Tips for Designing Constructible Concrete Structures

Part 1

By Clifford W. Schwinger, P.E.

The economy of cast-in-place concrete structures depends in large part on decisions made early in design regarding framing dimensions, repetition and simplicity of formwork. Once design is underway, attention to the ease of reinforcing steel placement contributes further to the economy of design. The term “constructability” with respect to cast-in-place concrete construction refers primarily to the ease with which formwork can be constructed and reinforcing steel placed. The next several QA Corner articles will discuss cast-in-place concrete constructability tips.

This month’s article focuses on a fundamental theme – making sure the reinforcing steel fits. As simple as it sounds, this issue is often overlooked. What follows is a list of suggestions related to placement of reinforcing steel.

Envision placing the reinforcing steel when designing the structure: Engineers should imagine themselves in the field trying to place the reinforcing steel in the structures that they design. Visualizing the construction process will aid in catching constructability flaws.

Draw reinforcing steel details to scale to verify that the bars will fit: Look for areas where reinforcing steel congestion may be a problem. Areas where congestion problems often occur include,

- Slab/column connections
- Narrow beams
- Columns with more than 2% vertical reinforcing steel
- Areas of slabs perforated with multiple openings, particularly near columns and slab edges
- Slabs in which electrical cable and conduit are installed
- Areas of slabs where embedded items such as those required to support facade supports

Designers need to consider actual dimensions of reinforcing bars, including hook dimensions and bend radiuses. *Figure 1* illustrates an example of wishful thinking by an engineer attempting to fit too much reinforcing steel in too little space.

Consider conflicts where multiple typical details occur at a single location: Engineers often use typical details to show frequently occurring conditions. Constructability issues can occur when multiple typical details occur at a single location.

Look for congestion when there are more than two layers of top or bottom bars in thin slabs: Two-way slabs usually have two layers of top bars and two layers of bottom bars spanning in orthogonal directions. Occasionally there can be a third layer of top or bottom bars, such as in a two-way slab where a non-typical diagonally spanning bay frames to an orthogonal bay. A third layer of top bars can be especially problematic, particularly at slab edges where those bars are hooked.

Consider hook dimensions when selecting reinforcing: Top bars with hooks are easiest to install when the hooks can be oriented straight down as shown in *Figure 2*. This can be more readily achieved by using the smallest bars practical and, when the bars are #5 or smaller, specifying the use of 90 degree stirrup hooks. Ninety degree stirrup hooks are smaller than 90 degree standard hooks for #3, #4 and #5 bars. For example, the dimension of a 90 degree hook on a #6 bar is 12 inches versus 6 inches for a 90 degree stirrup hook on a #5 bar. When hooked top bars are required in a 7.5-inch thick slab, the #5 bars can be easily installed with ¾-inch clear cover top and bottom, without having to rotate the bars to install them. While a larger number of smaller bars will be required, the cost for installing reinforcing steel is usually estimated based on the tonnage of reinforcing steel rather than number of bars. The only issue related to using 90 degree stirrup hooks is that ACI 318 specifies that a transverse bar perpendicular to the hooked bar be located inside the bend. This is generally not an issue though, since there is usually such a bar parallel to slab edges anyway. A good rule-of-thumb is to use bars of sufficiently small size such that the hook dimension does not exceed 80% of the slab thickness. While adhering to this rule may not always be possible, it’s a good starting point.

Avoid using 180 degree hooks in slabs: While the use of 180 degree bar hooks might seem like a good idea, doing so can complicate the placement of reinforcing steel. Consider the reinforcing steel shown in *Figure 3*. While bars with 90 degree hooks can be dropped straight down into place, bars with 180 degree hooks cannot be dropped into place unless the perpendicular edge bar is temporarily moved out of the way and then re-positioned after the hooked bars are installed. Consider top reinforcing steel occurring in a slab at a corner column. Visualize placing the slab top bars in both directions using 90 degree hooks versus placing bars with 180 degree hooks.

Limit the percentage of column vertical reinforcing steel to 2% for economy and 4% for constructability: ACI 318 permits columns to be reinforced with up to

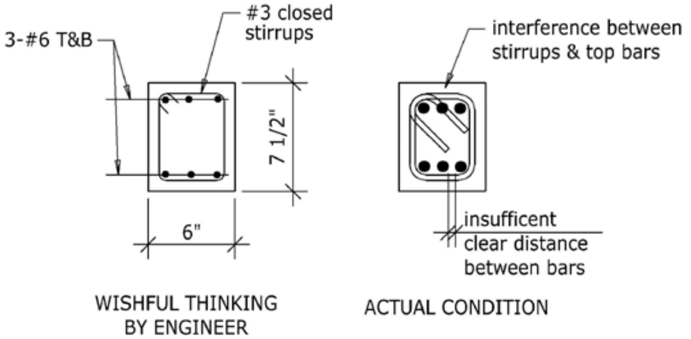

Figure 1: Actual bar dimensions must be considered.

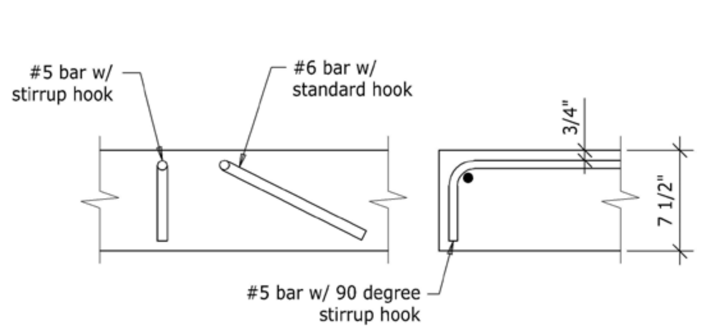

Figure 2: Bars with smaller hooks are easier to install in thin slabs.

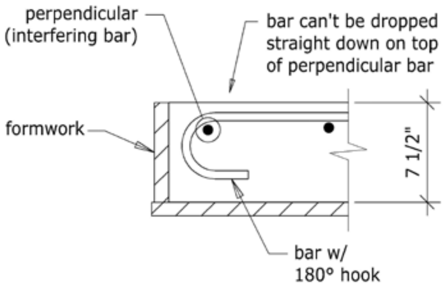

Figure 3: Avoid using 180 degree hooks in slabs.

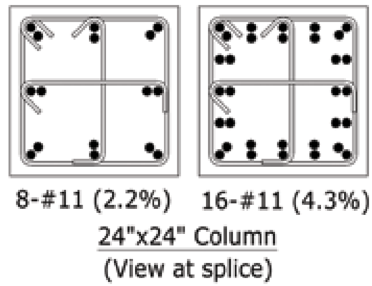

Figure 4: Avoid using more than 4% reinforcing steel in columns.

8% vertical reinforcing steel. Unfortunately, columns reinforced with 8% steel using lap splices will have 16% steel at splice locations unless mechanical splice couplers are used. *Figure 4* shows the reinforcing steel in two 24-inch by 24-inch columns – one reinforced with 8-#11 (ρ=2%) and one reinforced with 16-#11 (ρ=4%). The section was cut where the bars are lap spliced. Note the close bar spacing in the column with 16 vertical bars. Large numbers of vertical bars also require more ties. Installing beam and slab reinforcing through heavily reinforced columns also can be difficult.

Heavily reinforced columns are not only difficult to build, they are often not the most economical design.

Most of the axial load capacity in a concrete column is provided by the concrete, not the reinforcing steel. *Figure 5* compares the load capacity of three 24-inch by 24-inch columns (using Equation 10-2 in ACI 318) using different quantities of reinforcing steel and concrete strengths. Note that *doubling* the reinforcing from 2% to 4% increases the column strength by only 22% while increasing the compressive strength by a relatively small 30%, from 5 ksi to 6.5 ksi, achieves the same strength increase. While costs of concrete, reinforcing steel and labor vary geographically, the most economical column design is generally one with no more than 2% vertical reinforcing.

Avoid using bundled bars in columns: For the reasons discussed above, avoid using bundled bars in columns. If you have to bundle the bars, the column is too small. Splices in bundled bars must be staggered, which adds another level of complexity. Likewise, mechanical splice couplers, when required, cannot be easily installed on bundled bars.

Coordinate placement of slab embedded electrical conduit: Designers must specify criteria for installing slab embedded cable and conduit in floor slabs. Specifying such criteria on the general notes will, at a minimum, facilitate awareness that caution must be taken in coordinating where and how cables and conduits may be installed without compromising the structural integrity of the floor framing.

Specify reinforcing steel placing priority for reinforcing steel in slabs: Although reinforcing steel placing priority usually does not affect constructability, placing priority can affect flexural strength and deflection, especially in thin slabs. Specifying placing priority on the drawings and requiring that placing priority be indicated on the reinforcing steel placing drawings can eliminate conflicts and problems in the field.▪

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24"x24" CONCRETE COLUMN DESIGN OPTIONS				
f'_c	A_s	ρ	$ØP_n$	% increase
5 ksi	8-#11	2.2%	1635k	–
5 ksi	16-#11	4.3%	1977k	22%
6.5 ksi	8=#11	2.2%	2008k	23%

Figure 5: Column strength is most influenced by concrete strength.