Fasteners of Concrete Anchor – General Requirement

by Wei-Ming Wang

1 Introduction

Concrete is a material used extensively in structural applications across the world, creating a need to anchor other materials. Anchorage to concrete can be accomplished through a piece of steel, such as a threaded rod, bolt, or proprietary anchor, partially embedded in the base concrete and used to connect additional members. Fasteners of concrete anchor are used to connect structural and non-structural elements to the concrete. Fasteners of concrete anchor are solutions for fastening materials to concrete to solve concrete fastening problems. The connection is made by an assembling of different components such as: anchor bolts (also named fasteners), screw anchor, steel plates, and stiffeners (See ***Figure 1***). Concrete anchor bolts or screw anchors are for permanent and temporary applications usually – including screw anchors which can be used in solid brick and hollow-core slabs. Anchor bolts or screw anchors are fasteners that can attach one object to another in situations where screws, nails, adhesives or other simple fasteners are either impractical or ineffective. In other words, an anchor bolt or screw anchor is a used type of fastener that's designed to connect one or more objects to a masonry or concrete surface. With masonry or concrete being brittle, you can use anchor bolts or screws for applications to ensure the connected object or objects remain in place. Two common surfaces where anchor bolts or screw anchors are useful are :

(1) on extremely hard surfaces such as rock, masonry or concrete

(2) on hollow surfaces such as solid brick and hollow-core slabs walls and ceilings...especially where there is no convenient wood stud or beam behind the surface.

A connection between structural elements can be represented by steel column attached to reinforced concrete foundation. A common case of non-structural element attached to a structural one is represented by the connection between a facade system and a reinforced concrete wall. There are many styles of anchor bolts or screw anchors, each one having different strengths and weaknesses literally. An anchor bolt or screw anchor that is strong when installed in a drywall may not be as strong in concrete. Perhaps the biggest problem with anchors is almost all of them "feel" strong when first installed. Over time, though, an anchor that is mismatched to the wall material will eventually loosen up, causing damage to the wall, your hanging and whatever was underneath it!

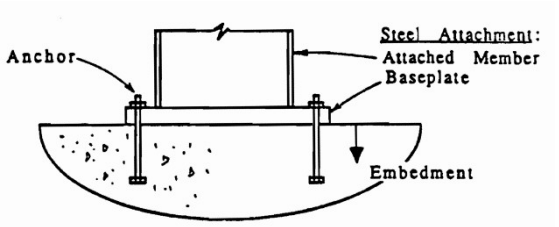


Figure 1 , A connection between structural and non-structural elements to the concrete (Source: https://en.wikipedia.org/wiki/Anchor_bolt)

Concrete anchor bolts or screw anchors transfer different types of load: tension forces and shear forces. How much load can an anchor bolt or screw anchor hold? It depends on (1) the type of object being loaded, (2) the type of surface the anchor bolt or screw anchor is installed on, (3) the condition of the surface... and, of course, (4) the type of anchor bolt or screw anchor.

2 Types of Concrete Anchor Fasteners

Fasteners in concrete can generally be divided according to the mechanism of transferring the force into the base material. These are friction, keying or bonding (See ***Figure 2***). The application of loading force on the anchoring system is limited by a maximum force which is determined by a failure mechanism, like e.g. concrete cone break out or steel failure. For the approval process, especially for safety relevant anchors special application conditions become of increasing interest. All anchors can be divided into two basic types. Anchorage of this type can be categorized as either cast in place or post installed. Advantages of cast in place anchors are their predictable and more reliable behavior and failure modes, but require a high level of accuracy in their placement to ensure proper alignment as they cannot be moved after the concrete hardens. Post installed anchors typically use proprietary methods to attach to hardened concrete. This allows for freedom in placement to ensure proper alignment, but can be subject to much more variability in performance and capacity of the anchor.

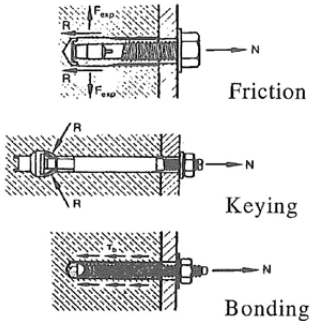


Figure 2 , Loading force working principles of anchoring systems (Source : page 22, July 2014, Anchor technology and design, Hilti)

2.1 Cast-in-place

The simplest – and strongest – form of anchor bolt is cast-in-place, with its embedded end consisting of a standard hexagonal head bolt and washer, 90-bend, or some sort of forged or welded flange. For all the type of the cast-in-place anchors, the load-transfer mechanism is the mechanical interlock, i.e. the embedded part of the anchors in concrete transfers and the applied load (axial or shear) via bearing pressure at the contact zone. At failure conditions, the level of bearing pressure can be higher than 10 times the concrete compressive strength, if a pure tension force is transferred.

The uses include anchoring machines to poured concrete floors and buildings to their concrete foundations. Various typically disposable aids, mainly of plastic, are produced to secure and align cast-in-place anchors prior to concrete placement. Moreover, their position must

also be coordinated with the reinforcement layout. The simplest anchor channels were used in precast concrete connections. The channel can be a hot-rolled or a cold-formed steel shape in which a T-shape screw is placed in order to transfer the load to the base material (See ***Figure 3***). It may be Headed Stud. It consists of a steel plate with headed studs welded on. If the anchor channel is threaded sleeves, it consists of a tube with an internal thread which is anchored back into the concrete. The last is used in concrete-steel composite structures as shear connectors.

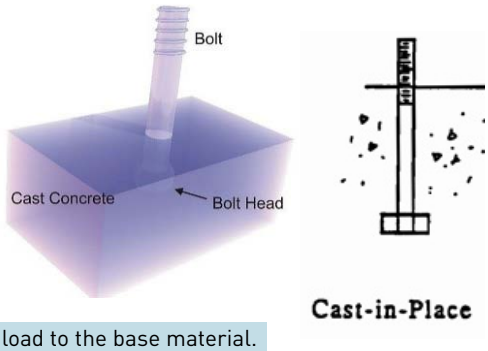


Figure 3 The bolt is used in precast concrete in order to transfer the load to the base material.

2.2 Post-installed

Once the concrete has been poured and set, you'll have to use post-installed anchors. (Once again, the name says it all.) This type of anchor is installed in a hole that is drilled in hardened and cured concrete. Post-installed anchors can be installed in any position of hardened concrete after a drilling operation. A distinction is made according to their principle of operation.

2.2.1 Expansion Anchors

Post-installed anchors are proprietary products manufactured by several companies. The force-transfer mechanism of mechanical expansion anchors (MEA) is based on friction mechanical interlock guaranteed by expansion forces. The work of friction shows in ***Figure 4***. When MEAs are inserted in pre-drilled holes, the anchors expand and bear against the concrete surface. They are inexpensive and easy to install, but they have relatively small tensile strength and are not recommended for use in tension zone where concrete is likely to crack.

There are many types of MEAs, with wedge anchors being the most common. Other types include sleeve anchors, strike anchors, and undercut anchors. It should be torque controlled or displacement controlled if mechanical expanded anchor is applied for objects to be anchored in masonry or concrete. The torque controlled anchor is inserted into the hole and secured by applying a specified torque to the bolt head or nut with a torque wrench. The displacement controlled expansion anchors usually consist of an expansion sleeve and a conical expansion plug, whereby the sleeve is internally threaded to accept a threaded element. As shown in the ***Figure 5***, tightening the bolt results in kinds of a mechanical expansion design feature being driven up against a sleeve, which expands it and causes it to compress against the material it is being fastened to. The advantages & disadvantages of mechanical expansion anchors is listed in ***Table 1***.

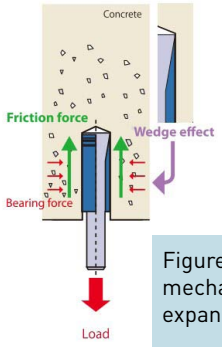


Figure 4 , The force-transfer mechanism of mechanical expansion anchors.

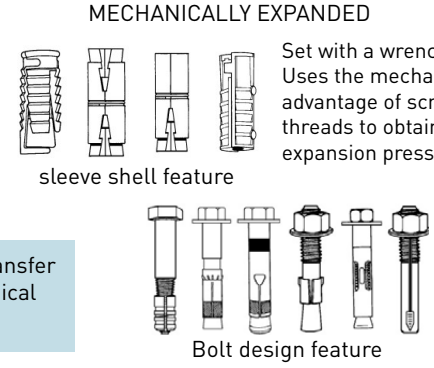


Figure 5 , Kinds of design features of mechanical expansion anchors

Figure 5 , Kinds of Design Features of Mechanical Expansion Anchors

MECHANICALLY EXPANDED (torque controlled anchor)	
Advantages	**Disadvantages**
• Can be loaded immediately. • Can be retightened. • Setting action can be felt. • Installation torque can be measured. • Stud and sleeve types are bolt size/hole size. • Shell types accept threaded rod. • Sleeve types work in hollow block when proper length is used. • Some are removable and reusable. • Available in wide range of applications	• Shell types require hole spotting. • Studs and sleeves slip under load. • Types made entirely of steel should not be used in high vibration. • Bolt size/hole size are not removable. • Limited fastening lengths with bolt size/hole size.
MANUALLY EXPANDED (displacement controlled expansion anchors)	
Advantages	**Disadvantages**
• Designed for shallow holes. • Shell types accept threaded rod. • Fast setting action.	• Cannot be retightened. • Difficult to tell if properly set. • Torque cannot be checked. • Should not be used in crumbling or old concrete.

2.2.2 Undercut Anchors

An undercut anchor is characterised by a strong mechanical interlock provided by the undercut in the concrete base material. A special drilling operation allows to create a contact surface between the anchor head and the hole's wall where bearing stresses are exchanged (See ***Figure 6***). The force-transfer mechanism is based on mechanical interlock. The mechanical interlock is formed by segments, which are made to open into the undercut shape either by turning the nut to draw the tapered cone into the segments or by driving the sleeves over the tapered cone. The undercut may be formed by a special drilling system or by the anchor itself. Undercut may be drilled before anchor installation or Undercut may be made during the setting of the anchor (self-undercut anchors).

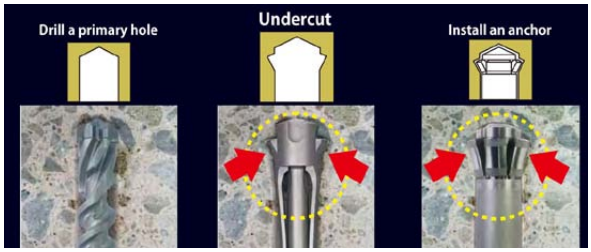


Figure 6 , A special drilling operation allows to create bearing stresses undercut shape

Undercut anchors are designed specifically for use in concrete although some may be used in dense stone. Common to all undercut anchors is the principle of establishing a positive mechanical interlock within the concrete. This is achieved by opening segments of the anchor shell over a tapered part of the shank and into an undercut shape formed in the concrete either by a separate drilling technique or by the anchor itself during installation.

This interlock ensures that, unlike some types of expansion anchors, the mode of failure is always by a concrete cone generated from the base of the anchor. This means the anchor is as strong as the concrete will allow and that the anchor will work even when set in a crack which opens after the anchor is installed. Undercut anchors' abilities to work in cracked or non-cracked concrete, together with good dynamic resistance and the variety of attachment configurations and finishes, make them one of the most versatile types of anchors.

2.2.3 Bonded Anchors

Bonded anchorage systems generally comprise of a steel anchor rod, either threaded or dowel (rebar), and a bonding material. Bonding materials are loosely defined as either adhesive or grouted depending on hole diameter. Bonded anchors are also referred as adhesive anchors or chemical anchors. The anchoring material is an adhesive (also called mortar) usually consisting of epoxy, polyester, or vinylester resins. The performance of this anchor's types in terms of 'load-bearing capacity', especially under tension loads. Bonded anchors, both adhesive and grouted, are generally installed the same way. A hole is drilled in base concrete using a rotary impact hammer or a diamond bit core drill. The hole is then cleaned with a brush, compressed air, and/or water jet. The bonding material then fills the hole and the anchor rod is inserted to the bottom of the hole. This process varies greatly by manufacturer. Adhesive anchors are generally installed with a caulking type gun or by a glass capsule that mixes the components in the hole, while cementitious anchors are mixed like concrete in the field or come ready to use from the manufacturer. The bonding material is then allowed to cure based a manufactures' recommendations, generally between 24 hours and 28 days, and load can then be applied. (See ***Figure 7***)

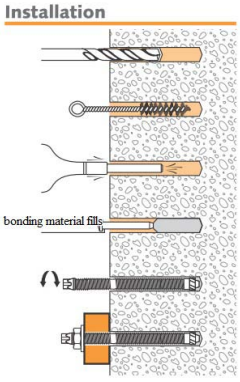
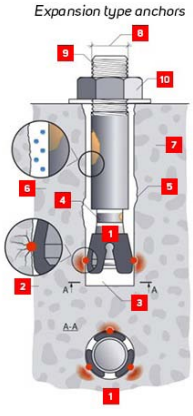
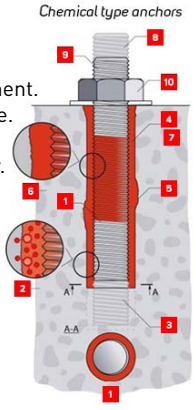


Figure 7 , Installation of bonded anchorage systems



1. Load is applied to the length of the embedment.
2. Stress is imparted directly into the substrate.
3. Setting depths are limited
4. Threaded rod material has a higher stability.
5. Not ideal for imperfect shaped holes
6. Prone to water ingress leading to corrosion.
7. Not suitable for softer base materials
8. Limited to stock sizes, length & diameter
9. High grades of steel can be specified.
10. Excessive torque destroys the fixing.



1. Load is concentrated at limited points
2. A molecular bond occurs, imparting no stress.
3. Unlimited setting depths can be specified.
4. Metal anchors can contain unseen weak points
5. Chemical injection can fill imperfect drilled holes.
6. Protects the fixing from corrosion.
7. Suitable for all substrates.
8. Large array of sizes available.
9. Limited to stock steel grades
10. Increased torque loads can be applied.

Figure 8 , The comparison of mechanical expansion anchor and bonded anchor.
(Source: https://www.allfasteners.com.au/news-articles/what-is-a-chemical-anchor)

The force-transfer mechanism is based on bond stresses provided by binding organic materials. Both ribbed bars and threaded rods can be used and a change of the local bond mechanism can be appreciated experimentally. In ribbed bars the resistance is prevalently due to shear behavior of concrete between the ribs whereas for threaded rods friction prevails.

The load-bearing capacity of bonded anchor is strictly related to the cleaning condition of the hole.

Experimental results showed that the reduction of the capacity is up to 60%. The same applies also for moisture condition of concrete, for wet concrete the reduction is of 20% using polyester resin. Other issues are represented by high temperature behavior and creep

response. Generally, grouted anchors can include either polymer or cementitious materials while bonded rely on polymer materials. Due to the larger diameter hole, grouted anchor systems can be installed with either headed or non-headed rod. The headed anchor rod changes the possible failure modes and can reach capacity at a lower embedment depth.

Chemical anchors —also known as chemical studs—can also be placed towards the edge of concrete substrates and through masonry block. The non-expanding nature of a chemically-held rod drastically reduces the chance of the surrounding concrete cracking. This is very good for securing railings on to shallower slabs, or concrete stairs, and similar applications. Finally, chemical anchoring gives you the opportunity to make slight adjustments to the stud's alignment while the chemical is curing, whereas a mechanical anchor needs a hole to be drilled millimetre-perfect every time, and if it isn't, it cannot be used. The comparison of mechanical expansion anchor and bonded anchor is shown in ***Figure 8***.

2.2.4 Screw Anchors

Screw Anchors are sometimes referred to as spiral anchors. Screw anchors impart little expansion stress on base concrete material with fast installation and high strength. Concrete screws installed into a pre-drilled cylindrical drill hole. The special thread of the anchor cuts an internal thread into the concrete member while setting (See ***Figure 9***). Concrete screws offer good design resistance and can be aesthetically pleasing. These are also easily removable which can be an advantage for temporary fixings.

Most guidelines of screw anchor products currently state the anchors may be used only once; this is because the threads can be worn out with reuse. Some products are now being provided with wear indicator 'go/no-go' gauges to identify the suitability of the screw for reuse.

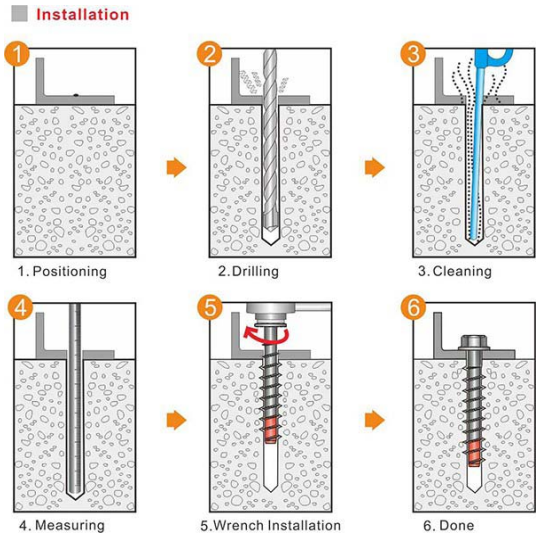


Figure 9 , Installation procedure of screw anchors with special thread (Source: SHEH KAI PRECISION CO., LTD. - https://www.shehkai.com)

Screw anchors care should be taken not to exceed the stated installation depth as trying to set them too deep will generate excessive installation torsion and can damage the screw. The force-transfer mechanism of the screw anchor is based on concentrated pressure exchange between the screw and concrete through the pitches. Because of the wear of cutting threaded teeth during drive installation, it is necessary to improve cutting teeth for better installation and reduced wear. The effective engagement of screw anchor shall be reduced if the wear of cutting threaded teeth during drive installation. Lowering wear and enhancing concrete thread shall be the solution to give more effective engagement. Corrosion shall be an issue for anchors to be applied for corrosion atmosphere. Stainless material shall have been introduced to the design of screw anchors and taken intended use into consideration. High quality customized screw anchor products shall have been developed successfully for high corrosion resistance performance with easily installation. It should be a bimetal material with alloy steel thread cutting tool performance and low wear hardened functional tip while is installing and stainless excellent anticorrosion characteristics itself after being installed (See ***Figure 10***).

Concrete screw anchors are gaining greater acceptance in building practice because they are reliable fastening elements with high capacities that can be easily installed. Because post-installed screw anchors are proprietary systems with unique mechanical and dimensional characteristics, it is necessary to evaluate their structural properties in accordance with a recognized standard. This is not unlike the qualification process currently used for post-installed expansion anchors, undercut anchors, and bonded anchors. Qualification criteria for anchors involve a test program with reference tests to determine baseline anchor performance in ideal conditions; reliability tests to determine performance of anchors in adverse conditions and over long-term use; Service condition tests to determine anchor performance in typical service loading conditions such as shear loading or anchors installed in corners; and identification tests to determine properties of the anchor for compliance with manufacturer's specifications. The qualification tests required for screw anchors were originally established in Europe and are found in ETAG 001 and later for the U.S. in ICC-ES AC193, "Acceptance Criteria for Mechanical Anchors in Concrete Elements." AC193 references ACI 355.2, "Qualification of Post-Installed Mechanical Anchors in Concrete," to describe the required test program but adds additional tests for concrete screw anchors to address some of the unique considerations for concrete screws such as hydrogen embrittlement testing and verification methods for the installation of screw anchors.

Drilling a hole is a common activity and is one that needs to be done correctly and safely for applying anchor concrete or masonry. A hole needs to be drilled in a concrete, brick or block wall to create a pathway for pipe or wiring. A hole needs to be drilled in order to install a concrete fastener or anchor. (This situation will not focus on anchor article itself.) It is important to use a proper drill tool or rotary drill in concrete applications. The use of wrong drilling tools or parameters to base material such as drill bit, speed setting, depth setting, may be critical for hole size and depth, especially for the concrete cracking unexpectedly. The load-bearing capacity of anchor area shall be reduced by unexpected concrete cracking. Drilling the right hole before drive anchor installation is the

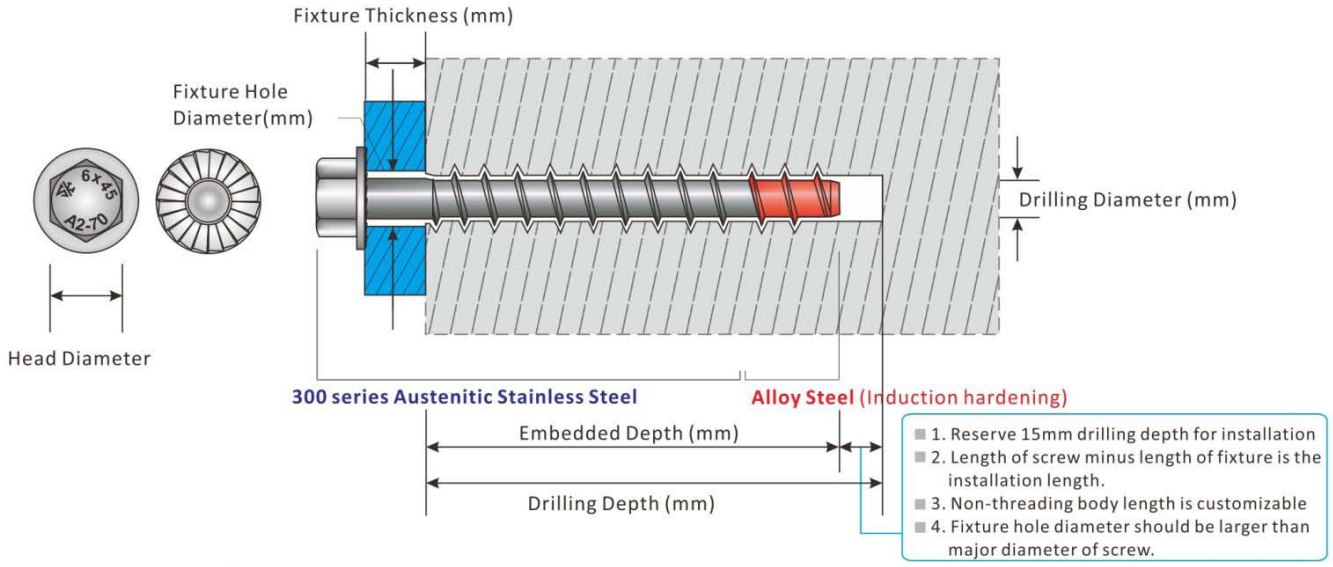


Figure 10 Customized high corrosion resistance performance screw anchor
(Source: SHEH KAI PRECISION CO., LTD. - https://www.shehkai.com)

key to give thread engagement to concrete for screw anchors. The tolerance of drilling hole size and depth should have been more seriously concerned than other anchors types of fasteners such as expansion anchors, bonded anchors. The drill bit size required, drill tools, and drilling working instruction shall be noticed clearly in technical specifications pages of the screw anchor manufacturers or designers properly.