Tips for Designing Constructible Concrete Structures

Part 2

By Clifford W. Schwinger, P.E.

This month's article is a continuation of Part 1 in the February 2011 issue. Engineers striving to design economical cast-in-place concrete structures must pay attention to constructability – that is, the ease and economy with which their designs can be constructed. Constructability issues, if not caught during design, can result in RFI's and change orders, or structural deficiencies. The design of constructible concrete structures is as much art as science. There are usually multiple good solutions to structural engineering design and detailing challenges. Construction practices vary around the country. What might be a good solution to a design challenge in one part of country might not be the best solution in another location. Variables such as the availability and cost of materials, labor costs and building code requirements will influence local preferred construction, design and detailing practices. The key for engineers is to develop their wealth of knowledge so that they know what pitfalls to watch out for, as well as to have a library of solutions available from which to draw when designing and detailing.

Consider development lengths when doweling reinforcing steel. Concrete into which hooked bars terminate must be anchored sufficiently deep so that the bars will be able to develop in tension. *Figure 6* illustrates a condition where dowels at the base of a cantilevered retaining wall are too large to be developed (or even installed) within the depth of the footing. The solution is to use smaller bars at a closer spacing and/or to make the footing deeper.

Avoid multiple parallel layers hooked bars. *Figure 7* illustrates a detail where several layers of parallel hooked bars are required. There are two problems with this detail. First, it is difficult to construct. Second, the available distance with which to develop the lower layer of hooked bars is reduced due to the need to offset the lower layers. If multiple layers of reinforcing bars cannot be avoided, designers should review if all layers need to have hooks. Sometimes it is possible to justify putting hooks on only one layer of bars. The use of headed anchors on the bars is another alternative that will enhance constructability.

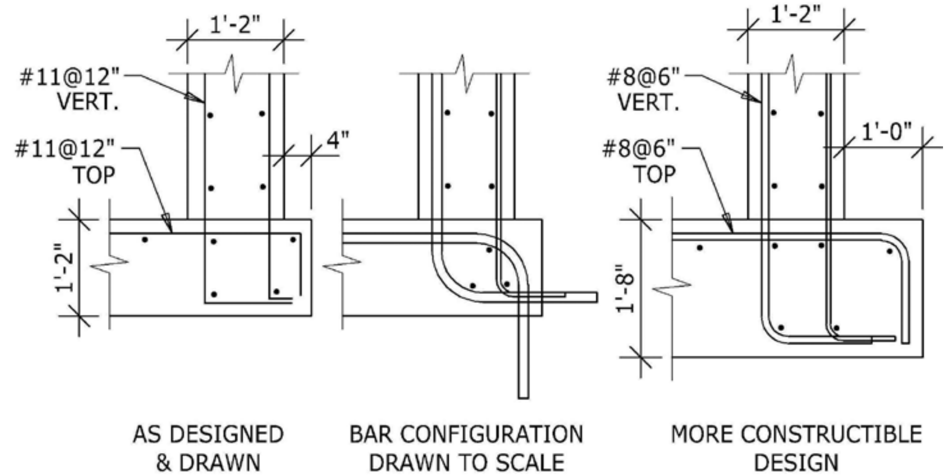

Figure 6: Insufficient footing dimensions to install and develop reinforcing steel.

Consider development and installation of hooked column vertical bars into slabs at tops of columns. *Figure 8* illustrates #9 column vertical bars exiting into an 8-inch thick roof slab. Large hooked bars embedded less than the standard development length will be unable to develop their yield strength in tension. Frequently, vertical column reinforcing steel does not need to develop the full tension strength in this condition. Designers should consider the use of lap spliced dowels, smaller than the column vertical bars which are sufficiently large to develop the required tensile force in the reinforcing steel, yet small enough to be able to easily fit within the thickness of the slab. Another benefit of loose dowels is that the hooks can be rotated as required to facilitate installation within the slab. Likewise, the use of headed anchors on the ends of the vertical column reinforcing steel will also make for easier installation.

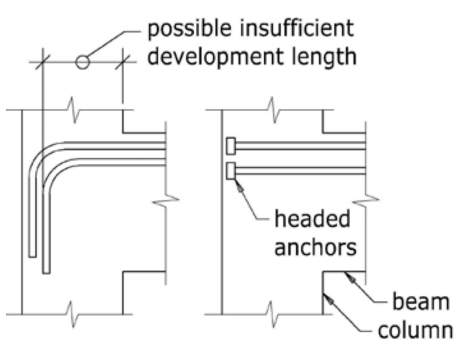

Figure 7: Avoid multiple layers of hooked reinforcing bars.

Do not hook the ends of bars that are threaded to mechanical couplers. It is difficult to screw reinforcing bars with hooks into threaded couplers. If the hooks are large, they may hit formwork and prevent rotation of the bars into the couplers. Where bars are closely spaced, the hooks may hit adjacent bars. Likewise, when the bars are fully tightened into the couplers, the hooks might be oriented pointing out of concrete. Consider screwing straight bars into the threaded couplers and lap splice with hooked bars (*Figure 9*).

Do not specify hooks larger than standard hooks. Hooks are used to develop bars in tension. There is rarely a need to specify hooks with dimensions larger than required per ACI 318.

Avoid one-piece closed stirrups in beams. Installation of reinforcing steel through closed stirrups is more difficult than with two-piece closed stirrups (*Figure 10*).

Avoid complex column tie configurations. Column tie configurations can be simplified by using as few vertical bars in the column as possible. ACI 318 requires corner bars and alternating vertical bars to have lateral support by a tie. Ties are required at all bars spaced further than 6 inches clear to laterally supported bars on both sides. Although the perimeter ties are usually one-piece closed ties, other ties should be single leg ties. *Figure 11* illustrates efficient and inefficient column tie arrangements.

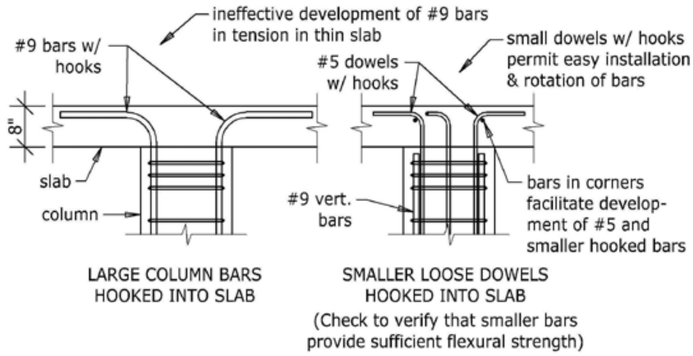

Figure 8: Do not embed large hooked bars into thin slabs.

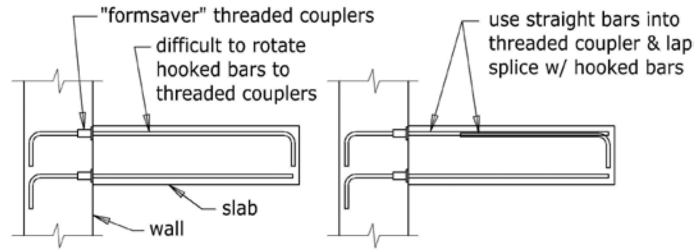

Figure 9: Avoid hooks on threaded bars.

Detail bar configurations in beams and columns. While some bar configurations require no clarification, others do.

Provide sections and details to clarify reinforcing steel placement and design intent. Contrary to the apparent belief of some structural engineers, reinforcing steel detailers are not mind readers. Provide sections and details on the framing plans at all locations where the design intent requires further clarification. Providing sections and details showing the placement and disposition of reinforcing steel also allows designers to spot constructability problems during design when such problems can be fixed with a pencil versus a torch.

Consider clear dimensions between bars at lap splices. ACI 318, Section 7.6 specifies minimum clear spacing limitations between reinforcing bars. The minimum bar spacing requirements are also applicable at lap splices. Heavily reinforced members often have closely spaced bars and lap splices. Designers must verify that bars are spaced far enough apart so that there is sufficient clearance between bars at splices.

Coordinate locations of slab openings during design. The locations of openings in floor slabs can affect constructability and structural integrity. Failure to coordinate the locations and dimensions of slab openings during design can lead to problems and delays during construction. Slab openings should not be thrown on the drawings (or into the BIM model) at the last minute without consideration as to their impact on the performance of the framing.

Do not put reinforcing steel through keyways. Installing reinforcing steel through keyways in construction joints requires drilling holes though the keyway material. A more constructible solution is to install reinforcing steel above and below the keys.

Avoid details where holes have to be drilled through formwork. Column and wall forms are expensive. Contractors do not like perforating them with holes. Anticipate and detail "formsaver" couplers (*Figure 9*).

Dimension column strips. Two-way slabs are divided into column strips and middle strips. ACI 318 specifies column strip dimensions. Where column bays vary or are irregular, column strip widths will vary. Engineers often "pass the buck" and require reinforcing steel detailers to compute column strip widths. It is better for engineers to dimension column strip widths on the framing plans. Dimensioning column strip widths will more clearly convey design intent, and allow designers to catch idiosyncrasies in column strip disposition before construction. In the process of dimensioning column strips, engineers should simplify column strip dimensions where possible. Column strips can be dimensioned nominally narrower than the dimensions specified in ACI 318 without adversely affecting structural performance. Simplifying the layout of column strips clarifies the framing plans, simplifies detailing and enhances constructability. For example, on a floor where every column strip might vary in width from 10 feet to 13 feet, or where the half strip dimension is 5 feet on one side of a column line and 6 feet on the other side of a column line, the column strips can all be made 10 feet wide.

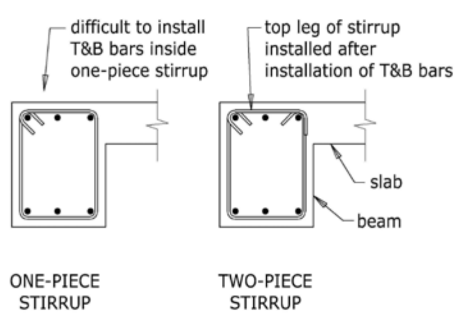

Figure 10: Avoid one-piece beam stirrups.

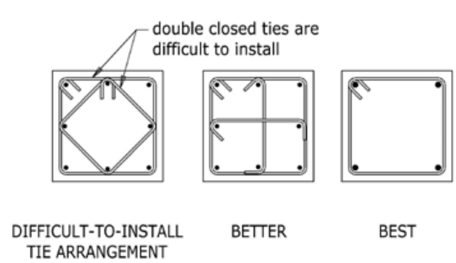

Figure 11: Simplify column tie arrangements.

Simplify formwork. Approximately half the cost of cast-in-place concrete construction is in the cost of formwork. The simpler and more repetitive the formwork is, the lower the cost. Since formwork construction is labor intensive, the need to simplify formwork is greatest where labor costs are high. Some ways to reduce formwork cost include,

- Strive for repetition
- Standardize column capital dimensions in two-way slabs, or eliminate capitals
- Minimize the use of beams and standardize beam dimensions where they are required
- Minimize the number of different column sizes
- Keep column sizes the same for the full height of the building
- Avoid steps or other irregularities in the underside of formwork. Where small steps are required in slabs, make slabs thicker or thinner, but keep the underside of the slab flat.

Where possible, use 0.5% vertical reinforcing steel in columns. ACI 318, Section 10.9.1 requires columns to have no less than 1% vertical reinforcing steel. Section 10.8.4, however, permits the minimum amount of reinforcing steel to be as little as 0.5%, subject to certain conditions and design constraints. When loads are sufficiently small, designers should take advantage of Section 10.8.4.▪

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