DESIGN OF ANCHOR BOLTS FOR TENSION

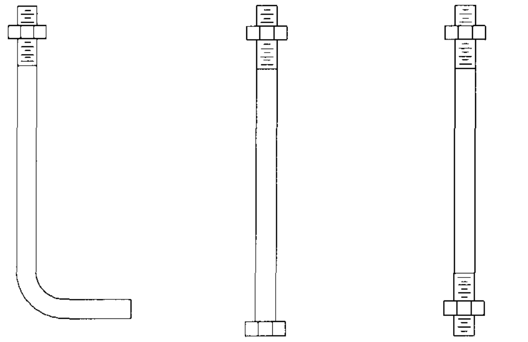
General Behavior

Anchor bolts are needed for all base plates. First they are used to safely anchor all plates to prevent column overturning during construction. They are also necessary when the plate is subject to large design moments or uplift.

There are two general types of anchor bolts, cast-in-place and drilled-in bolts. The drilled-in bolts are placed after the concrete sets. They are not normally used for base plates and their design is governed by the manufacturer's specifications, with additional information in the guide by Cannon, Godfrey and Moreadith (1981).

Different types of cast-in-place bolts are shown in Fig. 17. These are generally made from either bolts or bar stock, referred to as a rod. The commonly used hooked rod is made from a round shape and shown in Fig. 17 (a). The tensile load is resisted through bond developed along the length and by the hook. Smooth rods do not always form reliable bond however, due to oil, etc. Those with hooks may fail by straightening and pulling out of the concrete. A more positive anchorage is often preferred (Fisher 1981, Marsh and Burdette 1985a). Unless precautions are taken with hooked rods to assure proper anchorage, the hooked rod should be used only for axially loaded columns, where the development of any fixity at the base is not required, except during erection.

A more positive anchorage is formed when bolts or rods with threads and a nut are used, as shown in Fig. 17 (b) and (c). Marsh and Burdette have noted that the bolt head or a simple nut is all that is necessary. The anchorage is then developed by bearing on the head or nut. It is only necessary to provide for adequate embedment depth and edge distance. The failure mechanism is the pull-out of a cone of concrete radiating outward from the head of the bolt or nut. The use of a washer or plate only spreads out the cone and does not add significantly to the anchorage potential. In fact, the edge distance could be decreased by these, leading to earlier failure. Since headed bolts are not often available in lengths and diameters required for base plates, the designer should generally specify the rod with threaded ends and the provision of a nut for anchorage, as shown in Fig. 17 (c). The lower nut should be welded to the rod so that the rod does not turn out when the top nut is tightened.



(a) Hooked Bar (b) Bolt (c) Threaded Bar with Nut

Fig. 17. Anchor Bolts

Minimum Bolt Lengths and Edge Distances

Shipp and Haninger (1983) have presented minimum guidelines for bolt embedment and edge distance, adopted from ACI 349. These are presented for use in designing anchor bolts for tension as follows:

Bolt Type, Material	Minimum Embedded Length	Minimum Embedded Edge Distance
A307, A36	12 d	5 d > 4 in.
A325, A449	17 d	7 d > 4 in.

where d is the nominal diameter of the bolt or rod. The use of the above embedment lengths are conservative. The minimum edge distance is necessary to prevent blow-out. The failure associated with this involves the development of a conical failure surface between the anchor and the edge of the concrete, similar to the pull-out of a cone of concrete due to the direct tension. The minimum edge distance is an important consideration in determining pedestal sizes.

Design of Hooked Bolts

The design of hooked anchors should be based on the anchorage provided by the hook only. Fisher (1981) recommends that the hook be designed for bearing, with the tensile capacity T_h given by the following:

$$T_h = 0.7 f_c' \, d \, L_h$$

where d is the bolt diameter and L_h is the hook length. This is based on the ultimate capacity, and he recommends that a load factor of 1.7 be applied to this. For ASD, a factor of safety equal to 1.7 is then used, and thus the right side of the equation should be divided by 1.7. For LRFD, the equation for T_h should be used as it is. It is recommended that hooked anchors should only be used for axially loaded base plates where there is no specified design force. Since failure can occur by straightening and pulling out, it is recommended that the hook be designed to develop a minimum force equal to half the tensile capacity of the bolt. The erection procedure might require the need for an anchorage force greater than half the tensile capacity. Some bond is developed along the vertical part of the bolt, and this with the hook should prevent pull out of the bolt when the nuts are tightened. The hooked portion should be pointed diagonally inward toward the center of the foundation. It is necessary that the engineer use judgment to pick a suitable bolt diameter. The design of the hook should be based on the following procedure.

ASD Procedure:

1. Determine the allowable bolt tensile load T:

   $$T = A_g F_t$$

   where A_g is the gross area of the bolt and F_t is the allowable tensile stress, equal to 0.33 F_u

2. The required hook length to develop half of T is then:

   $$L_h = \frac{\left(\frac{T}{2}\right)}{\left(\frac{0.70 f_c' d}{1.7}\right)}$$

   where d is the diameter of the bolt. This is based on developing half the bolt tensile capacity.

3. The total length of the bolt should be equal to the hook length plus the length taken from the previous table.

Example 19 (ASD Procedure): Determine the hook length for a ¾ in. diameter anchor bolt made from A36 stock with a minimum tensile strength F_u = 58 ksi. f_c' is 3 ksi.

1. $T = \left(\frac{3.14 \times (0.75)^2}{4}\right) \times 0.33 \times 58 = 8.46$ kips

2. $L_h = \frac{\left(\frac{8.46}{2}\right)}{\left[\frac{(0.7 \times 3 \times 0.75)}{1.7}\right]} = 4.6$ in.

3. The total bolt length should be 4.6 plus the minimum embedment length, equal to 12 x 0.75 = 8 in. 13 in. is thus acceptable. The bolt should not be closer than 5 x 0.75 = 3.75, but a minimum of 4 in., from the edge of the concrete.

LRFD Procedure:

1. Determine the bolt tensile capacity T_u:

   $$T_u = .75\, \varphi_t F_u A_g$$

   where φ_t is the tensile resistance factor, equal to 0.75, F_u is the specified minimum tensile strength, and A_g is the gross area of the bolt.

2. The required hook length to develop half T_u is then:

   $$L_h = \frac{\left(\frac{T_u}{2}\right)}{0.7 f_c' d}$$

3. The total length of the bar should be equal to the hook length plus the length taken from the previous table.

Example 20 (LRFD Procedure): Determine the hook length for a ¾ in. diameter anchor bolt made from A36 bar stock with F_u = 58 ksi. f_c' = 3 ksi

1. $T_u = 0.75 \times 0.75 \times 58 \left[\frac{(3.14 \times (0.75)^2}{4}\right] = 14.4$ kips

2. $L_h = \frac{\left(\frac{14.4}{2}\right)}{(0.70 \times 3 \times 0.75)} = 4.6$ in

3. The total bolt length should be 4.6 plus the minimum embedment length, equal to 12 x 0.75 = 8 in., 13 in. is thus acceptable. The bar should not be closer than 5 x 0.75 = 3.75, but a minimum of 4 in., from the edge of the concrete.