CHAPTER 7—ONE-WAY SLABS

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7.1—Scope

7.1.1 This chapter shall apply to the design of nonprestressed and prestressed slabs reinforced for flexure in one direction, including:

(a) Solid slabs
(b) Slabs cast on stay-in-place, noncomposite steel deck
(c) Composite slabs of concrete elements constructed in separate placements but connected so that all elements resist loads as a unit
(d) Precast, prestressed hollow-core slabs

7.2—General

7.2.1 The effects of concentrated loads, slab openings, and voids within the slab shall be considered in design.

7.2.2 *Materials*

7.2.2.1 Design properties for concrete shall be selected to be in accordance with Chapter 19.

7.2.2.2 Design properties for steel reinforcement shall be selected to be in accordance with Chapter 20.

7.2.2.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with 20.6.

7.2.3 *Connection to other members*

7.2.3.1 For cast-in-place construction, joints shall satisfy Chapter 15.

7.2.3.2 For precast construction, connections shall satisfy the force transfer requirements of 16.2.

7.3—Design limits

7.3.1 *Minimum slab thickness*

7.3.1.1 For solid nonprestressed slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections, overall slab thickness h shall not be less than the limits in Table 7.3.1.1, unless the calculated deflection limits of 7.3.2 are satisfied.

COMMENTARY

R7.1—Scope

R7.1.1 Design and construction of composite concrete slabs on steel deck is described in "Standard for Steel Deck" (SD).

Provisions for one-way joist systems are provided in Chapter 9.

R7.2—General

R7.2.1 Concentrated loads and slab openings create local moments and shears and may cause regions of one-way slabs to have two-way behavior. One-way slabs with concentrated loading may be susceptible to two-way punching shear failure and localized flexural yielding around the loaded area. The influence of openings through the slab and voids within the slab (for example, those created forducts) and development of additional critical sections for flexural and shear strengths, as well as deflections, are to be considered.

R7.3—Design limits

R7.3.1 *Minimum slab thickness*

R7.3.1.1 The basis for minimum thickness for one-way slabs is the same as that for beams. Refer to R9.3.1 for additional information.

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Table 7.3.1.1—Minimum thickness of solid nonprestressed one-way slabs

Support condition	Minimum h[1]
Simply supported	$\ell/20$
One end continuous	$\ell/24$
Both ends continuous	$\ell/28$
Cantilever	$\ell/10$

[1]Expression applicable for normalweight concrete and f_y = 60,000 psi. For other cases, minimum h shall be modified in accordance with 7.3.1.1.1 through 7.3.1.1.3, as appropriate.

7.3.1.1.1 For f_y other than 60,000 psi, the expressions in Table 7.3.1.1 shall be multiplied by $(0.4 + f_y/100{,}000)$.

7.3.1.1.2 For nonprestressed slabs made of lightweight concrete having w_c in the range of 90 to 115 lb/ft^3, the expressions in Table 7.3.1.1 shall be multiplied by the greater of (a) and (b):

(a) $1.65 - 0.005w_c$
(b) 1.09

7.3.1.1.3 For nonprestressed composite concrete slabs made of a combination of lightweight and normalweight concrete, shored during construction, and where the lightweight concrete is in compression, the modifier of 7.3.1.1.2 shall apply.

7.3.1.2 The thickness of a concrete floor finish shall be permitted to be included in h if it is placed monolithically with the floor slab or if the floor finish is designed to be composite with the floor slab in accordance with 16.4.

7.3.2 *Calculated deflection limits*

7.3.2.1 For nonprestressed slabs not satisfying 7.3.1 and for prestressed slabs, immediate and time-dependent deflections shall be calculated in accordance with 24.2 and shall not exceed the limits in 24.2.2.

7.3.2.2 For nonprestressed composite concrete slabs satisfying 7.3.1, deflections occurring after the member becomes composite need not be calculated. Deflections occurring before the member becomes composite shall be investigated, unless the precomposite thickness also satisfies 7.3.1.

7.3.3 *Reinforcement strain limit in nonprestressed slabs*

7.3.3.1 Nonprestressed slabs shall be tension-controlled in accordance with Table 21.2.2.

COMMENTARY

R7.3.2 *Calculated deflection limits*

R7.3.2.1 The basis for calculated deflections for one-way slabs is the same as that for beams. Refer to R9.3.2 for additional information.

R7.3.3 *Reinforcement strain limit in nonprestressed slabs*

R7.3.3.1 The basis for a reinforcement strain limit for one-way slabs is the same as that for beams. Refer to R9.3.3 for additional information.

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7.3.4 *Stress limits in prestressed slabs*

7.3.4.1 Prestressed slabs shall be classified as Class U, T, or C in accordance with 24.5.2.

7.3.4.2 Stresses in prestressed slabs immediately after transfer and at service loads shall not exceed the permissible stresses in 24.5.3 and 24.5.4.

7.4—Required strength

7.4.1 *General*

7.4.1.1 Required strength shall be calculated in accordance with the factored load combinations in Chapter 5.

7.4.1.2 Required strength shall be calculated in accordance with the analysis procedures in Chapter 6.

7.4.1.3 For prestressed slabs, effects of reactions induced by prestressing shall be considered in accordance with 5.3.14.

7.4.2 *Factored moment*

7.4.2.1 For slabs built integrally with supports, M_u at the support shall be permitted to be calculated at the face of support.

7.4.3 *Factored shear*

7.4.3.1 For slabs built integrally with supports, V_u at the support shall be permitted to be calculated at the face of support.

7.4.3.2 Sections between the face of support and a critical section located d from the face of support for nonprestressed slabs or $h/2$ from the face of support for prestressed slabs shall be permitted to be designed for V_u at that critical section if (a) through (c) are satisfied:

(a) Support reaction, in direction of applied shear, introduces compression into the end region of the slab
(b) Loads are applied at or near the top surface of the slab
(c) No concentrated load occurs between the face of support and critical section

7.5—Design strength

7.5.1 *General*

7.5.1.1 For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$ including (a) and (b). Interaction between load effects shall be considered.

(a) $\phi M_n \geq M_u$

COMMENTARY

R7.4—Required strength

R7.4.3 *Factored shear*

R7.4.3.2 Requirements for the selection of the critical section for shear in one-way slabs are the same as those for beams. Refer to R9.4.3.2 for additional information.

R7.5—Design strength

R7.5.1 *General*

R7.5.1.1 Refer to R9.5.1.1.

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(b) $\phi V_n \geq V_u$

7.5.1.2 ϕ shall be determined in accordance with 21.2.

7.5.2 *Moment*

7.5.2.1 M_n shall be calculated in accordance with 22.3.

7.5.2.2 For prestressed slabs, external tendons shall be considered as unbonded tendons in calculating flexural strength, unless the external tendons are effectively bonded to the concrete section along the entire length.

7.5.2.3 If primary flexural reinforcement in a slab that is considered to be a T-beam flange is parallel to the longitudinal axis of the beam, reinforcement perpendicular to the longitudinal axis of the beam shall be provided in the top of the slab in accordance with (a) and (b). This provision does not apply to joist construction.

(a) Slab reinforcement perpendicular to the beam shall be designed to resist the factored load on the overhanging slab width assumed to act as a cantilever.

(b) Only the effective overhanging slab width in accordance with 6.3.2 need be considered.

7.5.3 *Shear*

7.5.3.1 V_n shall be calculated in accordance with 22.5.

7.5.3.2 For composite concrete slabs, horizontal shear strength V_{nh} shall be calculated in accordance with 16.4.

7.6—Reinforcement limits

7.6.1 *Minimum flexural reinforcement in nonprestressed slabs*

7.6.1.1 A minimum area of flexural reinforcement, $A_{s,min}$, of $0.0018A_g$ shall be provided.

7.6.2 *Minimum flexural reinforcement in prestressed slabs*

7.6.2.1 For slabs with bonded prestressed reinforcement, total quantity of A_s and A_{ps} shall be adequate to develop a factored load at least 1.2 times the cracking load calculated on the basis of f_r as given in 19.2.3.

COMMENTARY

R7.5.2 *Moment*

R7.5.2.3 This provision applies only where a T-beam is parallel to the span of a one-way slab. Such a beam might be used to support a wall or concentrated load that the slab alone cannot support. Reinforcement required by this provision is intended to consider "unintended" negative moments that may develop over the beam that exceed requirements for temperature and shrinkage reinforcement alone.

R7.6—Reinforcement limits

R7.6.1 *Minimum flexural reinforcement in nonprestressed slabs*

R7.6.1.1 Required area of deformed or welded wire reinforcement used as minimum flexural reinforcement is the same as provided for shrinkage and temperature in 24.4.3.2. However, whereas shrinkage and temperature reinforcement is permitted to be distributed between the two faces of the slab as deemed appropriate for specific conditions, minimum flexural reinforcement should be placed as close as practicable to the face of the concrete in tension due to applied loads.

R7.6.2 *Minimum flexural reinforcement in prestressed slabs*

R7.6.2.1 The minimum flexural reinforcement for prestressed one-way slabs is the same as the minimum for prestressed beams. Refer to R9.6.2 for additional information.

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7.6.2.2 For slabs with both flexural and shear design strength at least twice the required strength, 7.6.2.1 need not be satisfied.

7.6.2.3 For slabs with unbonded tendons, the minimum area of bonded deformed longitudinal reinforcement, $A_{s,min}$, shall be:

$$A_{s,min} \geq 0.004A_{ct} \quad (7.6.2.3)$$

where A_{ct} is the area of that part of the cross section between the flexural tension face and the centroid of the gross section.

7.6.3 *Minimum shear reinforcement*

7.6.3.1 A minimum area of shear reinforcement, $A_{v,min}$, shall be provided in all regions where $V_u > \phi V_c$. For precast prestressed hollow-core slabs with untopped h > 12.5 in., $A_{v,min}$ shall be provided in all regions where $V_u > 0.5\phi V_{cw}$.

7.6.3.2 If shown by testing that the required M_n and V_n can be developed, 7.6.3.1 need not be satisfied. Such tests shall simulate effects of differential settlement, creep, shrinkage, and temperature change, based on a realistic assessment of these effects occurring in service.

7.6.3.3 If shear reinforcement is required, $A_{v,min}$ shall be in accordance with 9.6.3.4.

7.6.4 *Minimum shrinkage and temperature reinforcement*

7.6.4.1 Reinforcement shall be provided to resist shrinkage and temperature stresses in accordance with 24.4.

7.6.4.2 If prestressed shrinkage and temperature reinforcement in accordance with 24.4.4 is used, 7.6.4.2.1 through 7.6.4.2.3 shall apply.

COMMENTARY

R7.6.3 *Minimum shear reinforcement*

R7.6.3.1 The basis for minimum shear reinforcement for one-way slabs is the same as that for beams. Refer to R9.6.3 for additional information.

The ratio V_u/V_c at which minimum shear reinforcement is required is generally greater for solid slabs and footings than for beams because, in solid slabs and footings, there is a possibility of load sharing.

Results of tests on precast, prestressed hollow-core units (Becker and Buettner 1985; Anderson 1978) with h ≤ 12.5 in. have shown shear strengths greater than those calculated by Eq. (22.5.6.2.1a) and Eq. (22.5.6.2.2). Results of tests on hollow-core units with h > 12.5 in. have shown that web-shear strengths in end regions can be less than strengths calculated by Eq. (22.5.6.2.2) (Hawkins and Ghosh 2006). In contrast, the test results indicated that flexure-shear strengths in the deeper hollow-core units equaled or exceeded strengths calculated by Eq. (22.5.6.2.1a).

R7.6.3.2 The basis for the testing-based strength evaluation for one-way slabs is the same as that for beams. Refer to R9.6.3.3 for additional information.

R7.6.4 *Minimum shrinkage and temperature reinforcement*

R7.6.4.2 In prestressed monolithic beam-and-slab construction, at least one shrinkage and temperature tendon is required between beams, even if the beam tendons alone provide at least 100 psi average compressive stress as required by 24.4.4.1 on the gross concrete area as defined in 7.6.4.2.1. A tendon of any size is permissible as long as all other requirements of 7.6.4.2 and 7.7.6.3 are satisfied. Application of the provisions of 7.6.4.2 and 7.7.6.3 to monolithic, cast-in-place, post-tensioned, beam-and-slab construction is illustrated in Fig. R7.6.4.2.

Tendons used for shrinkage and temperature reinforcement should be positioned as close as practicable to the mid-depth of the slab. In cases where the shrinkage and temperature tendons are used for supporting the principal tendons, variations from the slab centroid are permissible; however, the centroid of the shrinkage and temperature tendons should not fall outside the middle third of the slab thickness.

The effects of slab shortening should be evaluated to ensure the effectiveness of the prestressing. In most cases, the low level of prestressing recommended should not cause difficulties in a properly detailed structure. Additional attention may be required where thermal effects become significant.

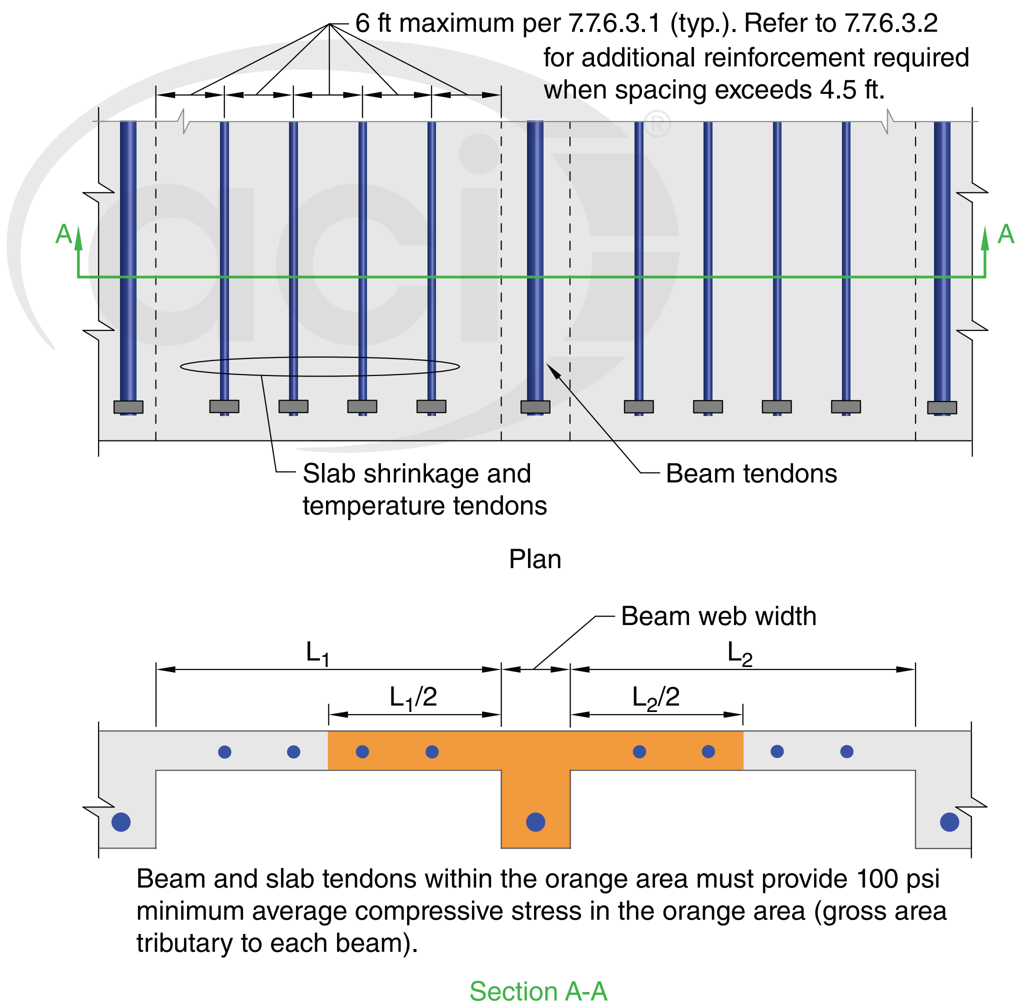

Fig. R7.6.4.2—Section through beams cast monolithically with slab.

7.6.4.2.1 For monolithic, cast-in-place, post-tensioned beam-and-slab construction, gross concrete area shall consist of the total beam area including the slab thickness and the slab area within half the clear distance to adjacent

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beam webs. It shall be permitted to include the effective force in beam tendons in the calculation of total prestress force acting on gross concrete area.

7.6.4.2.2 If slabs are supported on walls or not cast monolithically with beams, gross concrete area is the slab section tributary to the tendon or tendon group.

7.6.4.2.3 At least one tendon is required in the slab between faces of adjacent beams or walls.

7.7—Reinforcement detailing

7.7.1 *General*

7.7.1.1 Concrete cover for reinforcement shall be in accordance with 20.5.1.

7.7.1.2 Development lengths of deformed and prestressed reinforcement shall be in accordance with 25.4.

7.7.1.3 Splices of deformed reinforcement shall be in accordance with 25.5.

7.7.1.4 Bundled bars shall be in accordance with 25.6.

7.7.2 *Reinforcement spacing*

7.7.2.1 Minimum spacing s shall be in accordance with 25.2.

7.7.2.2 For nonprestressed and Class C prestressed slabs, spacing of bonded longitudinal reinforcement closest to the tension face shall not exceed s given in 24.3.

7.7.2.3 For nonprestressed and Class T and C prestressed slabs with unbonded tendons, maximum spacing s of deformed longitudinal reinforcement shall be the lesser of $3h$ and 18 in.

7.7.2.4 Maximum spacing, s, of reinforcement required by 7.5.2.3 shall be the lesser of $5h$ and 18 in.

7.7.3 *Flexural reinforcement in nonprestressed slabs*

7.7.3.1 Calculated tensile or compressive force in reinforcement at each section of the slab shall be developed on each side of that section.

7.7.3.2 Critical locations for development of reinforcement are points of maximum stress and points along the span where bent or terminated tension reinforcement is no longer required to resist flexure.

COMMENTARY

R7.7—Reinforcement detailing

R7.7.2 *Reinforcement spacing*

R7.7.2.3 Class T and C slabs prestressed with unbonded tendons rely solely on deformed reinforcement for crack control. Consequently, the requirements of 7.7.2.3 apply to Class T and C slabs prestressed with unbonded tendons.

R7.7.2.4 Spacing limitations for slab reinforcement are based on flange thickness, which for tapered flanges can be taken as the average thickness.

R7.7.3 *Flexural reinforcement in nonprestressed slabs*

R7.7.3.1 Requirements for development of reinforcement in one-way slabs are similar to those for beams. Refer to R9.7.3 for additional information.

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7.7.3.3 Reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance at least the greater of d and $12d_b$, except at supports of simply-supported spans and at free ends of cantilevers.

7.7.3.4 Continuing flexural tension reinforcement shall have an embedment length at least ℓ_d beyond the point where bent or terminated tension reinforcement is no longer required to resist flexure.

7.7.3.5 Flexural tension reinforcement shall not be terminated in a tension zone unless (a), (b), or (c) is satisfied:

(a) $V_u \leq (2/3)\phi V_n$ at the cutoff point.
(b) For No. 11 bars and smaller, continuing reinforcement provides double the area required for flexure at the cutoff point and $V_u \leq (3/4)\phi V_n$.
(c) Stirrup area in excess of that required for shear is provided along each terminated bar or wire over a distance $3/4d$ from the cutoff point. Excess stirrup area shall be not less than $60b_w s/f_{yt}$. Spacing s shall not exceed $d/(8\beta_b)$.

7.7.3.6 Adequate anchorage shall be provided for tension reinforcement where reinforcement stress is not directly proportional to moment, such as in sloped, stepped, or tapered slabs, or where tension reinforcement is not parallel to the compression face.

7.7.3.7 In slabs with spans not exceeding 10 ft, welded wire reinforcement, with wire size not exceeding W5 or D5, shall be permitted to be curved from a point near the top of slab over the support to a point near the bottom of slab at midspan, provided such reinforcement is continuous over, or developed at, the support.

7.7.3.8 *Termination of reinforcement*

7.7.3.8.1 At simple supports, at least one-third of the maximum positive moment reinforcement shall extend along the slab bottom into the support, except for precast slabs where such reinforcement shall extend at least to the center of the bearing length.

7.7.3.8.2 At other supports, at least one-fourth of the maximum positive moment reinforcement shall extend along the slab bottom into the support at least 6 in.

7.7.3.8.3 At simple supports and points of inflection, d_b for positive moment tension reinforcement shall be limited such that ℓ_d for that reinforcement satisfies (a) or (b). If reinforcement terminates beyond the centerline of supports by a standard hook or a mechanical anchorage at least equivalent to a standard hook, (a) or (b) need not be satisfied.

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R7.7.3.8 *Termination of reinforcement*

R7.7.3.8.1 Requirements for termination of reinforcement in one-way slabs are similar to those for beams. Refer to R9.7.3.8 for additional information.

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(a) $\ell_d \leq (1.3M_n/V_u + \ell_a)$ if end of reinforcement is confined by a compressive reaction
(b) $\ell_d \leq (M_n/V_u + \ell_a)$ if end of reinforcement is not confined by a compressive reaction

M_n is calculated assuming all reinforcement at the section is stressed to f_y and V_u is calculated at the section. At a support, ℓ_a is the embedment length beyond the center of the support. At a point of inflection, ℓ_a is the embedment length beyond the point of inflection, limited to the greater of d and $12d_b$.

7.7.3.8.4 At least one-third of the negative moment reinforcement at a support shall have an embedment length beyond the point of inflection at least the greatest of d, $12d_b$, and $\ell_n/16$.

7.7.4 *Flexural reinforcement in prestressed slabs*

7.7.4.1 External tendons shall be attached to the member in a manner that maintains the specified eccentricity between the tendons and the concrete centroid through the full range of anticipated member deflections.

7.7.4.2 If nonprestressed reinforcement is required to satisfy flexural strength, the detailing requirements of 7.7.3 shall be satisfied.

7.7.4.3 *Termination of prestressed reinforcement*

7.7.4.3.1 Post-tensioned anchorage zones shall be designed and detailed in accordance with 25.9.

7.7.4.3.2 Post-tensioning anchorages and couplers shall be designed and detailed in accordance with 25.8.

7.7.4.4 *Termination of deformed reinforcement in slabs with unbonded tendons*

7.7.4.4.1 Length of deformed reinforcement required by 7.6.2.3 shall be in accordance with (a) and (b):

(a) At least $\ell_n/3$ in positive moment areas and be centered in those areas
(b) At least $\ell_n/6$ on each side of the face of support

7.7.5 *Shear reinforcement*

7.7.5.1 If shear reinforcement is required, transverse reinforcement shall be detailed according to 9.7.6.2.

7.7.6 *Shrinkage and temperature reinforcement*

COMMENTARY

R7.7.4 *Flexural reinforcement in prestressed slabs*

R7.7.4.4 *Termination of deformed reinforcement in slabs with unbonded tendons*

R7.7.4.4.1 Requirements for termination of deformed reinforcement in one-way slabs with unbonded tendons are the same as those for beams. Refer to R9.7.4.4 for additional information.

R7.7.6 *Shrinkage and temperature reinforcement*

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7.7.6.1 Shrinkage and temperature reinforcement in accordance with 7.6.4 shall be placed perpendicular to flexural reinforcement.

7.7.6.2 *Nonprestressed reinforcement*

7.7.6.2.1 Spacing of deformed shrinkage and temperature reinforcement shall not exceed the lesser of 5*h* and 18 in.

7.7.6.3 *Prestressed reinforcement*

7.7.6.3.1 Spacing of slab tendons required by 7.6.4.2 and the distance between face of beam or wall to the nearest slab tendon shall not exceed 6 ft.

7.7.6.3.2 If spacing of slab tendons exceeds 4.5 ft, additional deformed shrinkage and temperature reinforcement conforming to 24.4.3 shall be provided parallel to the tendons, except 24.4.3.4 need not be satisfied. In calculating the area of additional reinforcement, it shall be permitted to take the gross concrete area in 24.4.3.2 as the slab area between faces of beams. This shrinkage and temperature reinforcement shall extend from the slab edge for a distance not less than the slab tendon spacing.

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R7.7.6.3 *Prestressed reinforcement*

R7.7.6.3.2 Widely spaced tendons result in non-uniform compressive stresses near slab edges. Additional deformed reinforcement is used to reinforce regions near the slab edge that may be inadequately compressed. Placement of this reinforcement is illustrated in Fig. R7.7.6.3.2.

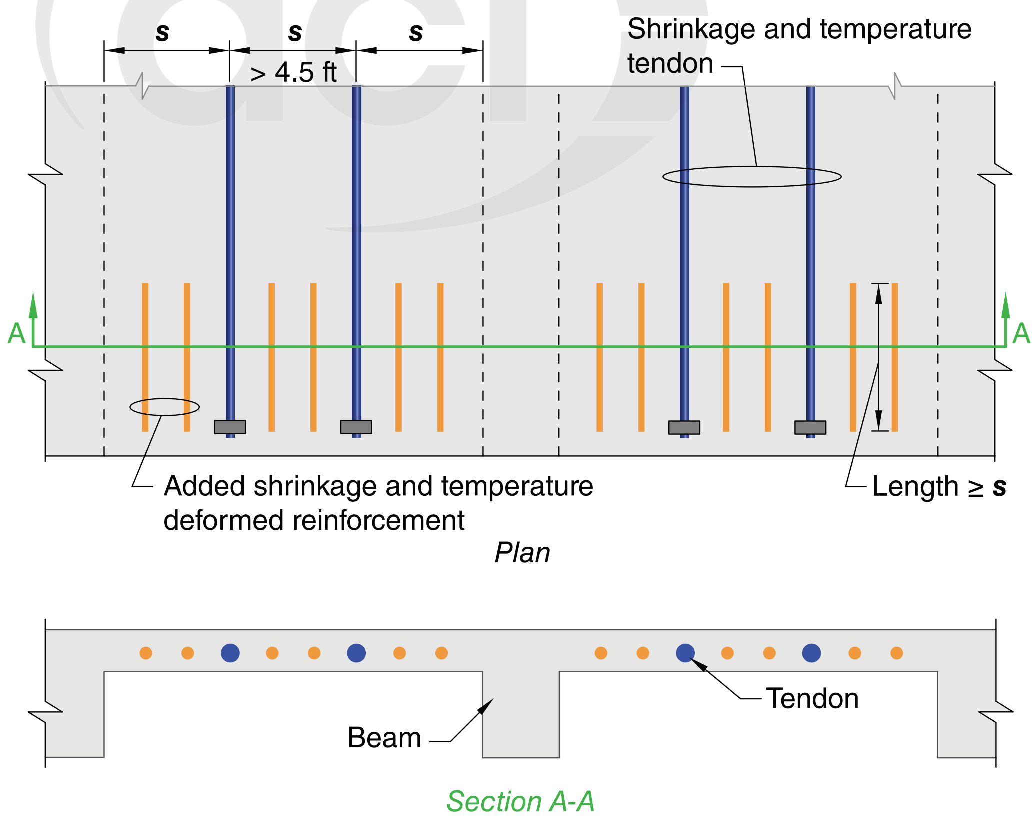

Fig. R7.7.6.3.2—Plan view at slab edge showing added shrinkage and temperature deformed reinforcement.

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7.7.7 *Structural integrity reinforcement in cast-in-place one-way slabs*

7.7.7.1 Longitudinal structural integrity reinforcement consisting of at least one-fourth of the maximum positive moment reinforcement shall be continuous.

7.7.7.2 Longitudinal structural integrity reinforcement at noncontinuous supports shall be developed in tension in accordance with 25.4 by substituting a bar stress of $1.25f_y$ for f_y at the face of the support.

7.7.7.3 If splices are necessary in continuous structural integrity reinforcement, the reinforcement shall be spliced near supports. Splices shall be mechanical or welded in accordance with 25.5.7 or Class B tension lap splices in accordance with 25.5.2.

COMMENTARY

R7.7.7 *Structural integrity reinforcement in cast-in-place one-way slabs*

R7.7.7.1 Positive moment structural integrity reinforcement for one-way slabs is intended to be similar to that for beams. Refer to R9.7.7 for a discussion of structural integrity reinforcement for beams.

Notes