, and gage (thickness) to meet the application requirements.

BASE MATERIALS (Continued)

A rib shape, formed in various depths and sizes, adds strength in flexure depending upon the length of span.

Steel deck may be supplied uncoated, painted, or zinc coated according to ASTM A 525 in various thicknesses. Common zinc coating thicknesses are Grade 90 (0.90 oz./ft2) and Grade 60 (0.60 oz./ft2). The following diagram shows a typical steel deck cross section.



A – Rib
B – Top Flange
C – Side Lap
D – Module
E – Web
F – Depth
G – Coverage Width

Industry standards for the design, manufacture, and use of steel deck are provided by the Steel Deck Institute (SDI), Factory Mutual Research Corporation (now known as FM Global), and Underwriters Laboratories (UL). Material requirements are also listed in ASTM A 611 and A 446. The yield strength of the steel deck varies from 25,000 to 80,000 psi, depending on the grade.

Today, steel deck is commonly specified by a decimal thickness rather than a gage number. Steel floor deck used for composite construction with concrete fill has typical rib depths of 1-1/2", 2", and 3". Other depths up to 7-1/2" are available. This type of deck is normally manufactured to a minimum yield strength of 33,000 psi. Non-composite steel form deck is used as a permanent form for concrete slabs with rib depths ranging from 1/2" to 2".

For steel roof deck, the ribs are classified as narrow, intermediate, or wide with a 1-1/2" minimum depth spaced at 6" on center. Deep rib deck with a 3" minimum depth with ribs spaced at 8" on center is also available. Other types of steel decking include acoustical sound absorbing floor or roof decks, long span roof decks, and cellular roof decks.

CORROSION RESISTANCE

The corrosive environment in which an anchor or fastener will be installed should be considered. Corrosion can be described broadly as the destruction of a material due to chemical or electrochemical reactions based upon the application environment. Industry estimates of the annual cost of corrosion place it in the billions of dollars. The subject of corrosion is very complex and knowledge is constantly being gained based on industry experience. Chemical and electrochemical corrosion are described in the following two sections to provide a basic understanding of the process.

Chemical Corrosion

Direct chemical attack occurs when an anchor or fastener is immersed in the corrosive substance, typically a liquid or a gas. For example, an anchor used to restrain equipment in a water treatment tank would have to be made from a material which would be resistant to chlorine or other corrosive liquids present. This type of corrosion can also occur when a stone facade is attached to a backup wall. Mild acids can be formed in the wall cavity due to reaction of condensation with the attached stone. The product selected would have to be resistant to the type of acid formed.

Electrochemical Corrosion

All metals have an electrical potential which has been measured through research and ranked into an electromotive force series. When two metals of different electric potential are brought into contact in the presence of an electrolyte, the metal with the lower potential (least noble) will form the anode while the metal with the higher potential (most noble) will form the cathode.

As current flows from the anode to the cathode, a chemical reaction will take place. The metal forming the anode will corrode and will deposit a layer of material on the metal forming the cathode. As the electric potential between two dissimilar metals increases, the stronger the current flow and corresponding rate of corrosion. The rate of corrosion will also be influenced by the conductivity of the electrolyte.

Galvanic Series

+ Corroded End (Anodic or least noble)

Magnesium
Magnesium alloys
Zinc
Aluminum 1100
Cadmium
Aluminum 2024-T4
Steel or Iron
Cast Iron
Chromium-iron (active)
Ni-Resist cast iron
Type 304 Stainless (active)
Type 316 Stainless (active)
Lead tin solders
Lead
Tin
Nickel (active)
Inconel nickel-chromium alloy (active)
Hastelloy Alloy C (active)
Brasses
Copper
Bronzes
Copper-nickel alloys
Monel nickel-copper alloy
Silver solder
Nickel (passive)
Inconel nickel-chromium alloy (passive)
Chromium-iron (passive)
Type 304 Stainless (passive)
Type 316 Stainless (passive)
Hastelloy Alloy C (passive)
Silver
Titanium
Graphite
Gold
Platinum

- Protected End (Cathodic or most noble)

CORROSION RESISTANCE (Continued)

In order to provide a more practical approach to understanding the electromotive force series, testing was conducted on commercial alloys and metals in sea water to develop a chart called the Galvanic Series. One of the reasons sea water was used as the electrolyte was because it has a high conductivity rate. The above chart lists a representative sample of dissimilar metals and indicates their relative potential for galvanic corrosion. When two dissimilar metals are in contact (coupled) in the presence of a conductive solution or electrolyte (i.e. water) electric current flows from the less noble (anodic) metal to the more noble (cathodic) metal. In any couple, the less noble metal is more active and corrodes while the more noble metal is galvanically protected.

To prevent galvanic corrosion, the following precautions can be used:

1. Use the same or similar metals in an assembly. Select metals which are close together in the Galvanic Series.
2. When dissimilar metals are connected in the presence of a conductive solution, separate them with dielectric materials such as insulation, a sealing washer, or a coating. Coatings should be kept in good repair to prevent accelerated attack at any imperfection.
3. Avoid combinations where the area of the less noble material is relatively small. It is good practice to use anchors or fasteners made from a metal which is more noble than that of the material being fastened.

In critical applications, testing should be conducted to simulate actual conditions.

Other types of electrochemical corrosion such as stress corrosion may need to be considered depending upon the application. In all cases, it is important to evaluate the application and the service environment to make a proper selection.

Coatings and Platings

A variety of coatings and platings are offered to resist various extremes of corrosion. A plating metal which is less noble (lower electric potential) than the base metal it is designed to protect is usually selected. When subjected to an electrochemical reaction, the plating will corrode or sacrifice while the base metal remains protected. Once the plating has been reduced significantly, the base material will then begin to corrode. If a plating metal which is more noble is selected, the base metal would begin to corrode immediately if the plating is damaged.

Zinc Coatings and Platings

For carbon steel anchors and fasteners, zinc is one of the most common plating materials used because it can be applied in a broad thickness range and because it is less noble than carbon steel. Zinc may be applied by electroplating, mechanical methods, or hot dip galvanizing.

The following table shows the typical mean corrosion rate of zinc based on data compiled by ASTM. Theoretically, the life expectancy of a zinc plating would be the thickness of the plating divided by the corrosion rate. These values should only be used as a guide since actual performance will vary with local conditions.

Atmosphere	Mean Corrosion Rate
Industrial	5.6 microns (0.00022") per year
Urban non-industrial or marine	1.5 microns (0.00006") per year
Suburban	1.3 microns (0.00005") per year
Rural	0.8 microns (0.00003") per year
Indoors	Considerably less than 0.5 microns (0.00002") per year

The standard zinc plating used on carbon steel anchors is applied using electroplating (often called 'commercial' zinc).The anchor components are immersed in a water based solution containing a zinc compound. An electrical current is then induced into the solution causing the zinc to precipitate out, depositing it onto the components. Powers carbon steel products are typically electroplated according to ASTM B 633, SC1, Type III. SC1 signifies Service Condition 1 which is for a mild environment with an average coating thickness of 5 microns (0.0002"). This condition is also classified as Fe/Zn 5. Type III indicates that a supplementary clear chromate treatment is applied over the zinc plating. Prior to applying the chromate treatment, heat treated products which are electroplated are normally baked to provide relief from any hydrogen trapped in the granular matrix and/or acid-free cleaning processes are used to ensure hydrogen is not introduced.

Note: Power-actuated fasteners are designed to be used in a non-corrosive atmosphere unless application specific corrosion testing has been performed. To reduce the possibility of the embrittlement of a heat treated part, the standard finish for all Powers' power-actuated fasteners is mechanically applied zinc meeting the requirements of ASTM B 695, Class 5. Class 5 signifies an average minimum coating thickness of 5 microns (0.0002").

Heavier zinc platings or coatings are often described using the term "galvanized". Another zinc coating which is available on some carbon steel anchors is mechanically applied (e.g. mechanical galvanized). To apply this coating, the anchor components and glass beads are placed in a chamber on an agitating machine. As the chamber is agitated, powdered zinc compound is gradually added allowing the glass beads to pound the zinc onto the surface of the anchor components. Carbon steel products which are coated using this method are mechanically galvanized according to ASTM, B 695. ASTM A 153, Type C describes the requirements for applying a zinc coating using a hot dip method. According to this specification, the anchor components are placed in a bath of molten zinc for a specified time to allow a metallurical reaction which bonds the zinc to the steel surface.

CORROSION RESISTANCE (Continued)

Barrier Coatings

To provide increased protection from the effects of corrosion on smaller diameter anchors and fasteners used in some roofing applications, a proprietary fluoropolymer coating called Perma-Seal™ has been developed. This coating provides better resistance to corrosion and abrasion than traditional zinc electroplating or mechanical galvanizing. Coatings of this type are often called barrier coatings because they seal the part as opposed to zinc platings which are sacrificial.

When a component is coated with Perma-Seal, a zinc enriched phosphate base is first applied to the surface followed by a proprietary process during which a polymer based material is bonded over the base coat. This creates a finish which resists the corrosive environment created by the high saline (salt) content of most insulation boards, acid rain, and the acids which are produced by ponded water in most built-up or single ply roofing systems. Coatings of this type are typically tested according to DIN Standard 50018, 2.0S, which is a test method referred to as a Kesternich Test. As a measure of corrosion resistance when using this test method, Factory Mutual Standard 4470 (now FM Global) establishes an allowable surface corrosion (red rust) limit of 15% of the surface area after 15 cycles of exposure. The Perma-Seal coating exceeds this requirement withstanding 30 cycles of exposure with less than 15% surface corrosion (red rust). Additional testing conducted in a salt spray chamber according to ASTM B 117 shows that the Perma-Seal coating can withstand over 1,000 hours of exposure with less than 5% surface corrosion.

Corrosion Resistant Materials

In addition to coatings and platings, a variety of other anchor and fastener materials are available which provide varying degrees of corrosion resistance.

Stainless Steel

Stainless steels were originally named according to their chromium and nickel content. One of the first types developed contained 18% chromium and 8% nickel and was therefore called 18-8 stainless steel. As newer types of stainless steel were developed with properties to meet specific application needs, the American Iron And Steel Institute (AISI) established a standard numbering system to classify the various types of stainless steel. In order to be considered a stainless steel in the AISI system, an alloy must contain at least 11.5% chromium. Chromium-nickel alloys became the 300 series stainless steels while chromium alloys became the 400 series.

Stainless steels develop their resistance to corrosion by forming a thin, self healing, passive film of chromium oxide on their surface. During the forming or machining process, the surface of components made from stainless steel may become contaminated with small particles of foreign matter. In order to maintain the optimum performance of the stainless steel for corrosion, components are passivated after manufacturing.

The basic passivation process involves cleaning or degreasing the components, immersion in a nitric acid bath, rinsing and drying. Once the process is complete, the oxide film is formed again without the entrapment of foreign particles.

The 300 series of stainless steels are austenitic alloys which are nonmagnetic and are not heat treatable, although they can be annealed. Anchors made from 300 series stainless steel can exhibit very slight magnetic properties due to the manufacturing process. In order to achieve higher tensile strengths, this series of stainless must be cold worked. For some components, a minimum yield strength is specified based on the work hardening which occurs during the cold forming process. In the industry, the term 18-8 is still used to generically describe the 300 series of alloys, especially Types 302, 303, and 304. Powers provides anchors formed from Types 303, 304, 304 Cu, and 316 stainless steel. Type 303 is used where machinability is required for products. This type of stainless steel has a higher sulfur content than Type 304 which reduces drag on cutting tools, especially when forming internal threads. Type 304 and 304 Cu (302 HQ) stainless steels are used to cold form anchor components. This type of stainless steel is one of the most widely specified. It is commonly used outdoors in a nonmarine environment and for applications in the food processing industry. For more severe corrosive environments, Type 316 stainless steel is available. Type 316 has a higher nickel content than Type 304 and the addition of molybdenum. This provides increased resistance to pitting caused by chlorides (salts) and corrosive attack by sulfurous acids such as those used in the paper industry. However the use of type 316 stainless steel in environments where pitting and stress corrosion is likely should be avoided due to the possibility of sudden failure without visual warning.

Ferritic and martensitic alloys make up the 400 series of stainless steels. Generally, the martensitic alloys in this series are heat treatable; however, their corrosion resistance is well below that of a 300 series stainless steel. They can be also treated with a supplemental barrier coating to help prevent early surface corrosion from developing. 400 series stainless steels can also exhibit magnetic properties.

Other Materials

Depending upon the corrosive environment, Powers also provides several alternate materials which may be used instead of stainless steel. These materials include:

Zamac alloy	Engineered plastic

CORROSION RESISTANCE (Continued)

Corrosion Tests

Two methods that have been used to evaluate relative corrosion resistance are salt spray (fog) testing and a European test method, DIN Standard 50018, 2.0S, known as a Kesternich Test.

Salt Spray Testing

Salt spray testing, also known as salt fog testing, is conducted according to ASTM B 117. Testing of this type is considered useful when evaluating the behavior of materials when subjected to exposure in a marine environment or coastal environment. The components to be tested are prepared and suspended in a sealed chamber where they are subjected to cycles of a spray or fog, typically of a neutral 5%salt solution which is atomized at a temperature of 95° F.

Coating/Plating/Material	% Surface Corrosion (red rust)
Perma-Seal® coating	5 to 10% after 1500 hours
Stainless steel – Type 304	None after 500 hours
Stainless steel – Type 316	None after 500 hours
Stainless steel – Type 410	More than 10% after 500 hours
Stainless steel – Type 410 with Class 4 coating	Less than 5% after 1500 hours
Zinc with clear chromate (ASTM B 633,SC1)	More than 15% after 500 hours
Mechanically galvanized, no chromate treatment (ASTM B 695, Class 55)	10% after 500 hours

Kesternich Test

This test method is a far more severe measure of corrosion resistance when compared to the salt spray method. The components to be tested are prepared and placed in a special unit called a Kesternich Test Cabinet. Corrosion testing is conducted according to DIN Standard 50018, 2.0S. Two liters of distilled water are placed in the bottom of the cabinet and it is then sealed. Once sealed, two liters of sulfur dioxide are injected into the cabinet and the internal temperature is set to 104° F for the cycle. Each 24 hour cycle begins with 8 hours of exposure to the acidic bath created in the cabinet.

The cabinet is then purged and opened, the test specimens are rinsed with distilled water then allowed to dry at room temperature for 16 hours. The test specimens are examined for surface corrosion (red rust) at the end of each cycle. The following table compares the relative surface corrosion (red rust) of various coatings, platings, and materials after up to 30 cycles of exposure in a Kesternich Test Cabinet.

Coating/Plating/Material	% Surface Corrosion
Cadium	100% after 4 cycles
Perma-Seal® coating	5 to 10% after 30 cycles
Stainless steel – Type 304	None after 30 cycles
Stainless steel – Type 316	None after 30 cycles
Stainless steel – Type 410	100% after 3 cycles
Stainless steel – Type 410 with Class 4 coating	5 to 10% after 30 cycles
Zinc with clear chromate (ASTM B 633,SC1)	100% after 3 cycles
Zinc with yellow dichromate treatment (ASTM B 633,SC1)	100% after 3 cycles
Mechanically galvanized, no chromate treatment (ASTM B 695)	100% after 3 cycles
Zinc Alloy	None after 30 cycles

Note: Percentage values for corrosion tests were made by visual observation of fasteners in regular intervals during testing. Test performance is based on tests on uninstalled fasteners and may not reflect actual performance when installed. The information is provided for comparison purposes only and estimates on service life of fasteners cannot be provided due to the many variables that influence corrosion.

Pressure Treated Lumber

Chemical preservatives protect wood from rotting due to insects and microbial agents. However, more recent formulations of chemical preservatives used in pressure treated lumber for applications in commercial and residential construction have shown to be more corrosive to metal fasteners when in direct contact with the wood members.

Research and testing has shown that Type 304 and 316 stainless steel fasteners corrode less than other alternatives when used in pressure treated lumber. When the use of stainless steel is not possible (or not suitable such as in the case of typical power-actuated fasteners), Powers Fasteners offers several compliant anchors and fasteners as a response to the marketplace requirements. Please consult product sections for more information.

TESTING AND DATA FUNDAMENTALS

The fundamentals of anchor and fastener design include the determination calculation of design load capacities based on laboratory test data conducted to simulate typical field conditions. Powers publishes design load capacities for anchors installed in concrete and masonry units along with other appropriate
base materials.

Test Procedures and Criteria

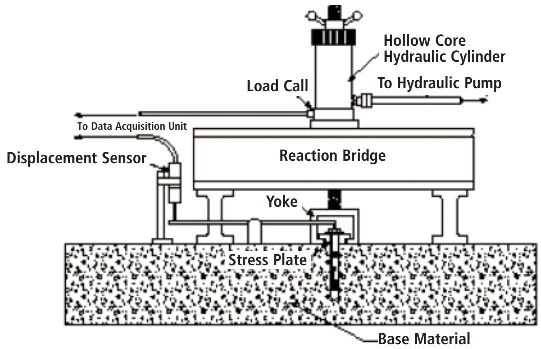
The test data for anchors published in this manual was developed according to ASTM E 488, Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements (and ASTM E 1512 where applicable). Published load values are average ultimate (failure) loads based on actual testing in the base materials listed in the individual product sections. Each individual data point is typically the average of a minimum of five or more individual tests. For power-actuated fasteners, test data was developed according to ASTM E 1190, Standard Test Methods for Strength of Powder Actuated Fasteners Installed in Structural Members. Published load values are average ultimate (failure) loads based on actual testing in the base materials listed in the section on these fasteners. Each individual data point is typically the average of a minimum of ten individual tests depending upon the coefficient of variation obtained.

Since the compressive strength of concrete will influence the strength of an anchor or fastener, testing is usually conducted in several different strengths. Normally, the base materials are unreinforced to provide a worst case simulation.

Tension Test Data

Tension test data is sometimes referred to as pullout or tensile test data. A typical hydraulic test assembly used to perform a tension test on an anchor is shown in the following diagram. A similar assembly is used for testing power-actuated fasteners except that deflection is not measured unless specified (e.g. ICC-ES AC70 Critera).

TESTING AND DATA FUNDAMENTALS (Continued)



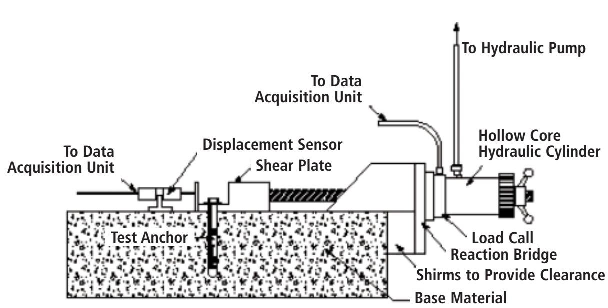
Typical static tension test assembly

The test equipment frame is designed to support the hydraulic test unit and span the test area so that reaction loading does not influence the test results. During testing, load is gradually applied to the anchor in an axial direction by a hydraulic cylinder while the displacement is measured using an electronic displacement sensor. The load is measured by a hollow core load cell and the resulting performance is recorded by a data acquisition unit. Loading is continued until the ultimate (failure) load is achieved. The ultimate load capacity recorded may be based on any one or combination of failure modes shown later in this manual.

During testing, the tension capacity of anchors and fasteners may increase with deeper embedments. This is due to the increased amount of base material available to resist the compressive forces applied by a mechanical expansion anchor, the increased compression area against the shank of a powder actuated fastener, or the increased surface area available for bonding with an adhesive type anchor. In some anchors, the capacity of the expansion mechanism may have been reached at the shallowest embedment and the load will not increase.

Shear Test Data

The typical setup for a hydraulic test unit used for applying a shear load to an anchor is shown in the following diagram. A similar set up would be used for testing power-actuated fasteners.



Typical shear test assembly

The test load is applied perpendicular to the anchor using the hydraulic equipment previously described. During testing of mechanical anchors, the shear capacity will increase as the embedment of the anchor increases, however, the increase may not be as significant as in tension. When a shear load is applied to a mechanical anchor, the anchor body resists the applied load by placing a bearing stress against the base material. Increasing the embedment will increase the area over which this stress is applied which in turn increases the resistance of the base material to the applied load. In addition, a mechanical anchor will tend to bend as a shear load is applied as the base material begins to crush. The applied load will actually be resisted by a combination of the bearing strength of the base material and the tension capacity of the anchor. Adhesive type anchors can usually develop the shear capacity of the anchor rod material at a medium or deep embedment when installed in concrete. Since the applied shear in most applications is through the threaded portion of an anchor or bolt, all shear testing simulates this situation. For bolt or screw style anchors, the design load should be the lesser of the allowable anchor load or load for the actual bolt or screw used.

Evaluation of Test Data

Allowable Stress Design (ASD)

Within the industry, two methods of evaluating test data to determine the allowable working loads for anchors or fasteners are currently used. The first and most common, because of its ease of use, is the safety factor method. Using this method, an appropriate safety factor is applied to the average ultimate load obtained from testing.

Allowable load = Ultimate load / Safety Factor

Safety factors are used to account for field variations which may differ from the testing conditions in the laboratory. Typical minimum safety factors established by industry are 4:1 for concrete and 5:1 for masonry materials.

Actual safety factors to be used should be determined by the design professional responsible for the product application and installation, based on the governing building code and after examining all influencing factors.

A second method which is used less frequently, but sometimes used as an alternative to applying straight safety factors is a statistical method in which the allowable working loads are based in part on the coefficient of variation (COV) obtained during testing. In most cases, the results obtained using the safety factor method are similar to those obtained when using the statistical method unless COV values are very high (e.g greater than 20%). Typical coefficients of variation are as follows on the following page:

TESTING AND DATA FUNDAMENTALS (Continued)

Product	COV
Mechanical Anchors	10 - 15%
Adhesive Anchors	10 - 15%
Power-actuated Fasteners in Steel	10 - 15%
Power-actuated Fasteners in Concrete	10 - 20%

Details on the use of appropriate safety factors are included in the sections describing anchor and power-actuated fastener selection guidelines.

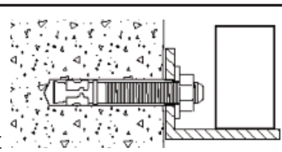
Strength Design (LRFD)

Methods in Strength Design (LRFD) for concrete are becoming more the norm as the International Building Code (IBC) has been adopted and accepted in most jurisdictions. This method incorporates reduction factors to characteristic values from qualification testing and gives consideration for different types of failure modes. Details of Strength Design (i.e. CCD method) as it applies to anchorage to concrete is detailed in ACI 318 Appendix D. This method is referenced by the code and is recommended where applicable.

APPLIED LOADS

The type of load and the manner in which it is applied by the fixture or other attachment is a principle consideration in the selection of an anchor. Applied loads can be generically described as static, dynamic, or shock. Some anchor types are suitable for use with static loads only, while others can be subjected to dynamic or shock loads. The suitability of an anchor for a specific application should be determined by a qualified design professional responsible for the product installation.

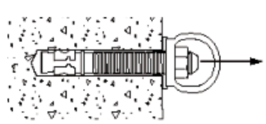
Static Loads



These are non-moving, constant loads such as those produced by an interior sign, cabinet, equipment, or other. A typical static load could be a combination of the dead load (weight of fixture) and the live load a fixture must support. Basic static load conditions are tension, shear, or a combination of both. To determine the allowable static working load, the industry practice is to reduce the ultimate load capacity of an anchor by a minimum safety factor. In cases of combined load, other reduction factors may be required.

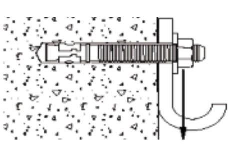
Tension Load

A tension load is applied directly in line with the axis of the anchor.



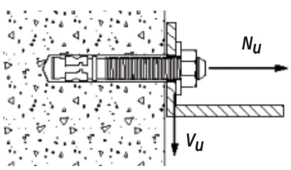
Shear Load

A shear load is applied perpendicularly across the anchor directly at the surface of the base material.



Combined Load

Most anchor installations are subjected to a combination of shear and tension loads.



For anchors loaded in both shear and tension, the combination of loads should be proportioned as follows based on allowable stress design (ASD):

$$\left(\frac{N_u}{N_n}\right) + \left(\frac{V_u}{V_n}\right) \leq 1 \quad \text{OR} \quad \left(\frac{N_u}{N_n}\right)^{\frac{5}{3}} + \left(\frac{V_u}{V_n}\right)^{\frac{5}{3}} \leq 1$$

[Straight Line and Parabolic Interaction Equations]

Where: N_u = Applied Service Tension Load
N_n = Allowable Tension Load
V_u = Applied Service Shear Load
V_n = Allowable Shear Load

or proportioned as follows based on Strength Design:

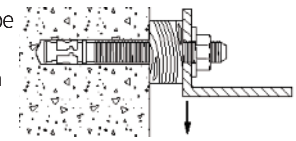
$$\left(\frac{N_{ua}}{\phi N_n}\right) + \left(\frac{V_{ua}}{\phi V_n}\right) \leq 1.2$$

Where: N_{ua} = Factored Tensile Load Applied to an Anchor or Group of Anchors
N_n = Nominal Strength in Tension
V_{ua} = Factored Shear Load Applied to an Anchor or Group of Anchors
V_n = Nominal Strength in Shear

Bending Load

One often overlooked result of static load is bending. It is frequently necessary to place shims or spacers between the fixture and the material for alignment or leveling. When this occurs, it is often the strength of the anchor material or bolt material that determines the capacity of the connection. The load is applied at a distance from the surface of the base material creating a lever-type action on the anchor. Typical examples of this type of loading are the installation of windows using plastic horse shoe shims or machinery installations with shims below the base plate. In loading such as this, it is often the physical strength of the anchor material, not the tension and shear load capacities, that limit the strength of the anchorage.

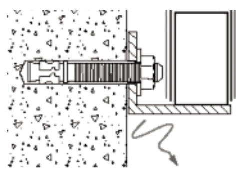
APPLIED LOADS (Continued)



The allowable bending load should be calculated by a design professional based on the material from which an anchor is manufactured. In concrete or masonry materials, the bending arm used in the calculation should be increased to allow for spalling around the top of the anchor hole, usually by 1/2 to 1 anchor diameter.

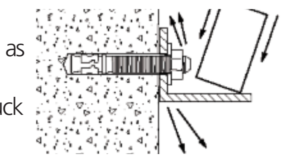
Dynamic and Shock Loads

Dynamic Loads



Dynamic loads are intermittent and varying loads such as those imposed by central air conditioning units, manufacturing machinery or earthquakes. They are normally the alternating or pulsating loads associated with vibration.

Shock Loads



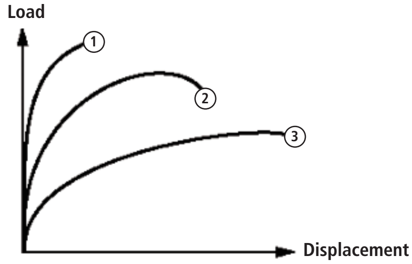
Shock loads are instantaneous, periodic loads of high intensity such as those applied by an automobile striking a guard rail support or a truck hitting a dock bumper. Standard industry practice with regard to safety factors varies depending upon the frequency and intensity of the load. However, safety factors for dynamic or shock load conditions may 10:1 or higher. Determination of the appropriate safety factor should be made by the design professional in charge of the actual product installation.

ANCHOR BEHAVIOR

The selection and specification of an anchor requires an understanding of basic anchor behavior or performance. A variety of performance attributes can be expected depending upon the type or style of anchor.

Displacement

As an anchor is loaded to its ultimate (failure) load capacity, displacement or movement of the anchor relative to the base material will occur. The amount of displacement will be affected by the anchor preload, the anchor material strength, the design of the expansion mechanism, and the strength of the base material. Typical load versus displacement curves are shown in the following diagram for three anchor types.



Curve 1 shows the typical performance of an adhesive type anchor. These anchors normally exhibit elastic behavior up to the ultimate load capacity. Performance will vary depending upon the type of adhesive used, the base material strength, and the strength of the anchor rod. A deformation controlled anchor such as a dropin anchor may also exhibit this type of behavior although the ultimate load capacity will normally be much less than that of an adhesive anchor. The compression force developed by a dropin is usually very high when compared to a torque controlled anchor resulting in low displacement characteristics.

Typical performance of a torque controlled anchor is shown in Curve 2. Displacement begins to occur after the initial preload in the anchor has been exceeded until the ultimate load capacity is achieved.

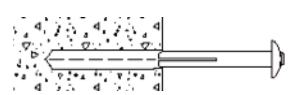
Anchors for use in light duty applications often exhibit the behavior shown in Curve 3. Once the working load has been exceeded, the anchor begins to displace or stretch until failure occurs.

Modes of Failure

As an anchor is loaded to its ultimate capacity, the following modes of failure can occur.

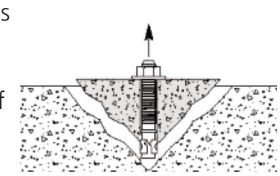
Anchor Pullout

This type of failure occurs when the applied load is greater than the friction or compressive force developed between the anchor body and the base material. The anchor is unable to fully transfer the load to develop the strength of the base material. For adhesive anchors, this can occur with products which have a low bond strength or have been installed in a poorly prepared anchor hole.



Base Material Failure

When the applied load is greater than the strength of the base material, the material pulls out or fails. In concrete, a shear prism/cone will be pulled, usually for anchors installed at a shallow depth. The angle of the shear prism/cone has been assumed to be 35-45°, however, this can vary slightly depending upon the anchor style and embedment depth.

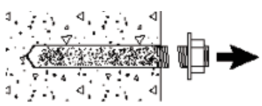


As the embedment of some anchor styles is increased to six diameters or beyond, the concrete can sustain the applied compression force and the load capacity of the anchor will increase up to a point at which either the capacity of the expansion mechanism or the bond is reached. In masonry, part of the individual unit may be pulled from the wall, especially in cases where the strength of the mortar may be low.

ANCHOR BEHAVIOR (Continued)

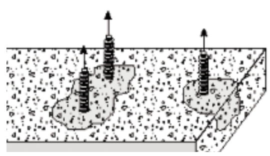
Anchor Material Failure

A failure of the anchor body or rod will occur when the applied load exceeds the strength of the material from which the anchor is manufactured. For mechanical anchors, this usually occurs for anchors which are embedded deep enough to develop the full strength of the expansion mechanism and the base material. For adhesive anchors, this will occur when the base material and bond strength of the adhesive is greater than the strength of the anchor rod.



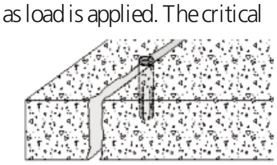
Spacing or Edge Failure

The spacing and edge distance of installed anchors will affect the mode of failure along with the resulting ultimate load capacity. Anchors which are spaced close together will have a compound influence on the base material resulting in lower individual ultimate load capacities. For anchors installed close to an unsupported edge, the load capacity will be affected by both the direction of the load and the distance from the edge. As load is applied, a concrete cone type of failure will occur. This can be caused by the compressive forces generated by the expansion mechanism or by the stresses created by the applied load.



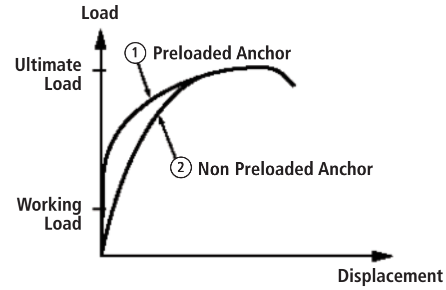
Base Material Splitting

Concrete and masonry units must be of sufficient size to prevent cracking or splitting during anchor installation and as load is applied. The critical dimensions include the thickness and the width of the base material.



Anchor Preload and Torque

Anchor preload is developed by the setting action in a displacement controlled anchor or the tightening of a bolt/nut in a torque controlled anchor. When a load is applied to an anchor, significant displacement will not occur until the preload in the anchor has been exceeded. The amount of preload normally does not have any effect on ultimate load capacity provided the anchor is properly set. By tightening a torque controlled anchor a particular number of turns or to a specific torque level, the anchor is initially preloaded. This action will reduce the overall displacement of the anchor and normally ensures that elastic behavior will occur in the working load range (but should not be counted on where cracking of the concrete may occur, e.g. seismic event). A preload may also be applied to achieve a clamping force between the fixture and the base material. The diagram below shows the effect of preload on the performance characteristics of two wedge anchor samples.



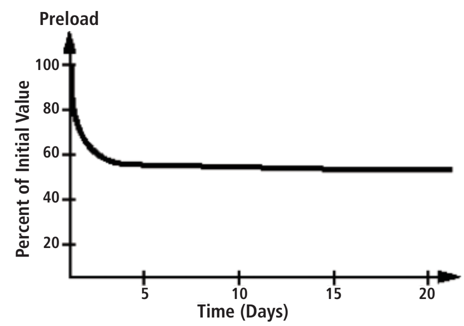
Effects of preload on anchor performance

In curve 1, the tightened anchor does not experience significant displacement until well above the working load. Curve 2 shows the performance of the anchor not tightened which experiences marked displacement in the working load range.

Preload Relaxation

In concrete, anchors which have been preloaded by tightening or the application of an installation torque will experience a phenomena called preload relaxation. This will also occur in masonry base materials. In a typical mechanical anchor installation, high bearing stresses against the concrete base material are created around the expansion mechanism of the anchor as it is preloaded. These high bearing stresses cause the concrete in the area of the expansion mechanism to creep which results in a slight movement of the anchor. This slight movement causes a reduction of preload and a corresponding reduction in the measured torque. Industry experience has shown that a decrease in preload in the range of 40 to 60 percent can be expected in normal-weight concrete. This will vary depending upon the modulus of elasticity of the concrete. The final preload is typically 1.5 to 2.0 times the working load based on the use of a safety factor of 4. Typical load relaxation is shown in the following diagram.

Typical preload relaxation



Relaxation begins immediately after tightening with most of the relaxation occurring during the first few hours after installation. For example, in an application where an installation torque of 60 foot-pounds is applied, a decrease in the torque measured 24 hours later to a level of 30 foot-pounds due to preload relaxation would be considered normal. Retorquing of the anchors may slightly increase the final value of the preload, however, this is not normally recommended as repeated tightening may eventually jack the anchor out of the base material, especially for expansion anchors where the high compressive forces developed by the expansion mechanism of some anchors may cause localized failure of the concrete.

ANCHOR BEHAVIOR (Continued)

Long Term Behavior

Various additional influences may need consideration for the proper long term behavior of an anchoring or fastening system. These important considerations include but are not limited to effects of concrete state (uncracked, cracked), earthquake loading, fatigue, freezing/thawing effects, sustained loading (i.e. creep), elevated temperature, fire, corrosion and/or chemical resistance. For instance, Powers current offering of adhesive anchoring systems have been independently tested and qualified to meet or exceed the creep requirements of ICC-ES AC308 and AC58. Product specific information can be found in individual product sections.

ANCHOR MATERIAL SELECTION

The material from which an anchor is manufactured is generally capable of sustaining the published tension and shear loads. However, other conditions such as bending loads should be checked. In certain loading situations, the material strength may be the weak link. Bolts or other materials used in conjunction with an anchor should be capable of sustaining the applied load and should be installed to the minimum recommended thread engagement. For reference purposes, the minimum expected mechanical properties of commonly used carbon steel and stainless steel materials are listed in various standards. The typical standards used are for externally threaded parts as assigned by the Society of Automotive Engineers (SAE), American Iron and Steel Institute (AISI) or the American Society for Testing and Materials (ASTM). Variations in strength will occur due to heat treating, strain hardening, or cold working. Consult the individual standards for details.

Allowable Steel Strength

In some cases, it may be desirable to calculate the allowable steel strength for a bolt or a threaded anchor rod. One method to calculate the allowable steel strength is based on the stresses as listed in the American Institute of Steel Construction (AISC) Manual of Steel Construction, Allowable Stress Design. Using this method, the allowable tensile stress, F_t, and the allowable shear stress, F_v, are calculated as follows:

$F_t = 0.33 \times F_u$
$F_v = 0.17 \times F_u$

Where F_u = minimum specified ultimate tensile strength for the steel material. This stress is then applied to the gross nominal area of the threaded section to calculate the load in pounds.

In addition to the load capability of the material, an anchor should be manufactured from material which is compatible with its intended use. For example, anchors manufactured from a material with a melting point of less than 1000°F are not normally recommended for overhead applications due to fire considerations unless specific fire rating tests have been performed. Special materials may be required for corrosive environments and galvanic reactions.

Powers reserves the right to use alternate anchor materials which will perform in a similar manner depending upon production requirements.

Material Certifications

Powers provides the following types of certification for products when requested by the user.

Certificate of Compliance

This type of certification, sometimes called a Certificate of Conformance, lists the materials and plating used in the manufacture of a product referencing pertinent specifications

or listings such as AISI, ASTM, SAE, UL, FM Global, or ICC-ES. All major components are described including nuts and washers. This is the most commonly requested type of certification. A Certificate of Compliance can be requested for any Powers product from the Customer Service Department.

Mill Certifications

Requests for Mill Certifications usually apply to steel anchors. Mill Certifications provide full traceability of a finished product back to the original lot of steel from which it was produced and usually include the heat number, material identification, chemical analysis, and physical properties. In order to produce a part which is traceable back to the original Mill Certification, the raw steel material must be identified at the start of the manufacturing process. Powers is able to perform this type of service, however, these certifications typically can be supplied only on material that is ordered as a special.

A price and delivery quotation for any item requiring Mill Certifications can be obtained by contacting the local Powers Branch office. Certain projects in the United States specify that steel components installed on site be manufactured from raw material steel that is originally melted, milled, wired, etc in the U.S. market conditions at the time of manufacture of a particular anchor type and its components will determine the origin of raw material steel. The origin of the raw material used for the manufacture of anchors already stocked or sold from authorized Powers distributors typically cannot be certified. A special order for the manufacture of anchors made from 100% U.S. steel needs to be quoted. Minimum quantities and minimum lead times of several weeks should be expected.

INSTALLATION CRITERIA

As with any building component, proper installation is the key to a successful application once an anchor has been designed and properly selected.

Drilled Hole

A properly drilled hole is a critical factor both for ease of installation and optimum anchor performance. The anchors selected and the drill bits to be used should be specified as part of the total anchoring system. Most Powers anchors are designed to be installed in holes drilled with carbide tipped bits meeting the requirements of the American National Standards Institute (ANSI) Standard B212.15 unless otherwise specified. If alternate bit types are used, the tip tolerance should be within the ANSI range unless otherwise permitted. The following table lists the nominal drill bit diameter along with the tolerance range established by ANSI for the carbide tip.

Nominal Drill	ANSI Standard	Nominal Drill	ANSI Standard
1/8"	0.134-0.140"	11/16"	0.713-0.723"
5/32"	0.165-0.171"	3/4"	0.775-0.787"
11/64"	0.181-0.187"	27/32"	0.869-0.881"
3/16"	0.198-0.206"	7/8"	0.905-0.917"
7/32"	0.229-0.237"	15/16"	0.968-0.980"
1/4"	0.260-0.268"	1"	1.030-1.042"
9/32"	0.296-0.304"	1-1/8"	1.160-1.175"
5/16"	0.327-0.335"	1-1/4"	1.285-1.300"
3/8"	0.390-0.398"	1-3/8"	1.410-1.425"
7/16"	0.458-0.468"	1-1/2"	1.535-1.550"
1/2"	0.520-0.530"	1-5/8"	1.655-1.675"
9/16"	0.582-0.592"	1-3/4"	1.772-1.792"
5/8"	0.650-0.660"	2"	2.008-2.028"

When drilling an anchor hole using a carbide tipped bit, the rotary hammer or hammer drill used transfers impact energy to the bit which forms the hole primarily due to a chiseling action. This action forms an anchor hole which has roughened walls. Mechanical anchors should not be installed in holes drilled with diamond tipped core bits unless testing has been conducted to verify performance. Adhesive anchors should also be tested. A diamond tipped bit drills a hole which has very smooth walls which can cause some anchor types to slip and fail prematurely. Smooth walls should generally be roughened and cleaned.

During the drilling operation, bit wear should be monitored to ensure that the carbide tip does not wear below the following limits to ensure proper anchor functioning. This is especially important when using mechanical anchors (including screw anchors). Generally, mechanical anchors can be installed in holes drilled with bits which have worn, but are still in the acceptable range. This depends on the base material, so this information should be used as a guide.

Nominal Drill	Lower Wear	Nominal Drill	Lower Wear
3/16"	0.190"	5/8"	0.639"
1/4"	0.252"	3/4"	0.764"
5/16"	0.319"	7/8"	0.897"
3/8"	0.381"	1"	1.022"
1/2"	0.510"	1-1/4"	1.270"

Anchor holes should be drilled to the proper depth which is based on the anchor style. The recommended drilling depth is listed in the installation instructions for the individual products. When a one-step anchor such as a wedge style is installed, the expansion mechanism scrapes the walls of the anchor hole. This scraping action pushes concrete dust particles ahead of the anchor. When using this style of anchor, the purpose of drilling the anchor hole to the recommended depth is to allow a place for the dust to settle as the anchor is installed. Anchor holes should be thoroughly cleaned prior to installation of the anchor unless otherwise noted.

This procedure is easily accomplished using compressed air or a vacuum. Dust and other debris must be removed from the hole to allow an anchor to be installed to the required embedment and to ensure that the expansion mechanism can be properly actuated. Extra care must be be taken when using adhesives. The drilled hole should be thoughly cleaned, including brushing and blowing of the anchor hole with suitable equipment to ensure that a proper bond is developed. See specific product information concerning suitability of installations in wet or submerged environments.

Anchor Alignment

Anchors should be installed perpendicular to the surface of the base material. Within the industry, +/- 6° is typically used as the permissible deviation from perpendicular. If anchors are installed beyond this point, calculations to ensure that a bending load has not been created may need to be performed. Job site tests may be required to determine actual load capacities if anchors are not installed perpendicular to the surface of the base material.

Clearance Holes

Powers anchors are designed to be installed in holes drilled in concrete and masonry base materials with carbide tipped drill bits meeting the requirements of ANSI B212.15 as listed in the previous section unless otherwise noted. The actual hole diameter drilled in the base material using an ANSI Standard carbide tipped bit is larger than the nominal diameter. For example, a 1/2" nominal diameter drill bit has an actual O.D. of 0.520" to 0.530". When selecting the diameter of the hole to be pre-drilled in a fixture, the diameter of the hole selected should allow for proper anchor installation.

For through fixture installations, it is necessary to pre-drill or punch a minimum clearance hole in the fixture which is large enough to allow the carbide tipped bit and the anchor to pass through.

One-step mechanical expansion anchors require a pre-drilled hole in the fixture which is large enough for the expansion mechanism to be driven through. Normally, for mechanical expansion anchor sizes up to 7/8", the minimum clearance hole required is the anchor diameter plus 1/16". For sizes 1" and larger, the minimum clearance hole is the anchor diameter plus 1/8". This clearance hole should be adjusted to allow for any coating applied to the fixture.

As in all applications, the design professional responsible for the installation should determine the clearance hole to be used based on the anchor selected and relevant code requirements.

INSTALLATION CRITERIA (Continued)

Oversized Holes

Unless otherwise noted, the performance values for Powers adhesive anchor systems are based upon testing of anchors installed in holes drilled with carbide-tipped bits typically with either 1/16-inch or 1/8-inch greater than the nominal diameter of the steel anchor element (see specific information contained in product sections). Some cases may warrant the consideration of oversizing the drilled holes (e.g. due to placement issues, construction adjustments). Although oversizing holes may be warranted depending upon the application and conditions, it can have an effect on performance and job site tests are recommended if oversizing is considered.

As in all applications, the design professional responsible for the installation should determine the clearance hole to be used based on the anchor selected and relevant code requirements.

Note: It is not recommended to install mechanical anchors in oversized holes.

Installation Torque

Certain anchor styles, sometimes referred to as torque controlled anchors, are actuated by tightening a bolt or nut. For typical field installations, especially where it is not practical to measure the torque, the commonly suggested tightening procedure for such anchors is to apply 3 to 5 turns to the head of the bolt or nut from the finger tight position or to within the maximum guide torque range. This is usually sufficient to initially expand the anchors and is standard industry practice. In some cases, it may be desirable to specify an installation torque for an anchor.

The frictional characteristics which govern the torque-tension relationship for an anchor will vary depending upon the anchor type and the base material. Other factors which may affect the relationship are the effects of fixture coatings or platings, lubrication of the anchor components due to the use of sealants around the anchor hole, and the anchor material. Powers publishes guide installation torque values for anchors that are actuated by tightening a bolt or nut. These values are based on standard product installations, and with the exception of torque-controlled expansion anchors which have a specified value based on testing, should be used as a guideline since performance may vary depending upon the application. For other anchor types such as adhesive anchors, a maximum torque may be published for use as a guide to prevent overloading when applying a clamping force to a fixture.

These values may have to be reduced for installations in masonry materials. Suggested allowable torque range values are also provided in the product sections.

Temperature

The product installation temperature and base material temperature can have an effect on performance of adhesive anchors. The selected product must be suitable for the application and installation conditions. It is recommended that the product be conditioned and installed in accordance with published instructions for best results.

For in-service temperature and freeze-thaw effects, reference the information contained in the specific product information sections.

Note: When adhesive anchors are installed in concrete which is in the freezing range, frost or ice can form on the walls of the anchor hole. If this occurs, injection type adhesives may not properly bond to the walls of the anchor hole. Spin-in type capsule systems which scrape the walls of the anchor hole during installation are less sensitive to this. A torch should normally not be used because it carbonates the concrete on the walls of the anchor hole creating a residual dust. Job site tests are recommended where a torch is used to dry the anchor hole.

Test Torque

To establish application specific installation torque values, a job site test is recommended. A typical procedure includes the following: Install the anchor duplicating the actual application. Using a torque wrench, apply the recommended number of full turns from the finger tight position. The number of turns may vary depending upon the base material strength. Upon completion of the final turn, record the torque reading from the wrench. This should be performed on a minimum sample of 5 anchors averaging the results to establish an installation torque range. Care should be taken by the design professional responsible for the installation to consider the material strength and composition of the anchor so that the tests do not damage the anchor or cause undue damage to the test location.

Should anchor failures occur during this job site test procedure, average ultimate torque values should be compared to published torque recommendations and an appropriate factor of safety should be applied (typically in the range of 2 to 2.5) subject to the design professional and/or building official as applicable.

If previously installed anchors are to be inspected with a torque wrench, it should be noted that anchors experience a relaxation of preload which begins immediately after tightening due to creep within the concrete or masonry material. This phenomenon is discussed in a previous section. The torque value measured after installation is typically 50% of that initially applied to set the anchor.

DESIGN RECOMMENDATIONS

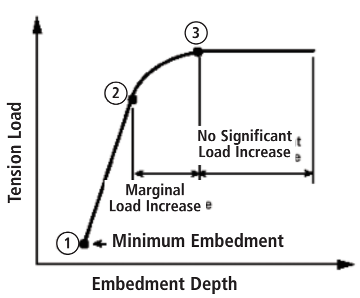
Allowable Load Capacities (ASD)

The allowable load which may be applied to an anchor is calculated based upon applying a safety factor to the average ultimate load capacity obtained from testing. One purpose of a safety factor is to allow for field variations which may differ from the testing conditions in the laboratory. Examples of these variations include differences in the type and strength of base material, the setting method used, and long term performance factors. The standards established by industry is to reduce the ultimate load capacity by a minimum safety factor of 4 or 5 (or greater) depending upon the type of base material and governing building code to calculate the allowable working load. For example, an anchor which has an average ultimate tension load capacity in solid normal-weight concrete of 12,000 pounds would have a maximum allowable working load anchor of 3,000 pounds. Critical applications such as overhead applications or dynamic loading may require higher safety factors. The allowable loads are recommendations, however, and local building codes should be consulted to determine the required safety factors. For adhesive anchors, maximum torque ranges are published with the load capacity charts for each adhesive anchoring system. Both the strength of the adhesive and the steel anchor rod must also be considered. As in all applications, the actual safety factors and design load capacities used should be reviewed and verified by a design professional responsible for the actual product installation.

Depth of Embedment

The depth of embedment published for each anchor in the load capacity charts is critical to achieving the expected load capacities. This depth is measured from the surface of the base material to the bottom of the anchor. For mechanical expansion anchors, this would be the depth measured to the bottom of the anchor prior to actuation. For each anchor type, a minimum embedment depth is specified. This depth is typically the minimum required for proper anchor installation and reliable functioning. Attempting to install an anchor at less than the minimum required may overstress the base material causing it to fail when the anchor is expanded. In some masonry materials, the minimum depth may be decreased depending upon the anchor style as noted in the load tables.

As noted previously, the load capacity of some anchor types will increase with deeper embedments. For anchors which exhibit this behavior, multiple embedment depths and the corresponding load capacity are listed. As the embedment depth is increased, the load capacity will increase up to a transition point. This point is usually the maximum embedment depth listed. At this point, mechanical anchors may experience material failure or localized failure of the base material around the expansion mechanism. Adhesive type anchors may reach the capacity of the bond, the anchor rod material, or the capacity of the base material. The following diagram shows the typical performance of a mechanical anchor installed in concrete.



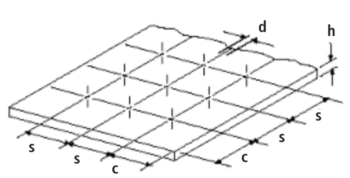
At the minimum embedment depth, the mode of failure at the ultimate load capacity is typically a concrete shear cone. As the anchor is installed at a deeper embedment depth, the size of the theoretical concrete shear cone increases, resulting in an increased load capacity. As the embedment depth is increased towards point 2, the mode of failure changes from a concrete shear cone to localized failure around the expansion mechanism. Beyond this point, marginal load capacity increases can be expected until the capacity of the expansion mechanism or anchor material is reached at embedment depths corresponding to point 3. The load capacity will not increase significantly for anchors installed at embedment depths beyond this point. This point is usually the deepest embedment listed in the anchor load capacity tables and is the maximum recommended. Applications which require an embedment deeper than those published should be tested to verify proper anchor performance. For applications requiring installation at embedment depths between those published, linear interpolation is permitted.

Base Material Strength

As discussed previously, the strength of the base materials in which anchors may be installed varies widely and is a key factor in the performance of an anchor. Powers publishes the average ultimate load capacities for anchors installed in concrete and masonry units along with other appropriate base materials depending upon the product. For installations in concrete, the load capacity of an anchor usually increases as the compressive strength increases. Most load capacities for anchors installed in concrete are published for various minimum compressive strengths between 2,000 and 8,000 psi. Linear interpolation of the data for intermediate compressive strengths is permissible. For masonry unit base materials, the published load capacities should be used as a guide since the consistency of these materials varies widely. Job site tests are recommended for critical applications in these materials.

Base Material Thickness

The minimum recommended thickness of solid concrete or masonry base material, *h,* when using a mechanical or adhesive anchor typically is 150% of the embedment to be used unless otherwise noted. For example, when installing an anchor to a depth of 4”, the base material should be at least 6” thick. Conversely, the maximum embedment should be two-thirds of the base material thickness. If a concrete slab is 12” thick, an 8” depth would be the maximum recommended anchor embedment. This does not apply to products designed for installation in hollow base materials as noted in the individual anchor sections.



d = Anchor Size
s = Spacing
c = Edge Distance
h = Base Material Thickness

DESIGN RECOMMENDATIONS (Continued)

Anchors for use in Seismic Design

Seismic design as based on the building codes require that building structures resist the effects of ground motion induced by an earthquake. Each structure is assigned to a seismic design category/zone based on the location of the building site as referenced in the building codes.

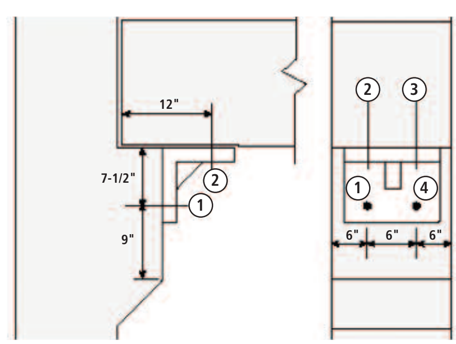
Seismic design is complex as it considers several influencing factors such as site geology and soil characteristics, building occupancy categories, building configuration, structural systems, and lateral forces. Lateral forces are critical because of an earthquakes tendency to shake the building structure from side to side.

Anchors to be used for seismic loads will not be fully loaded in place until an earthquake occurs. Test methods have been developed to provide a criteria for evaluating the performance of both adhesive and mechanical anchors when subjected to simulated seismic loading. Anchors are subjected to a simulated seismic load cycle. In shear, anchors are tested and are subjected to alternating load applications.

The criteria to be used as conditions of acceptance are based on conducted testing according to ASTM and ICC-ES Acceptance Criteria, including seismic qualification on several anchoring products. See individual product sections for more information.

Allowable Stress Design (ASD) Example

The following example is provided as a reference to familiarize the designer with the use of spacing and edge distance reduction factors. In this application, a steel angle is to be fastened to a 6,000 psi precast structure to reinforce the existing column and beam connections as shown in the following diagram. The designer has previously calculated the service loads and would prefer to use 4 anchors. Based on the calculations, the required service loads for an anchor at location No. 1 would be 1,500 lbs. in tension and 2000 lbs. in shear. The Wedge-Bolt+ anchor has been selected because of the finished appearance.



For an installation in 6,000 psi concrete, the following information is obtained from the load capacity chart for the carbon steel Wedge-Bolt+ anchor.

Anchor diameter: 3/4"

Embedment depth: 5"

Maximum Allowable Tension Load: 4,850 lbs.

Maximum Allowable Shear Load: 5,425 lbs.

The spacing and edge distance factors would be applied as follows. For anchor No. 1, the reductions which should be applied are for the influence of the spacing from anchor No. 4 and two edge distance influences (6" horizontally and 7-1/2" vertically). Refer to the Load Adjustment Factors for Normal-weight Concrete tables for the applicable reduction factors located in the product section of this manual.

Allowable Tension Load

For the 6" spacing, F_{NS} = 0.75 (taken from the spacing table for tension).

For the 6" edge distance, F_{NC} = 1.00 (taken from the edge distance table for tension).

For the 7-1/2" edge distance, F_{NC} = 1.00 (taken from the edge distance table for tension).

The allowable tension load based on the reduction factors is calculated as follows:

Allowable Load = 4,850 x 0.75 x 1.00 x 1.00 = 3,635 lbs.

Allowable Shear Load

For the 6" spacing, F_{VS} = 0.88 (taken from the spacing table for tension).

For the 6" edge distance, F_{VC} = 0.62 (taken from the edge distance table for tension).

For the 7-1/2" edge distance, F_{VC} = 0.81 (taken from the edge distance table for tension).

The allowable tension load based on the reduction factors is calculated as follows:

Allowable Load = 5,425 x 0.88 x 0.62 x 0.81 = 2,395 lbs.

Combined Loading

Once the allowable load capacities are established including the effects of spacing and edge distance, the combined loading formula should be checked.

$(1500/3635)^{5/3} + (2000/2395)^{5/3}$

$0.23 + 0.74 = 0.97 \leq 1$, OK.

The design approach would be similar for the remainder of the anchors using allowable stress design.

DESIGN RECOMMENDATIONS (Continued)

SD Reference Guide - Strength Design of Anchorage to Concrete ACI 318 (2008) Appendix D

The following is a reference tool for the design of post-installed anchors into concrete using ACI 318-08. This document compliments the following flowcharts and reference equations which is a compilation of relevant strength design equations (in ACI reference sequence) for post-installed mechanical expansion anchors, screw anchors and adhesive anchors.

Note: At this time the Appendix D equations for strength design specific to adhesive anchors are considered amendments to ACI 318. The details that accompany the amended strength design equations are found in the ICC-ES Acceptance Criteria 308, Annex A, Section 3.3.

The following steps should be taken to determine the controlling design strength (factored resistance) of the anchor system:

In all cases, the anchor system must be designed as follows:

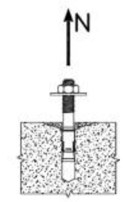
$\boldsymbol{\phi N_n \geq N_{ua}}$

where ϕN_n is the lowest design strength in tension from all appropriate failure modes;

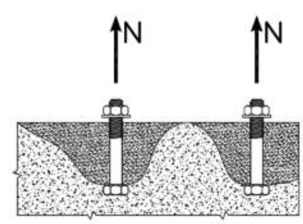
- For mechanical expansion and screw anchors, ϕN_n is the lowest design strength in tension of an anchor or group of anchors as determined from consideration of ϕN_{sa}, ϕN_{cb}, ϕN_{cbg} (or ϕN_{pn}).
- For adhesive anchors, ϕN_n is the lowest design strength in tension of an anchor or group of anchors as determined from consideration of ϕN_{sa}, ϕN_{cb}, ϕN_{cbg}, ϕN_a, (or ϕN_{ag},).
  (bond strength failure mode is not pictured)
- A supplemental design check and an additional strength reduction is required for adhesive anchors subjected to sustained tensile loads or load combinations with a sustained load component.
  Please see AC308, Annex A, Section 3.3.1.1 (D.4.1.4).

Failure modes:

Steel Failure



Pullout

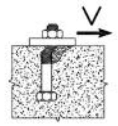


Concrete Breakout

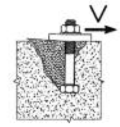
$\boldsymbol{\phi V_n \geq V_{ua}}$

where ϕV_n is the lowest design strength in shear from all appropriate failure modes;

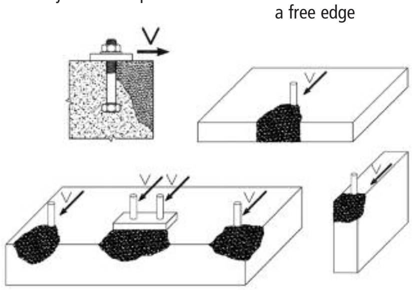
- For mechanical expansion and screw anchors, ϕV_n is the lowest design strength in shear of an anchor or group of anchors as determined from consideration of ϕV_{sa}, ϕV_{cb}, ϕV_{cbg}, ϕV_{cp} (or ϕV_{cpg}).
- For adhesive anchors, ϕV_n is the lowest design strength in shear of an anchor or group of anchors as determined from consideration of ϕV_{sa}, ϕV_{cb}, ϕV_{cbg}, ϕV_{cp} (or ϕV_{cpg}).



Steel failure proceeded by concrete spall



Concrete pryout for anchors far from a free edge



Concrete Breakout

DESIGN RECOMMENDATIONS (Continued)

Reference Guide - Strength Design of Anchorage to Concrete ACI 318 (2008) Appendix D

The following is a simple walkthrough of the steps taken to calculate the static design strength for a single post-installed mechanical or adhesive anchor in tension:

1. Check the minimum edge distance(s) and member thickness requirements reported from qualification testing for the selected anchor; for anchors in groups a check for the minimum spacing distance is required.
2. Calculate the steel strength (ϕN_{sa}) of the anchor.
3. Calculate the concrete breakout strength (ϕN_{cb}) including all appropriate factors.
4. Calculate the pullout strength of the mechanical anchor or determine bond strength of the adhesive anchor:
   a. Calculate pullout strength (ϕN_{pn}) of the mechanical expansion anchor or screw anchor. Nominal pullout values (N_p) are reported from testing and are product dependent;
   b. Determine the bond strength (ϕN_a) of the adhesive anchor for the appropriate temperature range and drilled hole condition. Include all appropriate factors.

Note: For sustained tensile loads or combined loads with a sustained tensile load component, see AC308, Annex A, Section 3.3.1.1 (D.4.1.4).

5. Determine the lowest controlling strength from the possible tension failure modes (splitting rather than side-face-blowout generally governs post-installed anchors; therefore, side-face-blowout is not calculated).

The following is a simple walkthrough of the steps taken to calculate the static design strength for a single post-installed mechanical or adhesive anchor in shear:

1. Check the minimum edge distance(s) and member thickness requirements reported from qualification testing for the selected anchor.
2. Calculate the steel strength (ϕV_{sa}) of the anchor.
3. Calculate the concrete breakout strength (ϕV_{cb}) including all appropriate factors.
4. Calculate the pryout strength of the mechanical anchor or determine pryout strength of the adhesive anchor:
   a. Calculate pryout strength (ϕV_{cp}) of the mechanical expansion anchor or screw anchor.
   b. Determine the pryout strength (ϕV_{cp}) of the adhesive anchor.
5. Determine the lowest controlling strength from the possible shear failure modes.

The following is guidance in application and use of anchors for seismic design considerations:

1. In regions of moderate or high seismic risk, or for structures assigned to intermediate or high seismic performance or design categories (i.e. C, D, E or F), the design strength of post-installed anchors (ϕN_n) and (ϕV_n), shall include an additional multiplication factor of 0.75 (see ACI 318-05 Section D.3.3.3).
2. Design of post-installed anchors in accordance with ACI 318 Appendix D is further modified by Section 1908.1.16 of the IBC for load combinations that include seismic loads. In summary, for anchorages that do not fulfill the ductility requirements of ACI 318 Appendix D, Sections D.3.3.4 and D.3.3.5 (as modified), 'the minimum design strength of anchors shall be at least 2.5 times the factored forces transmitted by the attachment.' In summary if this ductility factor is moved from the load (demand) side of the equation to the design capacity for the anchors, it is applied as an additional reduction factor of 0.40 for "non-ductile" anchors.
3. For anchorages that are classified as non-structural components, supports or attachments reference Chapter 13 of ASCE 7-05.

The following is guidance for design and use of anchors for sand-lightweight concrete; and single anchors installed through the soffit of steel deck floor and roof assemblies into structural sand-lightweight or normal weight concrete:

1. For anchors in sand-lightweight concrete, N_b, N_{pn}, V_{cb}, and V_{cp} shall be multiplied by a factor of 0.60.
2. For anchors installed through the flute (soffit) of steel deck into concrete, evaluation of N_{cb} to determine the controlling tension load is not required. Additional factors for sand-lightweight concrete need not be applied provided the anchors were tested and qualified in sand-lightweight concrete over steel deck.
3. For anchors through the flute (soffit) of steel deck into concrete, evaluation of V_{cb} and V_{cp} to determine the controlling shear load is not required. Additional factors for sand-lightweight concrete need not be applied provided the anchors were tested and qualified in sand-lightweight concrete over steel deck.

ACI 318 (2008) APPENDIX D and ICC-ESE AC193

MECHANICAL (EXPANSION/SCREW) ANCHORS - TENSION AND SHEAR

D.5 - DESIGN REQUIREMENTS FOR TENSILE LOADING

(D-1) $\phi N_n \geq N_{ua}$ where ϕN_n is the lowest design strength in tension from all appropriate failure modes. For mechanical expansion and screw anchors, ϕN_n is the lowest design strength in tension of an anchor or group of anchors as determined from consideration of ϕN_{sa}, ϕN_{cb}, ϕN_{cbg}, or ϕN_{pn}.

D.5.2 - CONCRETE BREAKOUT STRENGTH OF AN ANCHOR IN TENSION

D.5.2.1 - Nominal concrete breakout strength of a single anchor in tension (lbs)

(D-4) $N_{cb} = \frac{A_{Nc}}{A_{Nc0}} \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b$

D.5.2.1 - Nominal concrete breakout strength of an anchor group in tension (lbs)

(D-5) $N_{cbg} = \frac{A_{Nc}}{A_{Nc0}} \Psi_{ec,N} \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b$

D.5.2.1 - Full projected area for a single anchor (in^2)

(D-6) $A_{Nco} = 9h_{ef}^2$

D.5.2.2 - Basic concrete breakout strength (lbs)

(D-7) $N_b = k_c \sqrt{f'_c}\, h_{ef}^{1.5}$

When available select appropriate k_c factor from product report. *If none provided use:*

$k_c = 24$ *for uncracked concrete; and*

$k_c = 17$ *for cracked concrete*

D.5.2.4 - Modification factor for eccentricity

(D-9) $\Psi_{ec,N} = \frac{1}{\left(1 + \frac{2e'_N}{3h_{ef}}\right)} \leq 1.0$

D.5.2.5 - Modification factor for edge effects

(D-10) $\Psi_{ed,N} = 1.0$ if $c_{a,min} \geq 1.5h_{ef}$

(D-11) $\Psi_{ed,N} = 0.7 + 0.3 \frac{c_{a,min}}{1.5h_{ef}}$ if $c_{a,min} < 1.5h_{ef}$

D.5.2.6 - Modification factor for uncracked concrete

Where k_c is selected from product information report $\Psi_{c,N} = 1.0$ (select appropriate k_c factor from product report for cracked or uncracked concrete)

Where the value of k_c is not given in product information report $\Psi_{c,N}$ shall be taken as 1.4 for uncracked concrete. Where analysis indicates cracking at service load levels $\Psi_{c,N}$ shall be taken as 1.0

D.5.1.2 - STEEL STRENGTH OF AN ANCHOR IN TENSION

(D-3) $N_{sa} = nA_{se} f_{uta}$

D.5.3 - PULLOUT STRENGTH OF AN ANCHOR IN TENSION

D.5.3.1 - Nominal tension pullout strength (lbs) of a single anchor

(D-14) $N_{pn} = \Psi_{c,P} N_p$

(N_p for post-installed anchors typically taken from product report for cracked or uncracked concrete)

D.5.3.6 – For an anchor located in a region of concrete member where analysis indicates no cracking at service load levels, the following modification factor shall be permitted $\Psi_{c,P}$ shall be taken as 1.4. Where analysis indicates cracking at service load levels, $\Psi_{c,P}$ shall be taken as 1.0

N_p is typically given for 2,500 psi concrete. The characteristic pull-out resistance for greater concrete compressive strengths may be increased by multiplying the given value of N_p (2,500 psi) by:

$$\left(\frac{f'_c}{2500}\right)^n$$

The value for *n is given in the product report. The value of n typically is 0.5.*

D.3 – GENERAL REQUIREMENTS

D.3.3 – In regions of moderate or high seismic risk... the design strength of anchors shall be taken as *0.75* ϕN_n and *0.75* ϕV_n.

D.3.3.4 - In regions of moderate or high seismic risk...anchors shall be designed to be governed by tensile or shear strength of a ductile steel element. Unless D.3.3.5 is satisfied

D.3.4 (AC193) – If lightweight concrete is used, provisions for N_n and V_n shall be modified by multiplying all values of $\sqrt{f'_c}$ affecting N_n and V_n by 0.6 (AC193) for all structural sand-lightweight concrete.

D.5.2.7 - Modification factor for post-installed anchors (splitting failure) in uncracked concrete

(D-12) $\Psi_{cp,N} = 1.0$ if $c_{a,min} \geq c_{ac}$

(D-13) $\Psi_{cp,N} = \frac{c_{a,min}}{c_{ac}} \geq \frac{1.5h_{ef}}{c_{ac}}$ if $c_{a,min} < c_{ac}$

D.6 - DESIGN REQUIREMENTS FOR SHEAR LOADING

(D-2) $\phi V_n \geq V_{ua}$ where ϕV_n is the lowest design strength in shear from all appropriate failure modes. For mechanical expansion and screw anchors, ϕV_n is the lowest design strength in shear of an anchor or group of anchors as determined from consideration of ϕV_{sa}, ϕV_{cb}, ϕV_{cbg}, ϕV_{cp} or ϕV_{cpg}.

D.6.3 - CONCRETE PRYOUT STRENGTH OF AN ANCHOR IN SHEAR

D.6.3.1 - Nominal concrete pryout strength in shear of a single anchor (lbs)

(D-29) $V_{cp} = k_{cp} N_{cb}$

D.6.3.1 - Nominal concrete pryout strength in shear of an anchor group (lbs)

(D-30) $V_{cpg} = k_{cp} N_{cbg}$

(where N_{cb}, and N_{cbg} from tension calculations, (D-4) and (D-5) respectively)

D.6.1.2 - STEEL STRENGTH OF AN ANCHOR IN SHEAR

D-20) $V_{sa} = n(0.6) A_{se} f_{uta}$ (For post-installed anchors, take V_{sa} from product report)

D.7 - INTERACTION OF TENSILE AND SHEAR FORCES

D.7.1 - Full tension strength requirement

If $V_{ua} \leq 0.2\, \phi V_n$ then full tension strength is permitted: $\phi N_n \geq N_{ua}$

D.7.2 - Full shear strength requirement

If $N_{ua} \leq 0.2\, \phi N_n$ then full shear strength is permitted: $\phi V_n \geq V_{ua}$

D.7.3 - Combined loads

$$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \leq 1.2$$

D.8 – REQUIRED EDGE DISTANCES, SPACINGS, AND MEMBER THICKNESSES TO PRECLUDE SPLITTING FAILURE

Check to ensure that minimum spacings and edge distances for anchors and minimum member thicknesses of members shall conform to values given in the product report.

If no information is given in the product report refer to section D.8.1 through D.8.6 of ACI 318 (2005) Appendix D for minimum requirements.

D.6.2.8 - Modification factor for anchors located in concrete members

where $h_a < 1.5c_{a1}$

(D-28) $\Psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}} \geq 1.0$

D.6.2 - CONCRETE BREAKOUT STRENGTH OF AN ANCHOR IN SHEAR

D.6.2.1 – Nominal concrete breakout strength of a single anchor in shear (lbs)

(D-21) $V_{cb} = \frac{A_{Vc}}{A_{Vco}} \Psi_{ed,V} \Psi_{c,V} \Psi_{h,V} V_b$

D.6.2.1 – Nominal concrete breakout strength of a anchor group in shear (lbs)

(D-22) $V_{cb} = \frac{A_{Vc}}{A_{Vco}} \Psi_{ec,V} \Psi_{ed,V} \Psi_{h,V} \Psi_{c,V} V_b$

D.6.2.1 - Full projected concrete breakout shear area for a single anchor (in^2)

(D-23) $A_{Vco} = 4.5(c_{a1})^2$

D.6.2.2 - Basic concrete breakout strength for a single anchor in shear (lbs)

(D-24) $V_b = 7\left(\frac{l_e}{d_o}\right)^{0.2} \sqrt{d_o} \sqrt{f'_c}\,(c_{a1})^{1.5}$

D.6.2.5 - Modification factor *for eccentricity*

(D-26) $\Psi_{ec,V} = \frac{1}{\left(1 + \frac{2e'_V}{3c_{a1}}\right)} \leq 1.0$

D.6.2.6 - Modification factor for edge effects

(D-27) $\Psi_{ed,V} = 1.0$ if $c_{a2} \geq 1.5c_{a1}$

(D-28) $\Psi_{ed,V} = \left(0.7 + 0.3 \frac{c_{a2}}{1.5c_{a1}}\right)$ if $c_{a2} < 1.5c_{a1}$

D.6.2.7 - Modification factor for cracked or uncracked concrete

$\Psi_{c,V} = 1.4$ for uncracked concrete

$\Psi_{c,V} = 1.0$ for cracked concrete with < No. 4 perimeter bar

$\Psi_{c,V} = 1.2$ for cracked concrete with ≥ No. 4 perimeter bar between anchor and edge

$\Psi_{c,V} = 1.4$ for cracked concrete with ≥ No. 4 perimeter bar between anchor and edge and stirrups spaced ≤ 4 inches

ACI 318 (2008) APPENDIX D and ICC-ES AC308 (NOV 2008)

ADHESIVE ANCHORS (TENSION)

D.5 - DESIGN REQUIREMENTS FOR TENSILE LOADING

(D-1) $\phi N_n \geq N_{ua}$ where ϕN_n is the lowest design strength in tension from all appropriate failure modes;

For adhesive anchors, ϕN_n is the lowest design strength in tension of an anchor or group of anchors as determined from consideration of ϕN_{sa}, ϕN_{cb}, ϕN_{cbg}, ϕN_a or ϕN_{ag}.

D.5.1.2 - STEEL STRENGTH OF AN ANCHOR IN TENSION FOR SINGLE ANCHOR OR GROUP OF ANCHORS (LBS)

(D-3) $N_{sa} = nA_{se}f_{uta}$

Or see product report for N_{sa}

D.5.2 - CONCRETE BREAKOUT STRENGTH OF AN ANCHOR IN TENSION

D.5.2.1 - Nominal breakout strength of a single anchor (lbs)

(D-4) $N_{cb} = \frac{A_{Nc}}{A_{Nc0}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

D.5.2.1 - Nominal breakout strength of an anchor group (lbs)

(D-5) $N_{cbg} = \frac{A_{Nc}}{A_{Nc0}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

D.5.2.1 - Full projected area for a single anchor (in^2)

(D-6) $A_{Nco} = 9h_{ef}^2$

D.5.2.2 - Basic concrete breakout strength (lbs)

(D-7) $N_b = k_c \sqrt{f'_c}\, h_{ef}^{1.5}$

Select appropriate k_c factor for cracked or uncracked concrete, as applicable, from product report..

D.5.2.4 - Modification factor for eccentricity

(D-9) $\psi_{ec,N} = \frac{1}{\left(1 + \frac{2e'_N}{3h_{ef}}\right)} \leq 1.0$

D.5.2.5 - Modification factor for edge effects

(D-10) $\psi_{ed,N} = 1.0$ if $c_{a,min} \geq 1.5h_{ef}$

(D-11) $\psi_{ed,N} = 0.7 + 0.3 \frac{c_{a,min}}{1.5h_{ef}}$ if $c_{a,min} < 1.5h_{ef}$

D.5.2.6 - Modification factor for uncracked concrete

Where k_c is selected from product information report $\psi_{c,N} = 1.0$ (select appropriate k_c factor from product report for cracked or uncracked concrete)

D.5.2.7 - Modification factor for post-installed anchors (splitting failure) in uncracked concrete

(D-12) $\psi_{cp,N} = 1.0$ if $c_{a,min} \geq c_{ac}$

(D-13) $\psi_{cp,N} = \max\left|\frac{c_{a,min}}{c_{ac}}, \frac{1.5h_{ef}}{c_{ac}}\right|$

(greater of these two) if $c_{a,min} \leq c_{ac}$

D.4.1.4 – For adhesive anchors subjected to tension resulting from sustained loading, a supplementary design analysis shall be performed using Eq. (D-1) where N_{ua} is determined from the sustained load alone, e.g., the dead load and that portion of the live load acting that may be considered as sustained and $\emptyset N_n$ is determined as follow:

D.4.1.4.1 – For single anchors, $\emptyset N_n = 0.75\ \emptyset N_{ao}$

D.4.1.4.2 – For anchor groups, Eq. (D-1) shall be satisfied by taking , $\emptyset N_n = 0.75\ \emptyset N_{ao}$ for that anchor in an anchor group that resists the highest tension load.

D.4.1.4.3 - Where shear loads act concurrently with the sustained tension load, integration of tension and sheer shall be analyzed in accordance with D.4.1.3

D.5.3 - PULLOUT STRENGTH OF AN ANCHOR IN TENSION

D.5.3.7 - Nominal tension pullout [**bond**] strength of a single adhesive anchor (lbs)

(D-16a) $N_a = \frac{A_{Na}}{A_{Na0}} \psi_{ed,N_a} \psi_{p,N_a} N_{a0}$

D.5.3.7 - Nominal tension pullout [**bond**] strength of an adhesive anchor group (lbs)

(D-64b) $N_{ag} = \frac{A_{Na}}{A_{Na0}} \psi_{ed,N_a} \psi_{g,N_a} \psi_{ec,N_a} \psi_{p,N_a} N_{a0}$

D.5.3.7 - Full projected area for single adhesive anchor (in^2)

(D-16c) $A_{Na0} = (s_{cr,Na})^2$

D.5.3.8 - Critical spacing distance for an adhesive anchor (in.)

(D-16d) $s_{cr,Na} = 20(d)\sqrt{\frac{\tau_{k,uncr}}{1{,}450}} \leq 3h_{ef}$

D.5.3.8 - Critical edge distance for an adhesive anchor (in.)

(D-16e) $c_{cr,Na} = \frac{s_{cr,Na}}{2}$

D.5.3.9 - Basic tension pullout [bond] strength of a single adhesive anchor (lbs)

(D-16f) $N_{a0} = \tau_{k,(cr\ or\ uncr)} (\pi)(d)(h_{ef})$

D.5.3.10 - Modification factor for an adhesive anchor group

(D-16g) $\psi_{g,Na} = \psi_{g,Na0} + \left[\left(\frac{s}{s_{cr,Na}}\right)^{0.5} (1 - \psi_{g,Na0})\right]$

D.5.3.10 - Basic group modification factor

(D-16h) $\psi_{g,Na0} = \sqrt{n} - \left[(\sqrt{n} - 1)\left(\frac{\tau_{k,(cr\ or\ uncr)}}{\tau_{k,max(cr\ or\ uncr)}}\right)^{1.5}\right] \geq 1.0$

(where n = number of tension loaded anchors in a group)

D.5.3.10 - Maximum adhesive bond stress for cracked and uncracked concrete (psi)

(D-16i) $\tau_{k,max,cr} = \frac{k_{c,cr}}{\pi \cdot d} \sqrt{h_{ef} \cdot f'_c}$

(D-16n) $\tau_{k,max,uncr} = \frac{k_{c,uncr}}{\pi \cdot d} \sqrt{h_{ef} \cdot f'_c}$

D.5.3.11 - Modification factor for eccentricity of an adhesive anchor group

(D-16j) $\psi_{ec,Na} = \frac{1}{\left(1 + \frac{2e'_N}{s_{cr,Na}}\right)} \leq 1.0$ (for $e'_N \leq \frac{s}{2}$)

D.5.3.12 - Modification factor for edge effects of an adhesive anchor

(D-16l) $\psi_{ed,Na} = 1.0$ if $c_{a,min} \geq c_{cr,Na}$

(D-16m) $\psi_{ed,Na} = \left(0.7 + 0.3 \frac{c_{a,min}}{c_{cr,Na}}\right) \leq 1.0$ if $c_{a,min} < c_{cr,Na}$

D.5.3.14 - Modification factor for uncracked concrete (splitting failure) of an adhesive anchor in uncracked concrete

(D-16o) $\psi_{p,Na} = 1.0$ if $c_{a,min} \geq c_{ac}$

(D-16p) $\psi_{p,Na} = \frac{\max\ |c_{a,min}; c_{cr,Na}|}{c_{ac}}$ if $c_{a,min} < c_{ac}$

c_{ac} shall be determined by testing in accordance with AC308 and be provided in product literature.

ACI 318 (2008) APPENDIX D and ICC-ES AC308 (NOV 2008)

ADHESIVE ANCHORS (SHEAR)

D.6 - DESIGN REQUIREMENTS FOR SHEAR LOADING

(D-2) $\phi V_n \geq V_{ua}$ where ϕV_n is the lowest design strength in shear from all appropriate failure modes. For adhesive anchors, ϕV_n is the lowest design strength in shear of an anchor or group of anchors as determined from consideration of ϕV_{sa}, ϕV_{cb}, ϕV_{cbg}, ϕV_{cp} or ϕV_{cpg}.

D.6.2 - CONCRETE BREAKOUT STRENGTH OF AN ANCHOR IN SHEAR

D.5.1.2 - STEEL STRENGTH OF AN ANCHOR IN SHEAR FOR SINGLE ANCHOR OR GROUP OF ANCHORS (LBS)

(D-20) $V_{sa} = n(0.6) A_{se} f_{uta}$

Or see product report for V_{sa}

D.6.3- CONCRETE PRYOUT STRENGTH OF AN ANCHOR IN SHEAR

D.6.2.1 – Nominal concrete breakout strength of a single anchor in shear (lbs)

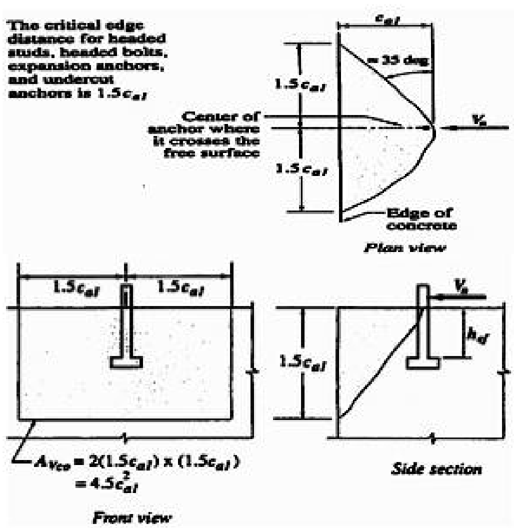
(D-21) $V_{cb} = \frac{A_{Vc}}{A_{Vco}} \Psi_{ed,V} \Psi_{c,V} V_b$

D.6.2.1 – Nominal concrete breakout strength of a anchor group in shear (lbs)

(D-22) $V_{cb,g} = \frac{A_{Vc}}{A_{Vco}} \Psi_{ec,V} \Psi_{ed,V} \Psi_{c,V} V_b$

D.6.2.1 - Full projected concrete breakout shear area for a single anchor (in²)

(D-23) $A_{vco} = 4.5(c_{a1})^2$



D.6.2.2 - Basic concrete breakout strength for a single anchor in shear (lbs)

(D-24) $V_b = 7\left(\frac{l_e}{d_o}\right)^{0.2} \sqrt{d_o}\sqrt{f'_c}(c_{a1})^{1.5}$

D.6.2.5 - Modification factor *for eccentricity*

(D-26) $\psi_{ec,V} = \frac{1}{(1+\frac{2e'_V}{3c_{a1}})} \leq 1.0$

D.6.2.6 - Modification factor for edge effects

(D-27) $\psi_{ed,V} = 1.0$ if $c_{a2} \geq 1.5c_{a1}$

(D-28) $\psi_{ed,V} = \left(0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}\right)$

if $c_{a2} < 1.5c_{a1}$

D.6.2.7 - Modification factor for cracked or uncracked concrete

$\psi_{c,V}$ = 1.4 for uncracked concrete

$\psi_{c,V}$ = 1.0 for cracked concrete with < No. 4 perimeter bar

$\psi_{c,V}$ = 1.2 for cracked concrete with ≥ No. 4 perimeter bar between anchor and edge

$\psi_{c,V}$ = 1.4 for cracked concrete with ≥ No. 4 perimeter bar between anchor and edge and stirrups spaced ≤ 4 inches

D.6.2.8 - Modification factor for anchors located in concrete members

where $h_a < 1.5c_{a1}$

(D-28) $\psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}}$

$\psi_{h,V}$ shall not be taken less than 1.0

D.6.3.2 - Nominal concrete pryout strength in shear of a single adhesive anchor (lbs)

(D-30a) $V_{cp} = \min|\, k_{cp}N_a;\, k_{cp}N_{cb}\,|$

(where N_{cb}, N_{cbg}, N_a and N_{ag} from tension calculations)

D.6.3.2 - Nominal concrete pryout strength in shear of an adhesive anchor group (lbs)

(D-30b) $V_{cpg} = \min|\, k_{cp}N_{ag};\, k_{cp}N_{cbg}\,|$

(where N_{cb}, N_{cbg}, N_a and N_{ag} from tension calculations)

D.6.3.2 - Modification factor for pryout

$k_{cp} = 1.0$ for $h_{ef} < 2.5$ in.

$k_{cp} = 2.0$ for $h_{ef} \geq 2.5$ in.

D.3 – GENERAL REQUIREMENTS

D.3.3 – In regions of moderate or high seismic risk... the design strength of anchors shall be taken as *0.75* ϕN_n and *0.75* ϕV_n.

D.3.3.4 - In regions of moderate or high seismic risk...anchors shall be designed to be governed by tensile or shear strength of a ductile steel element. Unless D.3.3.5 is satisfied.

D.7 - INTERACTION OF TENSILE AND SHEAR FORCES

D.7.1 - Full tension strength requirement

If $V_{ua} \leq 0.2\,\phi V_n$ then full tension strength is permitted: $\phi N_n \geq N_{ua}$

D.7.2 - Full shear strength requirement

If $N_{ua} \leq 0.2\,\phi N_n$ then full shear strength is permitted: $\phi V_n \geq V_{ua}$

D.7.3 - Combined loads

$$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \leq 1.2$$

D.8 – REQUIRED EDGE DISTANCES, SPACINGS, AND THICKNESSES TO PRECLUDE SPLITTING FAILURE

Check to ensure that minimum spacings and edge distances for anchors and minimum thicknesses of members shall conform to values given in the product report.

If no information is given in the product report refer to section D.8.1 through D.8.6 of ACI 318 (2005) Appendix D for minimum requirements.

Section (EQ)	Title	Equation
D.3	**General Requirements (Including Special Seismic Considerations)**	
	See Appendix D Section D.3.3 for special requirements concerning seismic loading. See Appendix D Section D.3.4 for provisions for lightweight concrete which are modified for post-installed mechanical anchors by AC193 Section 6.5.3 and reported.	
D.4	**General Requirements for Strength of Anchors**	
D.4.1.1 (D-1)	Tension strength design requirement	$\phi N_n \geq N_{ua}$
D.4.1.1 (D-2)	Shear strength design requirement	$\phi V_n \geq V_{ua}$
	See Appendix D Section D.4.1.2 as modified by AC308 Annex A, Section 3.3 for requirements concerning adhesive anchors. See Appendix D Section D.4.1.4 as modified by AC308 Annex A, Section 3.3.1.1 for special provisions for adhesive anchors subjected to tension resulting from sustained loading (a supplementary design check must be performed).	
D.5	**Design Requirements for Tensile Loading**	
D.5.1	**Steel Strength of an Anchor in Tension**	
D.5.1.2 (D-3)	Nominal strength of steel in tension (lbs)	$N_{sa} = n\,A_{se}\,f_{uta}$ (anchor or anchor group; for post-installed anchors check published N_{sa} value from product evaluation report and use lower value)
D.5.2	**Concrete Breakout Strength of an Anchor in Tension**	
D.5.2.1 (D-4)	Nominal breakout strength of a single anchor (lbs)	$N_{cb} = \frac{A_{Nc}}{A_{Nc0}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$
D.5.2.1 (D-5)	Nominal breakout strength of an anchor group (lbs)	$N_{cbg} = \frac{A_{Nc}}{A_{Nc0}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$
D.5.2.1 (D-6)	Full projected area for a single anchor (in^2)	$A_{Nco} = 9 h_{ef}^{\;2}$
D.5.2.2 (D-7)	Basic concrete breakout strength (lbs)	$N_b = k_c \lambda \sqrt{f'_c}\, h_{ef}^{\;1.5}$
D.5.2.4 (D-9)	Modification factor for eccentricity	$\psi_{ec,N} = \frac{1}{(1 + \frac{2e'_N}{3h_{ef}})} \leq 1.0$
D.5.2.5 (D-10) (D-11)	Modification factor for edge effects	$\psi_{ed,N} = 1.0$ if $c_{a,min} \geq c_{ac}$ $\psi_{ed,N} = 0.7 + 0.3 \frac{c_{a,min}}{1.5 h_{ef}}$ if $c_{a,min} \leq c_{ac}$

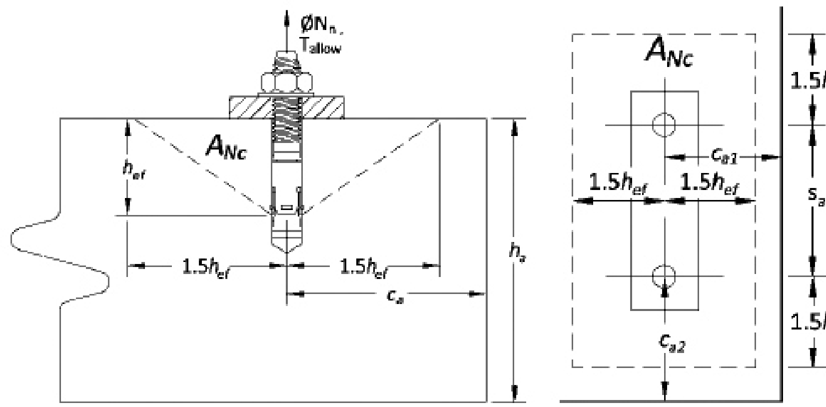
Section (EQ)	Title	Equation
D.5.2.6	Modification factor for uncracked concrete	$\psi_{c,N} = 1.0$ (select appropriate k_c factor from product report for cracked or uncracked concrete)
D.5.2.7 (D-12) (D-13)	Modification factor for post-installed anchors (splitting failure) in uncracked concrete	$\psi_{cp,N} = 1.0$ if $c_{a,min} \geq c_{ac}$ $\psi_{cp,N} = \frac{c_{a,min}}{c_{ac}} \geq \frac{1.5h_{ef}}{c_{ac}}$ (greater of these two) if $c_{a,min} \leq c_{ac}$
D.5.3	**Pullout Strength of an Anchor in Tension**	
D.5.3.1 (D-14)	Nominal tension pullout strength (lbs)	$N_{pn} = \psi_{c,p} N_p$ (N_p typically taken from product report for cracked or uncracked concrete)
D.5.3.7 (D-14a)	Nominal tension pullout [bond] strength of a single adhesive anchor (lbs)	$N_a = \frac{A_{Na}}{A_{Na0}} \psi_{ed,N_a} \psi_{p,N_a} N_{a0}$
D.5.3.7 (D-14b)	Nominal tension pullout [bond] strength of an adhesive anchor group (lbs)	$N_{ag} = \frac{A_{Na}}{A_{Na0}} \psi_{ed,N_a} \psi_{g,N_a} \psi_{ec,N_a} \psi_{p,N_a} N_{a0}$
D.5.3.7 (D-14c)	Full projected area for single adhesive anchor (in^2)	$A_{Na0} = (s_{cr,na})^2$
D.5.3.8 (D-14h)	Critical spacing distance for an adhesive anchor (in)	$s_{cr,Na} = 20(d)\sqrt{\frac{\tau_{k,uncr}}{1{,}450}} \leq 3h_{ef}$
D.5.3.8 (D-14i)	Critical edge distance for an adhesive anchor (in)	$c_{cr,Na} = \frac{s_{cr,Na}}{2}$
D.5.3.9 (D-14j)	Basic tension pullout [bond] strength of a single adhesive anchor (lbs)	$N_{a0} = \tau_{k,(cr\ or\ uncr)} (\pi)(d)(h_{ef})$
D.5.3.10 (D-14k)	Modification factor for an adhesive anchor group	$\psi_{g,Na} = \psi_{g,Na0} + \left[\left(\frac{s}{s_{cr,Na}}\right)^{0.5} (1 - \psi_{g,Na0})\right] \geq 1.0$
D.5.3.10	Basic group modification factor	$\psi_{g,Na0} = \sqrt{n} - \left[(\sqrt{n} - 1)\left(\frac{\tau_{k,(cr\ or\ uncr)}}{\tau_{k,max(cr\ or\ uncr)}}\right)^{1.5}\right] \geq 1.0$ (where n = number of tension loaded anchors in a group)
D.5.3.10 (D-14m)	Maximum adhesive bond stress for cracked concrete (psi)	$\tau_{k,max,cr} = \frac{k_{c,cr}}{\pi \cdot d} \sqrt{h_{ef} \cdot f'_c}$
D.5.3.11 (D-14n)	Modification factor for eccentricity of an adhesive anchor group	$\psi_{ec,Na} = \frac{1}{(1+\frac{2e'_N}{s_{cr,Na}})} \leq 1.0$ (for $e'_N \leq \frac{s}{2}$)
D.5.3.12 (D-14o) (D-14p)	Modification factor for edge effects of an adhesive anchor	$\psi_{ed,Na} = 1.0$ if $c_{a,min} \geq c_{cr,Na}$ $\psi_{ed,Na} = \left(0.7 + 0.3\frac{c_{a,min}}{c_{cr,Na}}\right)$ if $c_{a,min} \leq c_{ac}$
D.5.3.13 (D-14q)	Maximum bond stress for uncracked concrete for an adhesive anchor (psi)	$\tau_{k,max,uncr} = \frac{k_{c,uncr}}{\pi \cdot d} \sqrt{h_{ef} \cdot f'_c}$

Section (EQ)	Title	Equation
D.5.3.14 (D-14r) (D-14s)	Modification factor for uncracked concrete (splitting failure) of an adhesive anchor in uncracked concrete	$\Psi_{p,Na} = 1.0$ if $c_{a,min} \geq c_{ac}$ $\Psi_{p,Na} = \frac{\max \lvert c_{a,min}; c_{cr,Na} \rvert}{c_{ac}}$ if $c_{a,min} \leq c_{ac}$
D.6	**Design Requirements for Shear Loading**	
D.6.1	**Steel Strength of an Anchor in Shear**	
D.6.1.2 (D-20)	Nominal strength of a single anchor or group of anchors in shear (lbs)	$V_{sa} = n(0.6)\,A_{se} f_{uta}$ (For post-installed anchors, see product report for V_{sa})
D.6.2	**Concrete Breakout Strength of an Anchor in Shear**	
D.6.2.1 (D-21)	Nominal concrete breakout strength of a single anchor in shear (lbs)	$V_{cb} = \frac{A_{Vc}}{A_{Vco}} \Psi_{ed,V} \Psi_{c,V} V_b$
D.6.2.1 (D-23)	Full projected concrete breakout shear area for a single anchor (in^2)	$A_{vco} = 4.5(c_{a1})^2$
D.6.2.2 (D-24)	Basic concrete breakout strength for a single anchor in shear (lbs)	$V_b = 7\left(\frac{l_e}{d_o}\right)^{0.2} \lambda\sqrt{d_o}\sqrt{f'_c}(c_{a1})^{1.5}$ l_e = lesser of h_{ef} or $8d_O$ $l_e = 2d_O$ for torque-controlled expansion anchors with two or more sleeves. (for anchors near three or more edges, see Section D.6.2.4)
D.6.2.5 (D-26)	Modification factor for eccentricity	$\psi_{ec,V} = \frac{1}{(1+\frac{2e'_V}{3c_{a1}})} \leq 1.0$
D.6.2.6 (D-27) (D-28)	Modification factor for edge effects	$\psi_{ed,V} = 1.0$ if $c_{a2} \geq 1.5c_{a1}$ $\psi_{ed,V} = \left(0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}\right)$ if $c_{a2} \leq 1.5c_{a1}$
D.6.2.7	Modification factor for cracked or uncracked concrete	$\psi_{c,V} = 1.4$ for uncracked concrete $\psi_{c,V} = 1.0$ for cracked concrete with < No. 4 perimeter bar $\psi_{c,V} = 1.2$ for cracked concrete with ≥ No. 4 perimeter bar between anchor and edge $\psi_{c,V} = 1.4$ for cracked concrete with ≥ No. 4 perimeter bar between anchor and edge and stirrups spaced ≤ 4 inches
D.6.3	**Concrete Pryout Strength of an Anchor in Shear**	
D.6.3.1 (D-29)	Nominal concrete pryout strength in shear of a single	$V_{cp} = k_{cp} N_{cb}$ (where N_{cb}, and N_{cbg} from tension calculations)

Section (EQ)	Title	Equation
	anchor (lbs)	
D.6.3.1 (D-30)	Nominal concrete pryout strength in shear of an anchor group (lbs)	$V_{cpg} = k_{cp}N_{cbg}$ (where N_{cb}, and N_{cbg} from tension calculations)
D.6.3.2 (D-29a)	Nominal concrete pryout strength in shear of a single adhesive anchor (lbs)	$V_{cp} = \min\mid k_{cp}N_a ; k_{cp}N_{cb} \mid$ (where N_{cb}, N_{cbg}, N_a and N_{ag} from tension calculations)
D.6.3.2 (D-30a)	Nominal concrete pryout strength in shear of an adhesive anchor group (lbs)	$V_{cpg} = \min\mid k_{cp}N_{ag} ; k_{cp}N_{cbg} \mid$ (where N_{cb}, N_{cbg}, N_a and N_{ag} from tension calculations)
D.6.3.1	Modification factor for pryout	$k_{cp} = 1.0$ for $h_{ef} < 2.5$ in. $k_{cp} = 2.0$ for $h_{ef} \geq 2.5$ in.
D.7	**Interaction of Tensile and Shear Forces**	
D.7.1	Full tension strength requirement	If $V_{ua} \leq 0.2\ \phi V_n$ then full tension strength is permitted: $\phi N_n \geq N_{ua}$
D.7.2	Full shear strength requirement	If $N_{ua} \leq 0.2\ \phi N_n$ then full tension strength is permitted: $\phi V_n \geq V_{ua}$
D.7.3	Combined loads	$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \leq 1.2$
D.8	**Required Edge Distance(s), Spacing(s) and Member Thicknesses to Preclude Splitting Failure**	
D.8	Post-installed anchors	Values for minimum edge distance(s), spacing(s) and concrete member thickness shall be taken from product report for approved post-installed anchors

Given:
Two 3/8" Power-Stud+ SD2 anchors
Concrete compressive strength:
(f'_c) = 4,000 psi
No supplemental reinforcement:
(Condition B per ACI 318-08 D.4.4 c)
Assume cracked concrete, no loading eccentricity and a rigid plate

h_a = 5.0 in.
h_{ef} = 2.0 in.
s_a = 4.5 in.
$c_{a1} = c_{a,min}$ = 6.0 in.
$c_{a2} \geq 1.5c_{a1}$

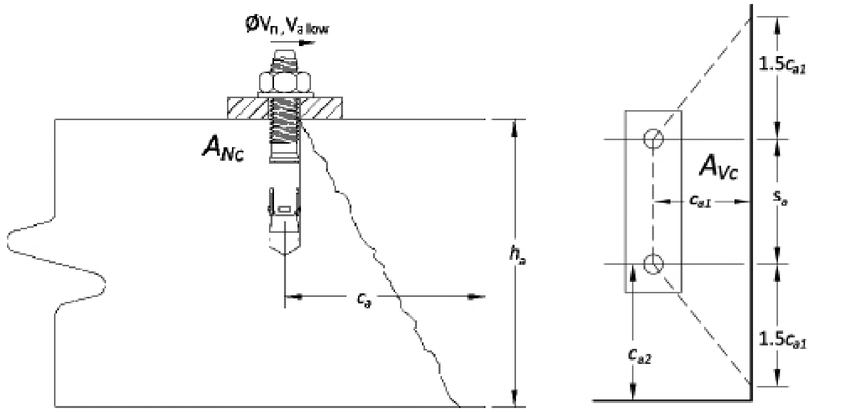


Calculate the factored resistance design strength in <u>tension</u> and equivalent allowable stress design load for the configuration.

Calculation in accordance with ACI 318-08 (ACI 318-05) and this report:	Code Ref.	Report Ref.
Step 1. Verify minimum member thickness, spacing and edge distance: h_a = 5.0 in. ≥ h_{min} = 4.0 in. ∴ OK s_a = 4.5 in. ≥ s_{min} = 3.5 in. ∴ OK $c_{a,min}$ = 6.0 in. ≥ c_{min} = 2.5 in. ∴ OK	D.8	Table 1
Step 2. Calculate steel strength of anchor group in tension: $N_{sag} = n \cdot N_{sa}$ = 2•6,625 lbs. = 13,250 lbs. Calculate steel capacity: ϕN_{sag} = 0.75 • 13,250 lbs. = **9,937 lbs.**	D.5.1.2	§4.1.1 Table 3
Step 3. Calculate concrete breakout strength of anchor group in tension: $N_{cbg} = \frac{A_{Nc}}{A_{Nc0}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$	D.5.2.1 (b)	§4.1.2
Step 3a. Calculate A_{Nco} and A_{Nc} $A_{Nco} = 9h_{ef}^2 = 9 \cdot (2.0)^2$ = **36.0 in.²** $A_{nc} = (3.0\ h_{ef}) \cdot (3.0\ h_{ef} + s_a)$ = (3.0 • 2.0)•((3.0 • 2.0) + 4.5) = **63.0 in.²** ∴ A_{Nc} = **63.0 in.²**	D.5.2.1 (b)	Table 1
Step 3b. Calculate $\psi_{ec,N} = \frac{1}{(1+\frac{2e'_N}{3h_{ef}})} \leq 1.0$; $e'_N = 0$ ∴ $\psi_{ec,N}$ = **1.0**	D.5.2.4	-
Step 3c. Calculate $\psi_{ed,N}$ = 1.0 if $c_{a,min} \geq 1.5h_{ef}$; $\psi_{ed,N} = 0.7 + 0.3\frac{c_{a,min}}{1.5h_{ef}}$ if $c_{a,min} < 1.5h_{ef}$ $c_{a,min}$ = 6.0 in. ≥ $1.5h_{ef}$ = 3.0 in. ∴ $\psi_{ed,N}$ = **1.0**	D.5.2.5	Table 1
Step 3d. Calculate $\psi_{c,N}$ = **1.0**	D.5.2.6	Table 3
Step 3e. Calculate $\psi_{cp,N}$ = **1.0** (cracked concrete)	D.5.2.7	-
Step 3f. Calculate $N_b = k_{cr} \lambda \sqrt{f'_c}\ h_{ef}^{1.5} = 17\ (1.0)\sqrt{4{,}000} \cdot 2.0^{1.5}$ = **3,041 lbs.**	D.5.2.2	Table 3
Step 3g. Calculate concrete breakout strength of anchor group in tension: N_{cbg} = (63.0/36.0) • 1.0 • 1.0 • 1.0 • 1.0 • 3,041 = 5,321 lbs. Calculate concrete breakout capacity = ϕN_{cbg} = 0.65 • 5,321 = **3,459 lbs.**	D.5.2.1 (b)	§4.1.2
Step 4. Calculate nominal pullout strength of a single anchor in tension: $N_{pn} = \psi_{c,P} \cdot N_{pn,f'c}$	D.5.3.1	§4.1.3 Table 3
Step 4a. Calculate $\psi_{c,P}$ = **1.0** (cracked concrete)	D.5.3.6	§4.1.9 Table 3
Step 4b. Calculate $N_{pn,f'c} = N_{p,cr}\left(\frac{f'c}{2500}\right)^{0.33} = 2{,}165\left(\frac{4000}{2500}\right)^{0.33}$ = 2,528 lbs. Calculate pullout capacity: ϕN_{pn} = 0.65 • 2,528 • 1.0 = **1,643 lbs.**	D.5.3.2	§4.1.3 Table 3
Step 5. Determine controlling resistance strength of the anchor group in tension: $\phi N_n = \min\lvert \phi N_{sag}, \phi N_{cbg}, n\phi N_{pn} \rvert = n\phi N_{pn}$ = **3,287 lbs.**	D.4.1.1 D.4.1.2	§4.1
Step 6. Calculate allowable stress design conversion factor for loading condition: Assume controlling load combination: 1.2*D* + 1.6*L* ; 50% Dead Load, 50% Live Load α = 1.2(50%) + 1.6(50%) = **1.40**	9.2	§4.2.1
Step 7. Calculate allowable stress design value: $T_{allowable,ASD} = \frac{\phi N_n}{\alpha} = \frac{3{,}287}{1.40}$ = **2,347 lbs.**	9.2	§4.2.1

Given:
Two 3/8" Power-Stud+ SD2 anchors
Concrete compressive strength:
(f'_c) = 4,000 psi
No supplemental reinforcement:
(Condition B per ACI 318-08 D.4.4 c)
Assume cracked concrete, no loading eccentricity and a rigid plate

h_a = 5.0 in.
h_{ef} = 2.0 in.
s_a = 4.5 in.
$c_{a1} = c_{a,min}$ = 6.0 in.
$c_{a2} \geq 1.5c_{a1}$



Calculate the factored resistance design strength in <u>shear</u> and equivalent allowable stress design load for the configuration.

Calculation in accordance with ACI 318-08 (ACI 318-05) and this report:	**Code Ref.**	**Report Ref.**
Step 1. Verify minimum member thickness, spacing and edge distance: h_a = 5.0 in. ≥ h_{min} = 4.0 in. ∴ OK s_a = 4.5 in. ≥ s_{min} = 3.5 in. ∴ OK $c_{a,min}$ = 6.0 in. ≥ c_{min} = 2.5 in. ∴ OK	D.8	Table 1
Step 2. Calculate steel strength of anchor group in shear: $V_{sag} = n \cdot V_{sa} = 2 \cdot 2{,}190$ lbs. = 4,380 lbs. Calculate steel capacity: ϕV_{sag} = 0.60 • 4,380 lbs. = **2,625 lbs.**	D.6.1.2	§4.1.4 Table 4
Step 3. Calculate concrete breakout strength of anchor group in shear: $V_{cbg} = \frac{A_{Vc}}{A_{Vc0}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b$	D.6.2.1 (b)	§4.1.5
Step 3a. Calculate A_{Vco} and A_{Vc} $A_{Vco} = 4.5\,(c_{a1})^2 = 4.5 \cdot (6.0)^2$ = **162.0 in.²** $A_{Vc} = (h_a) \cdot (3\,c_{a1} + s_a) = (5.0)((3 \cdot 6.0) + 4.5)$ = **112.5 in.²**	D.6.2.1	Table 1
Step 3b. Calculate $\psi_{ec,V} = \frac{1}{(1+\frac{2e'_N}{3c_{a1}})} \leq 1.0$; $e'_V = 0$ ∴ $\psi_{ec,V}$ = **1.0**	D.6.2.5	-
Step 3c. Calculate $\psi_{ed,V}$ = 1.0 if $c_{a2} \geq 1.5c_{a1}$; $\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$ if $c_{a2} < 1.5c_{a1}$ $c_{a2} \geq 1.5\,c_{a1}$ ∴ $\psi_{ed,V}$ = **1.0**	D.6.2.6	Table 1
Step 3d. Calculate $\psi_{c,V}$ = **1.0** (cracked concrete, no supplemental or edge reinforcement)	D.6.2.7	-
Step 3e. Calculate $\psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}}$; for members where $h_a < 1.5c_{a1}$ $h_a = 5.0 < 1.5c_{a1} = 9.0$ ∴ $\psi_{h,V} = \sqrt{\frac{9.0}{5.0}}$ = **1.34**	D.6.2.8 (*ACI 318-08 only*)	-
Step 3f. Calculate $V_b = \left(7\left(\frac{l_e}{d_a}\right)^{0.2}\sqrt{d_a}\right)\lambda\sqrt{f'_c}(c_{a1})^{1.5} = 7\left(\frac{2.0}{0.375}\right)^{0.2}\sqrt{0.375}\,(1.0)\sqrt{4000}(6.0)^{1.5}$ = **5,569 lbs.**	D.6.2.2	Table 4
Step 3g. Calculate concrete breakout strength of anchor group in shear: V_{cbg} = (112.5/162.0) • 1.0 • 1.0 • 1.0 • 1.34 • 5,569 = 5,182 lbs. Calculate concrete breakout capacity = ϕV_{cbg} = 0.70 • 5,182 = **3,627 lbs.**	D.6.2.1 (b)	§4.1.5
Step 4. Calculate nominal pryout strength of an anchor group in shear: $V_{cpg} = k_{cp} N_{cbg}$ = 1.0 • 5,321 lbs = 5,321 lbs. Calculate pryout capacity: ϕV_{cpg} = 0.70 • 5,321 lbs. = **3,724 lbs.**	D.6.3.1 (b)	§4.1.6 Table 4
Step 5. Determine controlling resistance strength in shear: $\phi V_n = \min\lvert \phi V_{sag}, \phi V_{cbg}, \phi V_{cpg} \rvert = \phi V_{sag}$ = **2,625 lbs.**	D.4.1.1 D.4.1.2	§4.1
Step 6. Calculate allowable stress design conversion factor for loading condition: Assume controlling load combination: 1.2*D* + 1.6*L* ; 50% Dead Load, 50% Live Load α = 1.2(30%) + 1.6(70%) = **1.40**	9.2	§4.2.1
Step 7. Calculate allowable stress design value: $V_{allowable,ASD} = \frac{\phi V_n}{\alpha} = \frac{2{,}625}{1.40}$ = **1,875 lbs.**	9.2	§4.2.1