Technology

information and updates on the impact of technology on structural engineering

Using Software to Control Anchor Design

By Marshall P. Carman, P.E., S.E.

Concrete Capacity Design (CCD) has been a code methodology for anchor design since it was introduced directly into section 1913 of the 2000 *International Building Code* (IBC). It was initially a strength design option and was limited to cast-in-place anchors only. The CCD method provided better predictions of concrete breakout strengths than the previously common 45-degree cone method. The new provisions also clearly identified specific limit states, which may not have been apparent in older design tables. The scope of the provisions expanded when they appeared in Appendix D of ACI 318-02, which standardized the analysis methodology for post-installed anchors.

Improved accuracy came at a cost. One of the advantages of the CCD method was that it used a simpler rectangular area, rather than overlapping circular cone areas. Unfortunately, over the past decade, a few paragraphs of text and an allowable stress design table have turned into the 48 pages of provisions and commentary that now reside in Appendix D of ACI 318-11.

Fortunately, there are several software applications that can assist with the heavy lifting of anchor design. However, each application has its own default set of assumptions, features, and limitations. It is incumbent upon the designer to be aware of these and work within the capabilities of each software application. Different applications can provide significantly different results for what may appear to be the same input parameters.

Seven different software applications are discussed below (see table), and are broken into the following three categories.

1) Proprietary Anchor Manufacturer Software
   a. Hilti PROFIS Anchor (Version 2.3.3)
   b. Powers Design Assist® (Version 2.1.4762.17678)
   c. Simpson Strong-Tie® Anchor Selector™ (Version 4.11.0.0)
2) Third-Party Anchor Software
   a. Quick Anchor by SK Ghosh Associates (Version 2.0.4)
   b. DS Anchor by Dimensional Solutions (Version 5.0.0)
3) Integrated Base Plate Design Software
   a. RISABase by RISA Technologies (Version 2.1)
   b. RAM Connection V8i Standalone by Bentley® Systems (Version 8.0)

Each vendor filled out a survey describing the assumptions and analysis methodology that its software used for various limit states, and identified its software's features. In addition to the survey, example problems were run comparing the results with the survey responses (see sidebar, *Example Problems, page 21*). All of the applications typically provided the same results for anchor groups subjected to concentrically applied tension, but results varied for anchor groups subjected to a bending moment or to shear.

Shear in Anchor Rod for Base Plates with Grout Pad or Stand-Off

If anchors rods are used to resist shear forces from a base plate, they may also be subject to flexure. Because of this, shear lugs, embedded columns, or other alternatives are likely better options for transferring shear unless the loads are small. Where shear is transferred through the anchor rods in lightly loaded connections, oversized holes to accommodate erection tolerances prevent predictable shear transfer through the anchors. In this case, shear can be transferred to the anchor rods via plate washers welded to the top of the base plate. This will result in a moment arm at least as long as the base plate thickness. Furthermore, some flexure could be induced into the anchor rods for any base plates with a stand-off condition, with or without grout.

ACI 318 Appendix D does not explicitly contain provisions for considering flexural forces in anchor rods. Any reduction in capacity due to stand-off is limited to the provisions in section D.6.1.3, which require that the shear capacity of the anchor rods be multiplied by 0.8 when used with a built-up grout pad.

Other publications, which are not referenced by the IBC, have a more thorough treatment of this condition. AISC Steel Design Guide 1, *Base Plate and Anchor Rod Design*, Second Edition, provides a design example in section 4.11 considering flexure in anchor rods for base plates with oversized holes. Section 4.2.2.4 of Annex C of ETAG 001, *Guideline for European Technical Approval of Metal Anchors for Use in Concrete*, provides more detailed requirements for considering flexure in anchor rods for base plates with grout or a clear stand-off.

None of the software applications currently use the AISC methodology. Most of them only consider the 0.8 reduction factor as required by ACI 318 Appendix D. Hilti PROFIS Anchor and Powers Design Assist consider the ETAG methodology by default. This results in a significant difference in anchor shear capacities between software applications, especially where small-diameter anchors or thick grout pads are used. In Example Problem #1, the capacity differed by a factor greater than five between applications that considered flexure and those that did not. The detailed output in both Hilti PROFIS Anchor and Powers Design Assist provides a capacity that does not consider flexure due to the stand-off or

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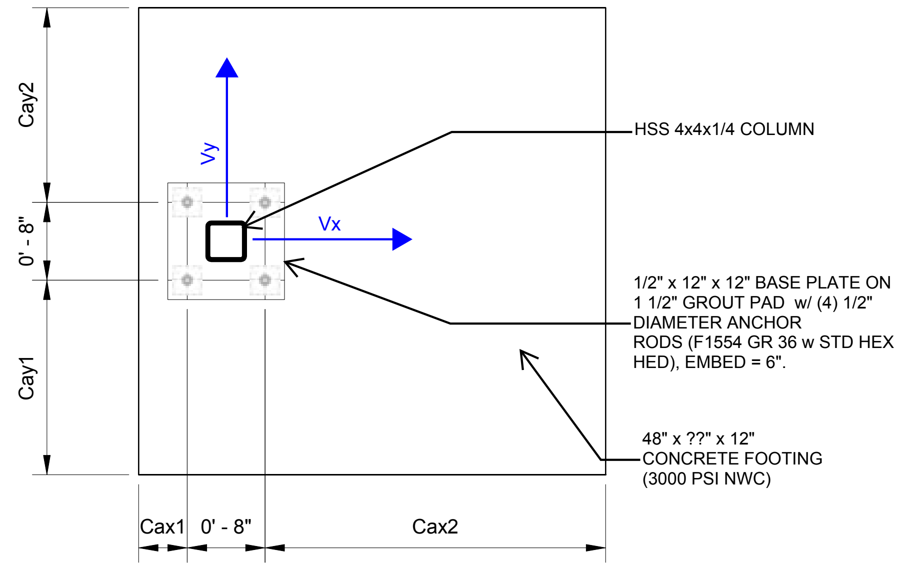

grout pad, but that value is not included in the final interaction equations or the typical results shown on the screen.

Concrete Breakout in Shear for Loads Perpendicular to an Edge

Commentary section RD.6.2.1 of ACI 318-11 describes three potential cases for evaluating concrete breakout perpendicular to an edge for a group of anchors with multiple rows. Case 1 assumes that the critical breakout is based upon the front anchors and their projected area, and evaluates it against the shear load proportional to that row. Case 2 permits the breakout area to be based upon the rear anchors, but evaluates the capacity against the total shear on the anchor group. Case 3 assumes that the breakout area is based upon the front anchors and evaluates the capacity against the total shear on the anchor group. Case 3 could conservatively be applied to all situations, but is only referenced for specific anchor spacing and edge distance conditions.

Since this information is in the commentary, it is not actually part of the code itself. It is therefore the responsibility of the designer to determine the appropriate breakout behavior for each situation. However, the default breakout area varies between programs. For example, Hilti PROFIS Anchor and Powers Design Assist always use Case 3, which will provide a significantly lower capacity than applications using Case 1 or Case 2. In *Example Problem 2*, the difference between these two assumptions was a factor of two.

The designer has control over the breakout areas in some of the software applications. Simpson Strong-Tie Anchor Selector allows the designer to select a check box to "Apply entire shear load at front row for breakout" in order to force the use of Case 3. The stated rationale for this is that, due to the potential annular space between the rod and the baseplate, it is possible that the baseplate will engage only the front row of anchors and transfer the entire shear load to it prior to making contact with the rear row. Both Hilti PROFIS Anchor and Powers Design Assist allow the designer to select from anchor group templates that have slotted holes to prevent the application of shear to specific anchors. DS Anchor allows the designer to select which specific anchors take shear or tension.

Concrete Breakout in Shear for Loads Parallel to an Edge

Per section 6.2.1.c of ACI 318 Appendix D, the breakout capacity for a shear load parallel to an edge is equal to two times the capacity of a fictitious load perpendicular to the edge. While the commentary provides potential breakout cases for loads perpendicular to an edge, there is no corresponding commentary regarding concrete breakout in shear for loads parallel to an edge.

Powers Design Assist and Hilti PROFIS Anchor both use the anchor row nearest to the edge to determine the breakout area. Hilti PROFIS Anchor compares this capacity to the shear demand on the entire anchor group, which is consistent with how the software considers shear perpendicular to an edge (Case 3). By contrast, Powers Design Assist treats shear parallel to an edge differently than it treats shear perpendicular to an edge, comparing the breakout capacity to the proportional shear demand on the anchor row nearest to the edge (Case 1).

Where anchors are located near a narrow section of a slab or wall, the provisions of section D.6.2.4 of ACI 318 may result in a significant reduction in the allowable breakout area in the perpendicular direction, such that the parallel breakout case no long controls. Software applications that allow the user to enter an infinite edge distance will apply this provision differently than applications that consider a large but finite edge distance. In *Example Problem #1a*, concrete breakout shear capacities differed by a factor greater than three.

Consideration of Base Plate and Distribution of Axial Forces to Anchors

When an anchor group is subject to an eccentric tension load or applied moment, how the software models or considers the base plate will affect the resulting tension force in the anchors.

DS Anchor and Quick Anchor do not consider a base plate at all. In DS Anchor, if a moment is applied to an anchor group, the software will distribute tension and compression loads to the anchors based upon the section modulus of the bolt group. In Quick Anchor, the anchor bolts are not assumed to take any compression, so the designer has to model only the anchors subject to tension and determine the resultant tension force on the anchor group outside of the software. Generally, the force distribution assumed by DS Anchor will be conservative, but if the designer is concerned that the difference between the base plate bearing method and the anchor rod section modulus method is significant, then the approach required by Quick Anchor could be applied to a DS Anchor model as well.

The other software applications consider base plate bearing to resist compression and distribute tension to the anchors accordingly. However, their results differ slightly, depending on how they model the base plate. Most of the applications treat the base plate as rigid, but RISABase considers the stiffness of the base plate, so changing the thickness will result in a different load distribution. This analysis methodology will identify the effects of prying action for thin base plates subject to uplift, which can result in a higher tension demand.

RAM Connection allows the user to choose whether to consider strain compatibility, and whether compressive bearing stress is distributed in a rectangular or triangular pattern. Each of these choices can affect the tension force indicated for the anchors.

Custom Anchor Layouts

Most of the applications are limited to rectangular or preselected anchor layouts. Hilti PROFIS Anchor, DS Anchor, and RAM Connection permit custom anchor layouts. This can be helpful when analyzing circular patterns, or asymmetric patterns subject to a moment or eccentric load. However, analyzing a custom anchor bolt pattern may provide unexpected results for shear breakout limit states.

The concrete breakout cases described in commentary section RD.6.2.1 of ACI 318 are set up for rows or columns of anchors orthogonal to the concrete edge. Anchors that

Anchor Design Software Comparison.

		Proprietary Anchor Manufacturer Software			Third-Party Anchor Software		Integrated Base Plate Design Software	
		Hilti PROFIS Anchor	Powers Design Assist	Simpson Strong-Tie Anchor Selector	Dimensional Solutions DS Anchor	S.K. Ghosh Associates Inc. Quick Anchor	RAM Connection	RISABase
CIP Anchor Type	Headed “Bolt”	X	X	X	X	X	X	X
	L or J “Bolt”		X	X	X	X	X	
	Welded Headed Studs	X			X	X	w	
Grout Bed	Flexure in Rod	ETAG 001 Annex C	ETAG 001 Annex C	ACI 318 D6.3.1	ACI 318 D6.3.1	ACI 318 D6.3.1	ACI 318 D6.3.1	ACI 318 D6.3.1
Governing Code	ACI 318-02		X					
	ACI 318-05		X	X	X	X		X
	ACI 318-08	X	X	X	X	X	X	X
	ACI 318-11	X*			X	X		X
Post-Installed Anchor Type	Adhesive	Hilti	Powers + Custom	X	Custom Database	Custom	N/A	N/A
	Undercut	Hilti	Powers + Custom	X	Custom Database	Custom	N/A	N/A
	Expansion	Hilti	Powers + Custom	X	Custom Database	Custom	N/A	N/A
	Concrete Screw	Hilti	Powers + Custom	X	Custom Database	Custom	N/A	N/A
Anchor Patterns	Rectangular/Predefined	X	X	X	X	X	X	X
	Custom/Asymmetric	X			X		X	**
Breakout Edge Distance	Perpendicular – Rigid	Case 2	N/A	N/A	Case 2	Case 2	Cases 1&2	Case 2
	Parallel – Rigid	Case 2	N/A	N/A	Case 2	Case 1	Cases 1&2	Case 2
	Perpendicular	Case 3	Case 3	Cases 1&2 or 3	Cases 1&2	Cases 1&2	Cases 1&2	Cases 1&2
	Parallel	Case 3	Case 1	Case 1	Cases 1&2	Case 1	Cases 1&2	Cases 1&2
Pullout Bearing Area	Standard Hex Nut	X	X		X	X	X	X
	Heavy Hex Nut	X	X	X		X	X	X
	Square Nut	X				X	X	X
	Heavy Square Nut	X					X	
	Custom Input / Plate Washer			PAB Anchors	X	X		
Miscellaneous Features	Lightweight Concrete	ACI 318-11 Only	X***	X	Custom/ User Input	X	N/A	X
	Multiple Load Combinations				X		X	X

** Post-installed mechanical anchors only*
*** Does not evaluate anchor groups with asymmetric layout*
**** Sand-lightweight concrete only*

are not perfectly equidistant from an edge are considered different rows.

Anchor software that assumes Case 3 for breakout behavior, such as Hilti PROFIS Anchor, provides the unexpected result of significantly *decreasing* the shear breakout capacity of an anchor group when a single anchor is moved *away* from the row nearest the edge. With one less anchor in this row, the breakout area of the row nearest to the edge is reduced, but the software still assumes the full shear on the anchor group is resisted by this row, so the demand/capacity ratio increases.

Anchor software that assumes Case 1 or Case 2 behavior, such as RAM Connection, provides the opposite but equally unexpected result. If a single anchor is moved slightly *towards* the edge, the group breakout capacity may actually *increase*. Similar to the above example, the breakout area of the front row is still reduced, but the shear demand on this anchor may be reduced even more. The software is no longer subtracting the overlapping breakout areas of individual anchors, because they are not technically located in the same row.

Analysis of Third-Party or Generic Anchors

An engineer may design for a specific post-installed anchor, but a contractor may submit a request for substitution to use an alternate product. If the designer uses software from a different vendor to analyze the substitute anchor, it may be difficult to determine if the results are different because the anchors are different, or simply because the software's assumptions are different.

Powers Design Assist and Quick Anchor both allow the designer to enter parameters for a generic or third-party post-installed anchor. While this requires manually entering anchor properties each time, it allows for comparison between anchor products while keeping all other modeling assumptions the same. DS Anchor allows the user to create a database of post installed anchors, which can be referenced from any subsequent model. The engineer is responsible for maintaining the third-party anchor data and ensuring that it is being applied appropriately, in accordance with the corresponding Evaluation Report.

Other Features

The applications have several other different features and limitations. Some can handle multiple load combinations, while others are limited to a single load case. Some do not include reduction factors for lightweight concrete, while others do. Some incorporate baseplate design, include headed studs for embed plate design, or permit custom bearing areas for cast-in-place anchors with plate washers. If an application is missing a feature, some hand calculations in the margins can usually fill in the missing information. In addition, the software vendors are constantly updating and improving their software. What may seem like a missing feature in one application today may be added in the near future.

In conclusion, it is very important to be aware of the assumptions that are being made by the software, be familiar with the output, and recognize that when switching between applications, results may vary – even though both may very well be *correct*.▪

Example Problems

Code:	ACI 318-08
Concrete Strength:	3,000 psi, Normal Weight
Cracked Concrete:	Yes
Concrete Thickness:	12 inches
Grout Pad:	1½ inches
Anchor Type:	½-inch Dia ASTM F 1554 Gr 36 (Std Hex Head), Embed = 6 inches
Anchor Spacing:	8 inches in square pattern, unless noted otherwise
Anchors Welded:	No
Ductility:	Assumed No Ductility in Connection
Supplemental Reinf:	No
Anchor Reinf:	No
Edge Reinf:	No
Baseplate:	½ inch x 12 inches x 1 foot 0 inches
Column Profile:	HSS 4x4x¼

Example Problem 1: Shear Parallel to Edge with Grout Pad/Small Edge Distance

Edge Distance:	Cax1 = 5 inches, Cax2 = 35 inches, Cay1 = 20 inches, Cay2 = 20 inches
Applied Load:	Vy = 3,000 pounds, T = 3,000 pounds, All Seismic Load (SDC C+)

Example Problem 1a: Shear Parallel to Edge with Grout Pad/Large Edge Distance

Edge Distance:	Cax1 = 5 inches, Cax2 = 35 inches, Cay1 = 300 inches (or infinite), Cay2 = 300 inches (or infinite)
Applied Load:	Vy = 3,000 pounds, T = 3,000 pounds, All Seismic Load (SDC C+)

Example Problem 2: Shear Perpendicular to Edge with Grout Pad/Symmetric

Edge Distance:	Cax1 = 5 inches, Cax2 = 35 inches Cay1 = 20inches, Cay2 = 20 inches, C
Applied Load:	Vx = -1,500 pounds, T = 3,000 pounds, All Seismic Load (SDC C+)

Example Problem 3: Shear Perpendicular to Edge with Grout Pad/Asymmetric

Anchor Spacing:	1 anchor moved ¼ inch out of near row
Edge Distance:	Cax1 = 5 inches, Cax2 = 35 inches Cay1 = 20 inches, Cay2 = 20 inches, C
Applied Load:	Vx = -1,500 pounds, T = 3,000 pounds, All Seismic Load (SDC C+)