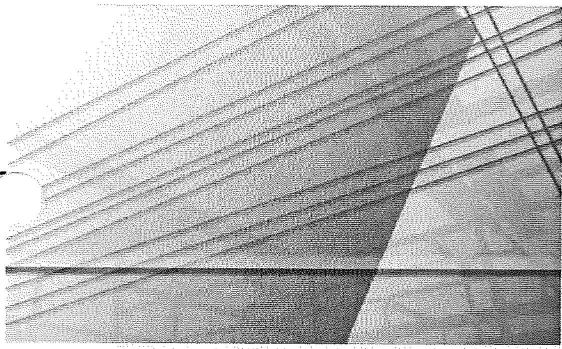


from experience

Alternatives to ACI 318-02

Appendix D - "Anchoring to Concrete"

By Colleen Bush, P.E. and Ed Schwieter, P.E.

ACI 318-02 Appendix D "Anchoring to Concrete" provides strength design equations for cast-in-place and post-installed anchors. Our interpretation of the code is that it is based on unreinforced, cracked concrete and non-ductile failure under seismic loads. Section 1913 of the International Building Code (IBC) 2000 is based on a preliminary version of ACI 318-02 Appendix D, and is not as conservative as the final version of Appendix D. Section 1913 of the IBC 2003 references Appendix D of ACI 318-02 and is therefore more conservative than IBC 2000. The ACI and IBC codes provide seven possible failure modes of the anchor or concrete that typically result in footing, pedestal, and anchor rod sizes larger than designs based on previously accepted engineering principles. The nominal tensile and shear strengths as calculated by the IBC and ACI equations are small compared to traditional design methods.

One previously accepted method of anchor rod design is from chapter 6 of the PCI Design Handbook, Fourth Edition. *Tables 1 & 2* demonstrate the differences between the PCI and ACI Appendix D methods.

Method	Edge Distance (in)	Height of Pedestal (in)	Pedestal Size	Result (% overstressed)
PCI	5	24	1'-6" x 1'-6"	OK
ACI	5	24	1'-6" x 1'-6"	No Good (234%)
ACI	11	24	2'-6" x 2'-6"	OK

Table 1: (4) 3/4" diameter A307 anchor rods with 9" embedment spaced at 8" on center each way
Shear = 7 kips, Tension = 2 kips (total unfactored force on bolt group)
#3 ties at 12" on center
Compressive Strength of Concrete = 4000 psi
Seismic Design Category B

Method	Edge Distance (in)	Footing Thickness (in)	Footing Size	Result (% overstressed)
PCI	20	12	4'-0" x 4'-0"	OK
ACI	20	12	4'-0" x 4'-0"	No Good (11%)
ACI	28	12	5'-4" x 5'-4"	OK
ACI	20	14	4'-0" x 4'-0"	OK

Table 2: (4) 3/4" diameter A307 anchor rods with 9" embedment spaced at 8" on center each way
Shear = 7 kips, Tension = 2 kips (total unfactored force on bolt group)
Compressive Strength of Concrete = 3000 psi
Seismic Design Category B

Since the provisions of Appendix D result in foundation sizes that are significantly larger than traditional solutions, we use an alternate method to transfer shear and/or tension loads from the anchor rods to the reinforced concrete. In a pedestal situation, the anchor rods are lapped with the pedestal vertical bars to transfer the load to the pedestal and in a spread footing, the reinforcing bars resist the shear and tension loads rather than the unreinforced concrete. The anchor rods must have a nut or a plate and a nut at the bottom to provide positive concrete bearing. Using reinforced concrete design instead of the unreinforced design provisions of Appendix D results in practical base plate sizes, anchor rod sizes, and pedestal sizes.

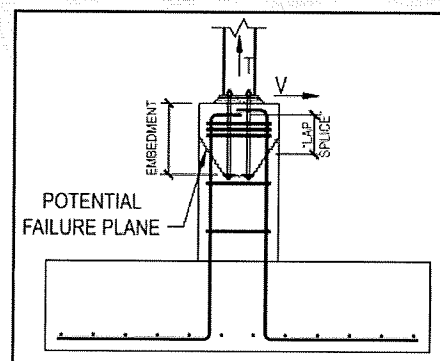
> *"...anchor rods are lapped with the vertical bars in the pedestal..."*

Pedestals

Anchor rods in pedestals can be designed based on reinforced concrete theory to reduce the edge distance and allow the use of customary pedestal sizes. The embedment of the anchor rods into the concrete is sufficient to develop the pedestal reinforcement and transfer the load from the anchor rods to the pedestal vertical bars. The tension splice length of the vertical bars is calculated per ACI 318. The top of the vertical bars can be hooked to reduce the required splice length. The minimum embedment of the anchor rod is the sum of the splice length, the top clear cover, and the offset distance between the anchor rod and the vertical bars. The shear friction of the anchor rods determines the shear capacity of the interface of the base plate and pedestal.

Spread Footings

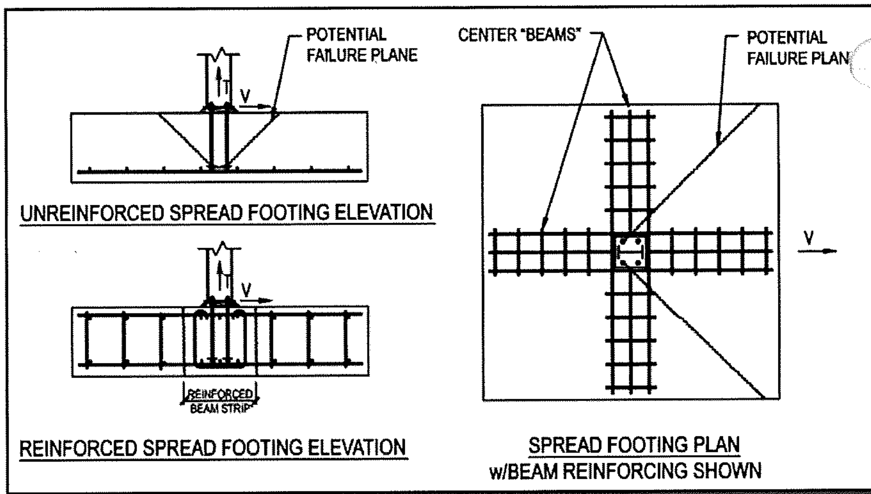
The anchor rods in a spread footing can also be designed using reinforced concrete theory to avoid a large number of anchor rods and large footings. A spread footing with large applied shear and tension loads and limited plan dimensions can be designed with one or two center "beams" within the footing. The remaining portion of the footing is cantilevered from the center "beams". The anchor rod embedment into the footing is designed to develop bearing of the bottom plate of the anchor rod on the bottom of the "beams". For anchor rods that undergo tension, the top of the "beams" are in tension and designed as reinforced concrete, and the bottom of the "beams" are in compression. The top and bottom bars of the "beams" also resist the horizontal shear of the anchor rods by having adequate development length on each side of the potential shear failure planes to transfer the shear of the anchor rods into the footing. Since the "beams" are designed as reinforced concrete sections under the tension loads, top bars and possibly shear stirrups may be required depending on the loads.



PEDESTAL ELEVATION

If the shear and/or tension forces on the anchor rods are small or the footing is large, the Appendix D provisions can easily be met. With moderate to large shear and/or tension forces on the anchor rods or base plates near edges, the provisions of Appendix

D are difficult to meet. From our experience, it is more practical to use more reinforcement than to increase the size and number of anchor rods and footings sizes. We feel that the Appendix D design provisions are conservative because they are based on unreinforced, cracked concrete and the lack of ductile failure in unreinforced concrete under seismic loads. Reasonable foundation details can be achieved by using an alternate reinforced concrete design method and some additional reinforcing and attention to detail to avoid the provisions of Appendix D.▪



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Questions and Comments…

Are the ACI 318-02 Appendix D equations based on actual failures or on research? Did observed failures lead to the research?

Are the equations based on unreinforced, cracked concrete and the non-ductile failure of the anchor rod connection under seismic loads?

Why is the nominal steel strength of the anchor rods calculated by Appendix D smaller than the AISC values?

How are the Appendix D requirements different from the check for punching shear through an unreinforced slab or footing using $V_c = 4\sqrt{f'_c}\, b_o d$?

Four ¾" diameter anchor rods into the top of a pedestal may not meet the code requirements, but four #6 vertical bars from the pedestal into the footing meet the code requirements. How are the anchor rod design requirements of Appendix D different from the design requirements of the vertical bars from a pedestal to the footing? Why are anchor rods treated differently than vertical bars in concrete? Why are the ACI requirements for connecting steel to concrete different from the requirements for connecting concrete to concrete?

Does Appendix D allow for alternate anchor rod design methods? Where is that referenced?

Another possible option to avoid the anchor rod requirements of Appendix D is to replace the anchor rods with rebar. The rebar would have threads at the top and a hook at the bottom and be designed per ACI 318 rebar development requirements.

In a pedestal, increased anchor rod embedment does not increase the strength. In addition, increased anchor rod sizes do not necessarily result in increased strength since the strength of the anchor rod does not govern with small edge distances. Typically, the size of the pedestal must be increased to provide larger edge distance. This can result in unreasonable pedestal sizes.

In a heavily loaded spread footing, there are limits to the benefits of increasing the embedment length and the edge distance. Typically, in those instances the steel strength controls.▪