Frequently Asked Questions

Shrinkage and Temperature Reinforcement

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QUESTION: When designing one way slabs in post-tensioned beam and slab construction, is it acceptable to provide all of the required continuous shrinkage and temperature reinforcement in the beams only?

ANSWER: **No.** It is PTI's opinion that one-way slab shrinkage and temperature reinforcement cannot be provided by beam tendons alone. Elimination of shrinkage and temperature reinforcement in the slabs of one-way beam-and-slab structures violates the requirements of the ACI Building Code. Following is a detailed discussion that explains the PTI position.

COMMENTARY:

ACI CODE REQUIREMENTS

Requirements for shrinkage and temperature reinforcement in one-way slabs are specified in the ACI Building Code (current edition ACI 318-05)[1] in Section **7.12**. Section **7.12.1** (see below) states in mandatory language that reinforcement shall be provided for shrinkage and temperature stresses.

> ***7.12.1*** *– Reinforcement for shrinkage and temperature stresses normal to flexural reinforcement shall be provided in structural slabs where the flexural reinforcement extends in one direction only.*

Either non-prestressed reinforcement (Section **7.12.2**) or prestressed reinforcement (Section **7.12.3**) is permitted to be used to satisfy this requirement. The code specifies three criteria when prestressed reinforcement is used. They are repeated below:

> ***7.12.3.1*** *– Tendons shall be proportioned to provide a minimum average compressive stress of 100 psi on gross concrete area using effective prestress, after losses, in accordance with* ***18.6****.*
>
> ***7.12.3.2*** *– Spacing of tendons shall not exceed 6 feet.*
>
> ***7.12.3.3*** *– When spacing of tendons exceeds 54 in., additional bonded shrinkage and temperature reinforcement conforming to* ***7.12.2*** *shall be provided between the tendons at slab edges extending from the slab edge for a distance equal to the tendon spacing.*

Commentary Section **R7.12.3** states, "Application of the provisions of **7.12.3** to monolithic cast-in-place post-tensioned beam and slab construction is illustrated in Fig. **R7.12.3**." Commentary Fig. **R7.12.3** is repeated below as Fig. 1.

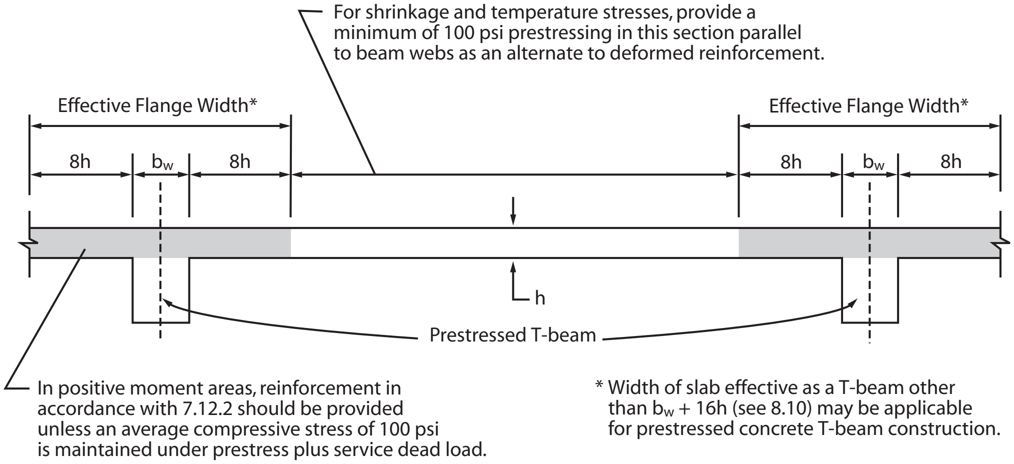

Fig. 1 – ACI Fig. R7.12.3—Prestressing used for shrinkage and temperature (Adapted from ACI 318-05)[1]

BACKGROUND AND INTENT OF SECTION 7.12

In the development of Sections **7.12.3** and **R7.12.3**, which permit the use of prestressed shrinkage and temperature reinforcement, ACI Committee 318 recognized, for post-tensioned beams with unbonded tendons, the "Effective flange width" in Fig. **R7.12.3** (see Fig. 1) will automatically satisfy the minimum shrinkage and temperature requirements of **7.12.2** or **7.12.3**. Section **18.9.2** requires a minimum amount of bonded non-prestressed reinforcement in beams with unbonded tendons equal to 0.004 times the concrete area between the flexural tension face and the centroid of the beam cross-section. In negative moment areas, where the flexural tension face is the top of the slab, this means that the shaded portion of the slab in Fig. **R7.12.3** (see Fig. 1) must contain a minimum area of bonded reinforcement (0.004 times the shaded area) which is at least twice that required for shrinkage and temperature by **7.12.2.1** (a **maximum** of 0.0020 times the shaded area). In positive moment areas of the beam the slab flange is in compression, and compressive stress in the slab flange is virtually always greater than 100 psi, even near points of contraflexure where bending stresses are small and the primary contribution to compressive stress is provided by the axial force from the beam tendons alone.

So regardless of the width of effective slab flange assumed in the design, it will automatically satisfy either **7.12.2** or **7.12.3**, and therefore the committee felt that requirements for slab shrinkage and temperature reinforcement need apply only to the slab area **between** effective flange widths. Thus when prestressed reinforcement is used for shrinkage and temperature resistance, Fig. **R7.12.3** (see Fig. 1) clearly indicates that the 100 psi requirement for compression (Section **7.12.3.1**) applies to the portion of the slab between the effective flange widths assumed in the beam design. The spacing of prestressed tendons used for shrinkage and temperature reinforcement in the slab is limited by **7.12.3.2** and **7.12.3.3**.

The flange width shown in Fig. **R7.12.3** (see Fig. 1) is $b_w + 16h$, a commonly used, but non-mandatory, assumption (see the exemption of Sections **8.10.2**, **8.10.3** and **8.10.4** in Section **18.1.3**). Even if the designer chose to use the **entire** slab tributary as the effective flange width for the design of the beam, the entire slab would thus satisfy shrinkage and temperature requirements as a part of the flexural design of the beam, although a minimum amount of prestressed tendons would still be required in the slab by the spacing criteria of **7.12.3.2**.

TYPICAL APPLICATION OF SECTION 7.12.3 – AN EXAMPLE

A cross-section through the beams for a commonly used geometry in cast-in-place post-tensioned parking structures is shown below in Fig. 2.

In Fig. 2 the effective beam flange width is $b_w + 16h$, which for this geometry is 14 +16 × 5 = 94 in. For this configuration, **7.12.3.1** (as clarified by **R7.12.3** and **Fig. R7.12.3**) would require 5 × 122 × 0.1 = 61 kips of prestressing force to provide a compressive stress of 100 psi on the slab between effective beam flanges. This compressive stress requirement would typically be satisfied by providing three ½" diameter 270 ksi temperature tendons in the slab section between the effective flange widths. Many engineers prefer to place these three slab tendons between the slab flanges, as shown in Figure 2, where the locations of the three slab temperature tendons and the beam tendons are shown as black dots. In this case, the slab tendon closest to the beam is located at a "half-space" from the edge of the flange (122/3 = 41; 41/2 = 21"), and the other two tendons spaced at 40". With this configuration the maximum spacing from the centerline of the beam to the first temperature tendon is 5'-8" which satisfies the maximum spacing requirement of **7.12.3.2** (6 ft.). However **7.12.3.3** would require added reinforcement at the slab edge (the spacing of some of the temperature tendons exceeds 54 in.). It is also reasonable to base the spacing from the beam to the first temperature tendon on the **face** of the beam, rather than the centerline. In this case the spacing would be 5'-1" rather than 5'-8", however the added slab edge reinforcement would still be required. Other engineers would sim-

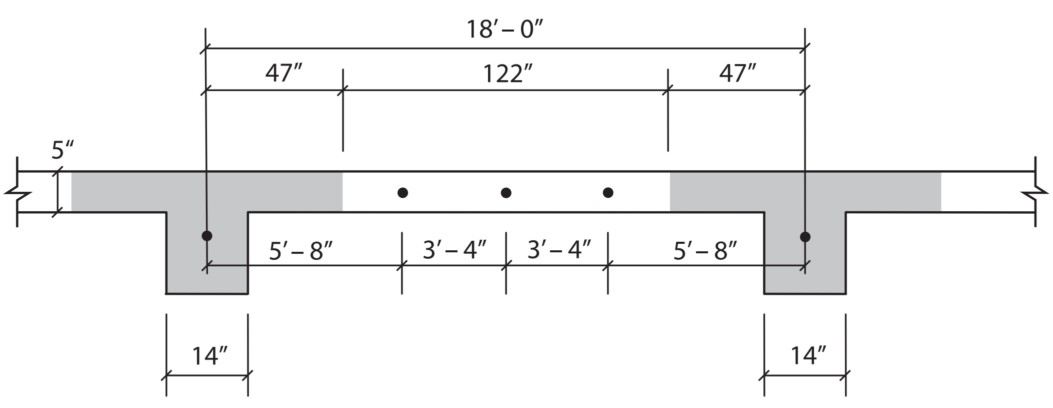

Fig. 2 – Example cast-in-place post-tensioned parking structure

ply space the three temperature tendons equally between beam centerlines or beam faces. If the equal spacing was based on beam centerlines (18'-0"), the spacing between temperature tendons would be 4'-6", which is less than 72" and equal to 54" and thus has the advantage of eliminating the requirement for slab edge reinforcement.

The assumption of a flange width less than $b_w + 16h$ is virtually never used for interior beams. Larger flange widths are occasionally assumed in beam design. If the entire slab tributary was assumed as an effective flange width in this example, a minimum of 2 temperature tendons would still be required between beams, governed by the 6-ft. maximum spacing criteria in **7.12.3.2**. This would also require non-prestressed shrinkage and temperature reinforcement at the slab edge in accordance with **7.12.3.3**.

AN ALTERNATE INTERPRETATION

It can be rationally argued that a compressive force applied to the beam web, beyond a certain distance inward from the edge of the slab, applies uniform compression over the entire cross-section of beam and slab. Thus the required minimum compressive stress in the slab between effective flange widths could theoretically be satisfied by beam tendons alone, if they were sufficient in number to provide a compressive stress of 100 psi over the entire cross-section tributary to the beam. It can further be argued that temperature tendons placed in the slab, above the flexural neutral axis of the T-beam cross-section, slightly reduce the positive flexural capacity of the beam and increase beam deflection.

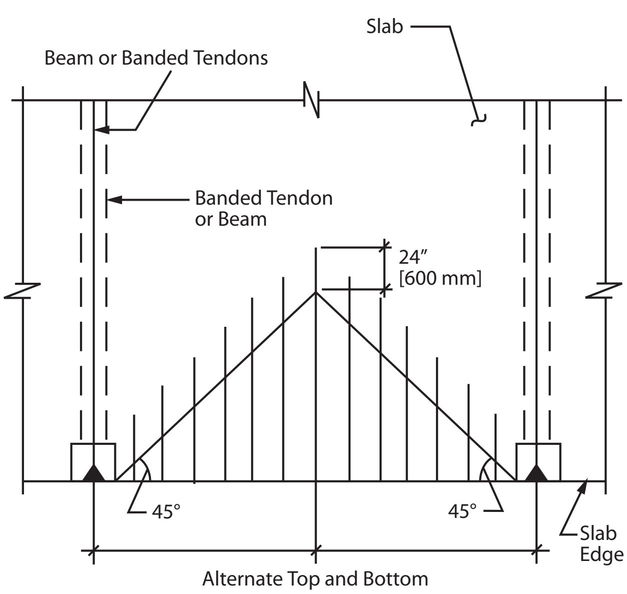

Fig. 3 – Arrangement of temperature and shrinkage reinforcement

Supported by these arguments, an interpretation of Section **7.12.3** has been proposed that **all** of the prestressed reinforcement required for shrinkage and temperature can be placed in the beam web and **none** in the slab between the beams. In this interpretation, non-prestressed reinforcement in accordance with **7.12.2** is placed in the slab parallel to the beams in the small triangular area between beams assumed to exist between the "spread" of compressive forces applied in the beam webs. Beyond this triangular area, normally assumed to extend inward from the edge of the slab a distance equal to one-half the beam spacing, no temperature reinforcement of any kind is supplied between the beams. The details of this interpretation are shown in Fig. 3 below.

This interpretation of ACI 318 Section **7.12.3** is discussed in three published PTI documents, *Design Fundamentals of Post-Tensioned Concrete Floors*[2] in Section 2.17.2, *PTI Technical Notes* #1, "Effective Width and Post-Tensioning,"[3] Section 5 and *PTI Technical Notes* #8, "Layout of Post-Tensioning and Passive Reinforcement in Floor Slabs,"[4] Section 3.2. This alternate interpretation is further supported by the analogy between one-way beam and slab framing and two-way post-tensioned slabs with a banded tendon distribution, where no reinforcement is normally supplied parallel to and between the banded tendons.

Some structures have been designed and built using the alternate interpretation. Their behavior is reported to be adequate.

OFFICIAL POSITION OF THE POST-TENSIONING INSTITUTE (PTI)

The analogy using the banded two-way slab is irrelevant from a code-conformance standpoint since the shrinkage and temperature requirements of Section **7.12** apply only to one-way slabs. While the behavioral arguments cited may well be correct, PTI cannot support the use of the interpretation of shrinkage and temperature requirements shown in Fig. 3. PTI considers this alternate interpretation to be the opinion and recommendation of the authors of the three cited PTI documents, and not the official position of the Institute. PTI feels that the alternate interpretation of Section **7.12.3** shown in Figure 3 conflicts with the spirit and original intent of Section **7.12.3**, and specifically violates Section **7.12.3.2** which requires a maximum tendon spacing of 6 ft. when prestressing tendons are used to satisfy requirements for shrinkage and temperature reinforcement. It is possible that ACI 318-05 Section **1.4**, which allows the use of "special systems of design or construction" which do not conform to the code (subject to the review and approval of the building official) could sanction the use of the alternate interpretation on a job-to-job basis.

Finally, the concept of providing **no shrinkage and temperature reinforcement whatsoever** for lengthy distances in one way slabs spanning between beams is a departure from standard structural engineering practice. In recognition of the fact that some designers support the alternate interpretation, and some structures have been built using it, PTI plans to communicate formally with ACI Committee 318 to request a review of the alternate interpretation. However until the code is changed to clearly condone its use, PTI's position is that design and construction using the alternate interpretation shown in Fig. 3 does not conform to the ACI Building Code.

REFERENCES

1 *Building Code Requirements for Structural Concrete and Commentary*, ACI 318-05, American Concrete Institute, Farmington Hills, MI, 2005.

2 Aalami, B. O. and Bommer A., *Design Fundamentals of Post-Tensioned Concrete Floors*, Post-Tensioning Insitute, Phoenix, AZ, 1999.

3 Aalami, B. O., "Effective Width in Post-Tensioning," *PTI Technical Notes,* Issue 1, Post-Tensioning Institute, Phoenix, AZ, April 1993.

4 Aalami, B. O., "Layout of Post-Tensioning and Passive Reinforcement in Floor Slabs," *PTI Technical Notes,* Issue 8, Post-Tensioning Institute, Phoenix, AZ, April 2000.

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