Frequently Asked Questions

The Use of Drop Caps to Reduce Flexural Reinforcement in Two-Way Post-Tensioned Slabs

Answers from the PTI DC-70 Special Topics Committee March 2010 • Issue No. 10

Primary Author:
Ken Bondy

Q Do the ACI 318-08 Chapter 13 dimensional limitations for drop panels used to reduce negative moment reinforcement apply to post-tensioned slabs?

A No. Dimensional limitations for drop panels or caps used to increase slab depth and reduce negative moment reinforcement in ACI 318-08[1] Sections 13.2.5 and 13.3.7 apply only to nonprestressed slabs. Chapter 13 is excluded in its entirety from applicability to prestressed concrete in Section 18.1.3 "…except as specifically noted." No reference to either Section 13.2.5 or 13.3.7 appears anywhere in Chapter 18; therefore, the limitations on drop cap dimensions do not apply to two-way prestressed slab systems. Thus, it is fully appropriate—in two-way post-tensioned slabs—to use the additional depth of the drop cap in calculations for negative moment reinforcement in cross sections including the drop cap.

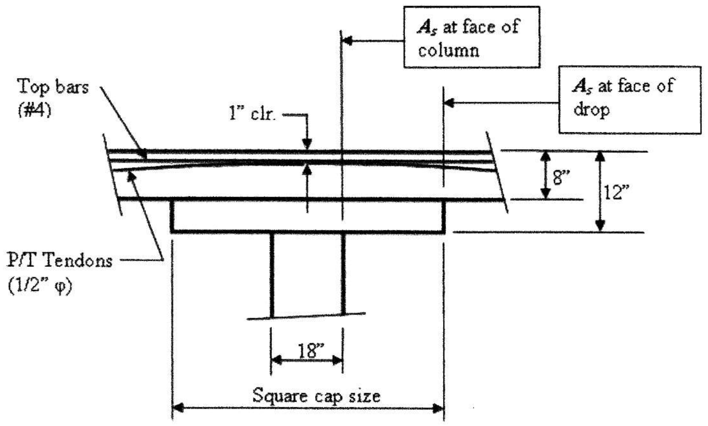

Fig. 1—Detail of a slab-column joint. (Note: 1 in. = 25.4 mm; #4 = No. 13.)

BACKGROUND

The use of drop caps increases punching shear capacity and can reduce the amount of required nonprestressed negative moment reinforcement. There is no code limitation on the size (plan dimension or depth) of drop caps used in two-way prestressed slabs, and a plan size of 4 ft (1.2 m) square has been commonly and effectively used. To demonstrate this, a computer study was made comparing the required amount of negative moment reinforcement in a reasonably proportioned and loaded two-way post-tensioned slab with varying cap sizes. The model consisted of an equivalent frame with four 30 ft (9.1 m) spans, a slab tributary width of 30 ft (9.1 m) (a 30 x 30 ft bay size), an 8 in. (200 mm) thick slab, and 18 in. (450 mm) square columns with lengths of 12 ft (3.7 m) above and below the slab. Concrete strength was 5000 psi (34 MPa) for slabs, 4000 psi (28 MPa) for columns, and the applied uniform nonskipped superimposed load in all spans was 20 psf (0.96 kN/m^2) dead load and 75 psf (3.6 kN/m^2) live load. A relatively high superimposed loading was selected to focus on the variance in nonprestressed flexural reinforcement as a function of cap size, and the comparison between nonprestressed flexural reinforcement and minimum steel requirements. Prestressing force was held constant in all cases (all flexural stress criteria were satisfied), and yield stress in nonprestressed reinforcement was taken as f_y = 60 ksi (415 MPa). The study was based upon the slab-column joint at the second interior column of the four-span frame (the center column). No inelastic redistribution of moments was assumed.

Various square cap sizes were studied, ranging from none to the full size required for nonprestressed slabs by ACI 318 Chapter 13. Although a 10 in. (250 mm) total cap depth would be permitted by Chapter 13 for this configuration, a 12 in. (300 mm) total cap depth was used for all cap plan sizes because it was required to satisfy ACI Code punching shear requirements. The plan cap dimensions studied were 10 ft (3 m), (the minimum size required for nonprestressed slabs by Chapter 13), 8 ft (2.4 m), 6 ft (1.8 m), and 4 ft (1.2 m) (probably the most commonly used cap dimension in post-tensioned slabs), 3 ft (910 mm), and 2.5 ft (760 mm) (the smallest size, which is effective in resisting shear with a 12 in. [300 mm] cap depth). It should be noted that in the "no cap" condition, some type of shear reinforcement would be required (such as headed stud assemblies) because the geometry and properties of the slab and column alone, without a cap, do not satisfy ACI code punching shear requirements. Details at the cap are shown in Fig. 1.

For each cap size, the required cross-sectional area of nonprestressed negative moment reinforcement was determined at the face of the column (using the full cap depth), and at the face of the drop cap (using only the slab depth). These were compared to the minimum area of top slab reinforcement required by ACI 318-08 Section 18.9.3.3, which

Table 1—Reinforcement required for various drop cap sizes

	At face of column		At face of drop		
Square cap size, in.	A_s, in.^{2}	M_u, ft-kips	A_s, in.^{2}	M_u, ft-kips	$A_{s,min}$, in.^{2}, Section 18.9.3.3
120	0	455	0	74	2.16
96	0	449	0	144	2.16
72	0	443	0	222	2.16
48	0	436	1.70	308	2.16
36	2.22*	434	2.72	355	2.16
30	3.22†	433	3.28	380	2.16
None	4.30	427	4.30	427	2.16

*2.22 in.^{2} is sum of compression plus tension reinforcement required to develop 434 ft-kips with 36 in. compression width. This is less than area of tension reinforcement required to develop same moment using slab depth only (ignoring cap).

†3.22 in.^{2} is sum of compression plus tension reinforcement required to develop 433 ft-kips with 30 in. compression width. This is less than area of tension reinforcement required to develop same moment using slab depth only (ignoring cap).

Note: 1 in. = 25.4 mm; 1 in.^{2} = 645 mm^2; 1 ft-kip = 1.36 Nm.

is a function of the slab depth only and is therefore constant for all cap sizes in this study.

In evaluating these results, it should be noted that as the cap size decreases, the stiffness of the slab-beam decreases, and the slab attracts a smaller percentage of the total joint moment. Therefore, the moment at the face of the column decreases as the cap size decreases. However, as the cap size decreases the negative moment at the face of the cap dramatically increases due the steep negative moment gradient near the column. These effects are combined at the face of the column in the condition with no drop cap. The required amount of negative reinforcement is also affected by the location of the tendon CGS at the face of the drop cap as the cap size varies. For cap sizes less than 48 in. (1.2 m), compression steel was required at the bottom of the cap at the face of the column to develop the required moment. In these cases, the combined area of compression and tension steel was compared with the area of tension steel required using the slab alone (ignoring the drop) and the smaller used in the discussion that follows.

At the center column for each cap size, the negative moment and required nonprestressed flexural and minimum reinforcement was determined and tabulated in Table 1. The controlling area of reinforcement for each cap size is indicated by shading in the appropriate cell. All caps have a total depth of 12 in (300 mm).

For a 10-ft. (3 m) square drop cap, the minimum size permitted for nonprestressed slabs by ACI 318 Chapter 13, no supplemental nonprestressed reinforcement is required either at the face of the column or at the face of the drop. This is because the tendon force alone is sufficient to develop the required moment at both locations. In this case, the minimum area of top reinforcement required by Section 18.9.3.3 (2.16 in.^{2} [1400 mm^2]) governs. This relationship is true also for the 8- and 6-ft (2.4 and 1.8 m) square caps.

For a 4-ft. (1.2 m) square drop cap, which is commonly used in practice, once again the minimum required area controls over the 1.70 in.^{2} (1100 mm^2) required for flexural strength at the face of the drop. For a 3-ft (910 mm) square cap, the required area at the face of the drop does control (2.72 in.^{2} [1750 mm^2]) over the minimum required (2.16 in.^{2} [1400 mm^2]), but it is less than the 4.30 in.^{2} (2770 mm^2) required at the face of the column with no cap. For cap sizes less than 3-ft. (910 mm) square—not often used in practice—the steel area at the face of the drop cap controls as it approaches the maximum amount required in the condition with no cap.

In summary, minimum drop cap sizes specified in ACI 318 Chapter 13 do not apply to post-tensioned two-way slab systems designed in accordance with Chapter 18. It is code-conformant and appropriate to use the additional depth of drop caps of any size in post-tensioned slabs in flexural calculations. While the study presented in this FAQ does not, of course, address all configurations and loading conditions, it does suggest that for the cap sizes generally used in practice, the use of the full cap depth in flexural calculations will reduce the required amount of nonprestressed negative moment (top) reinforcement in two-way post-tensioned slabs.

REFERENCES

1. ACI Committee 318, "Building Code Requirements for Structural Concrete and Commentary (ACI 318-08)," American Concrete Institute, Farmington Hills, MI, 2008, 473 pp.

POST-TENSIONING INSTITUTE ®

Frequently Asked Questions, Mar. 2010

38800 Country Club Drive, Farmington Hills, MI 48331
Phone: (248) 848-3180 • Fax: (248) 848-3181 • Web: www.post-tensioning.org