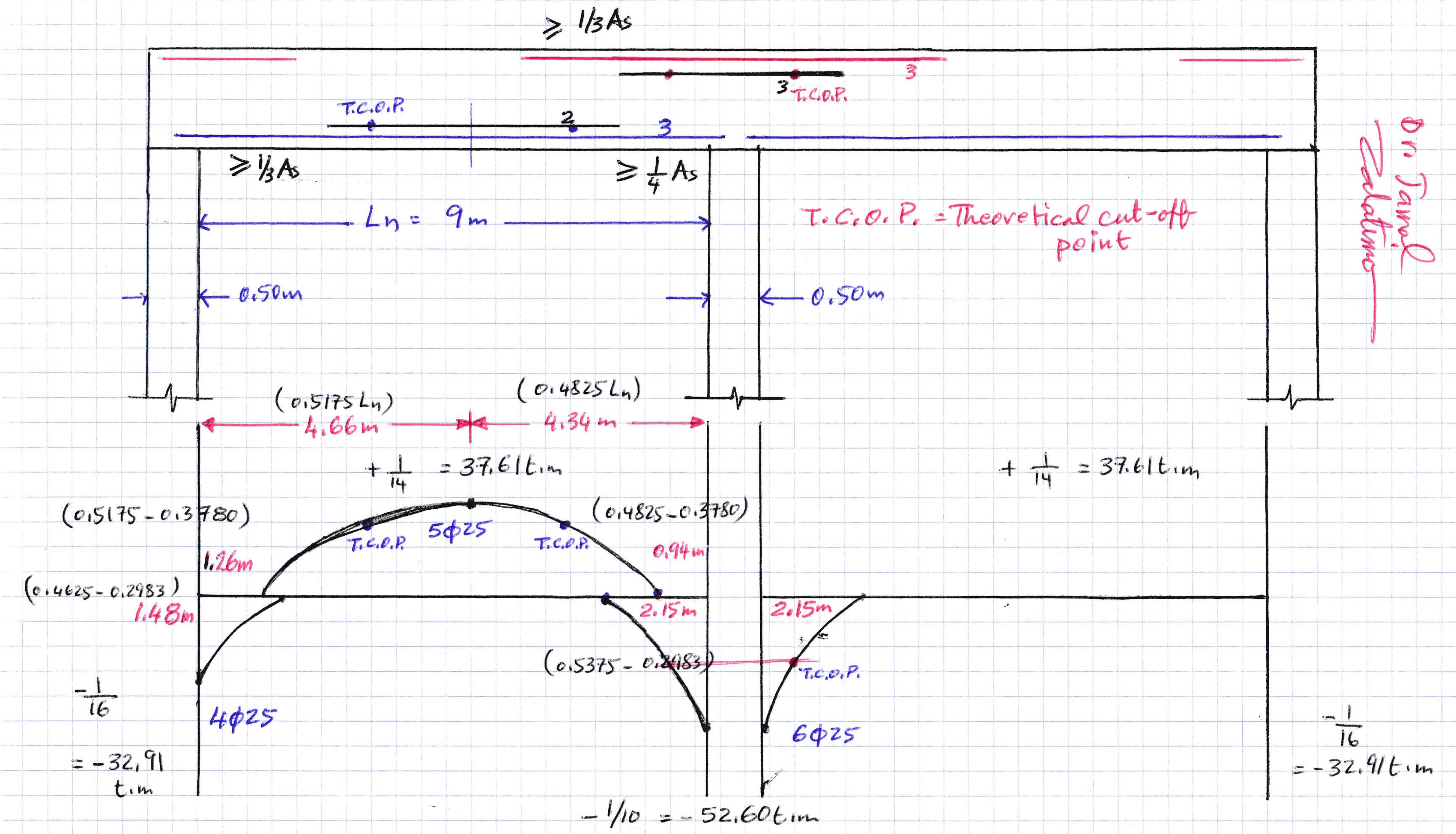

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$W_u = 6.5\ t/m$

$M_u = 52.6\ t.m$

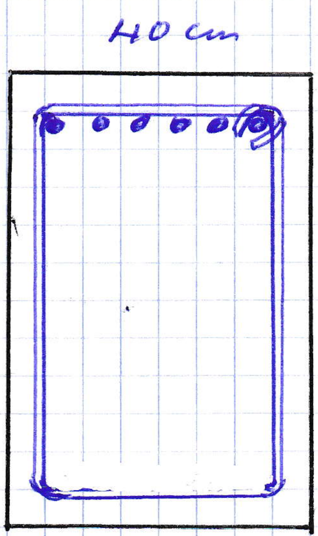
$M_{n\,req} = 58.45\ t.m$

$\dfrac{A_{s\,actual}}{A_{s\,max}\ (\epsilon_t = 0.005)} = 0.76$

6φ25 in one layer

$h = 60\ cm$

$d = 53.75\ cm$



$A_{s\,provided} = 6\phi 25 = 29.45\ cm^2$

$T_{actual} = 29.45 \times 4.2 = 123.7\ t$

$$a = \frac{123.7}{0.85(0.28)(40)} = 12.99\ cm$$

$$M_n = 123.7\left(\frac{53.75 - 12.99/2}{100}\right) = 58.45\ t.m$$

$$\phi M_n = (0.9)(58.45) = 52.61\ t.m$$

for $M_u = 37.61\ t.m$, $M_{n\,req} = 41.79\ t.m$

$5\phi 25 = 25.54\ cm^2$

for $M_u = 32.91\ t.m$, $M_{n\,req} = 36.57\ t.m$

$4\phi 25 = 19.63\ cm^2$

$$A_{s\,min} = \frac{0.25\sqrt{28}}{420}(40)(53.75) \geq \frac{1.4}{420}(40)(53.75)$$

$$= 6.77\ cm^2 \geq 7.17\ cm^2$$

Note $2\phi 25 = 9.82\ cm^2$

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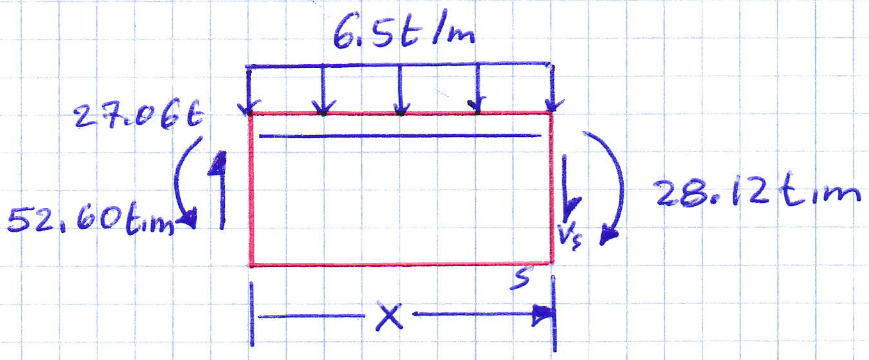
-ve Reinforcement Interior support

for the 3 Φ25 continuing bars,

A_s = 14.73 cm^2, T = 61.87 t, a = 6.50 cm

M_n = 31.24 t.m , ΦM_n = 28.12 t.m



from Fig 7.5.3, (b), the shear $V_u = 0.4625\, W_u L_n = 27.06\,t$

$\Sigma M @ S = 0$ (+ clockwise)

$$-52.60 + 27.06x - \frac{6.5x^2}{2} + 28.12 = 0$$

$x = 1.03$ m

d = 53.75 cm, $12 d_b$ = 30 cm (use 54 cm)

∴ from the face of support,

available length = 103 + 54 = 157 cm

Category A, $L_d = \frac{(420)(1.3)(1.0)}{1.7\,(1.0)\sqrt{28}}(2.5) = 152$ cm

∴ available length = 157 cm > Required length, L_d = 152 cm

∴ Total length of the short bars = 157 + 50 + 157 = 364 cm

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beyond the inflection point:

$\geq 1/3 A_s$

Distance: $d = 53.75$ cm

$12 d_b = 30$ cm

$L_n/16 = 56.25$ cm (use 57 cm)

∴ Available length = 215 + 57 − 103 = 169 cm

> Required length, L_d = 152 cm

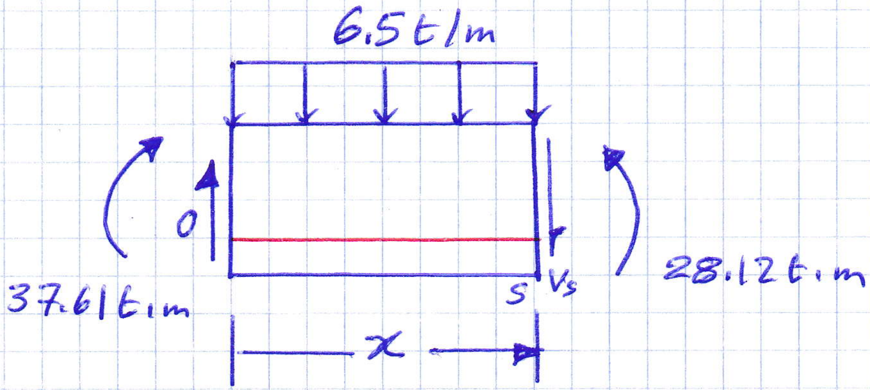
∴ total length of the short bars = 364 cm

total length of the long bars = (215 + 57) x 2 + 50 = 594 cm

Positive Reinforcement

For the continuing bars, $3\phi 25$ — Dr. Jamal Zalatimo

$$\phi M_n = 28.12\ t.m$$



$\Sigma M @ S = 0$

$$+37.61 - \frac{6.5x^2}{2} - 28.12 = 0$$

$$x = 1.71\ m$$

$d = 53.75\ cm$, $12d_b = 30\ cm$ (use 54 cm)

available length $= 171 + 54 = 225\ cm$

Category A, $L_d = \frac{(420)(1.0)(1.0)}{1.7(1.0)(\sqrt{28})}(2.5) = 117\ cm$

∴ available length $= 225\ cm$ > Required length, $L_d = 117\ cm$

∴ total length of the short bars,

$= 225 \times 2 = 450\ cm$

+ve reinforcement exterior support

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For illustration, the left support is treated as a simple support,

$$\underbrace{\frac{1.3\,M_n}{V_u} + L_a}_{\text{available}} \geq L_d$$

$L_d = 117\,cm$

$M_n = 31.24\ t.m$

from 7.5.1 (a), $V_u = 0.4264\,(6.5)(9)$
$= 29.94\,t$

L_a = Distance extended beyond the ℄ of support.

The bottom bars need only be extended a distance of 15 cm into the support, for which $L_a = 0$

$$\frac{1.3\,M_n}{V_u} + L_a = \frac{1.3\,(31.24)}{29.94} \times 100 + 0$$

$$= 163\,cm > L_d = 117\,cm$$

∴ OK

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+ve reinforcement interior support

On the other side, (continuity)

$$\frac{M_n}{V_u} + L_a \geq L_d$$

(available)

$L_d = 117\,cm$

$M_n = 31.24\ t.m$, $V_u = 29.94\ t$

L_a : actual $= 94 + 15 = 109\ cm$

usable $= d = 53.75$, $12 d_b = 30\,cm$ → larger $= 54\,cm$

smaller $= 54\ cm$

$\therefore L_a = 54\ cm$

$$\frac{M_n}{V_u} + L_a = \frac{3124\ t.cm}{29.94\ t} + 54 = 158\ cm$$

$> L_d = 117\ cm$

$\therefore$ ok

$\therefore$ Total length of the long bars $= 900 + 15 + 15 = 930\ cm$

-ve reinforcement

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exterior support

For the -ve reinforcement at the discontinuous support,

$L_d = 152$ cm , Available $\simeq 45$ cm

∴ A standard hook is required, but must be checked.

$$l_{dh} = \frac{0.24(1.0)(420)}{(1.0)(\sqrt{28})}(2.5)$$

$$\times 0.7$$

$$\times \frac{17.45}{19.63}$$

$$= 29.63 \text{ cm} \quad (\text{use } 30 \text{ cm})$$

$$> 8d_b = 20 \text{ cm}$$

$$> 15 \text{ cm}$$

∴ $l_{dh} = 30$ cm

Available = 45 cm ∴ OK

To the right of the face of the support,

available = 126 + 57 = 183 cm

$> L_d = 152$ cm

∴ OK

CODE

COMMENTARY

$\sqrt{f_c'}$ up to 8.3 MPa, and because of the long-standing use of the $\sqrt{f_c'}$ in design, ACI Committee 318 has chosen not to change the exponent applied to the compressive strength used to calculate development and lap splice lengths, but rather to set an upper limit of 8.3 MPa on $\sqrt{f_c'}$.

25.4.2 *Development of deformed bars and deformed wires in tension*

25.4.2.1 Development length ℓ_d for deformed bars and deformed wires in tension shall be the greater of (a) and (b):

(a) Length calculated in accordance with 25.4.2.2 or 25.4.2.3 using the applicable modification factors of 25.4.2.4

(b) 300 mm

25.4.2.2 For deformed bars or deformed wires, ℓ_d shall be calculated in accordance with Table 25.4.2.2.

Table 25.4.2.2—Development length for deformed bars and deformed wires in tension

Spacing and cover	No. 19 and smaller bars and deformed wires	No. 22 and larger bars
Clear spacing of bars or wires being developed or lap spliced not less than d_b, clear cover at least d_b, and stirrups or ties throughout ℓ_d not less than the Code minimum or Clear spacing of bars or wires being developed or lap spliced at least $2d_b$ and clear cover at least d_b	$\left(\frac{f_y\psi_t\psi_e}{2.1\lambda\sqrt{f_c'}}\right)d_b$	$\left(\frac{f_y\psi_t\psi_e}{1.7\lambda\sqrt{f_c'}}\right)d_b$
Other cases	$\left(\frac{f_y\psi_t\psi_e}{1.4\lambda\sqrt{f_c'}}\right)d_b$	$\left(\frac{f_y\psi_t\psi_e}{1.1\lambda\sqrt{f_c'}}\right)d_b$

R25.4.2 *Development of deformed bars and deformed wires in tension*

R25.4.2.1 This provision gives a two-tier approach for the calculation of tension development length. The user can either use the simplified provisions of 25.4.2.2 or the general development length equation (Eq. (25.4.2.3a)), which is based on the expression previously endorsed by ACI 408.1R (Jirsa et al. 1979). In Table 25.4.2.2, ℓ_d is based on two preselected values of $(c_b + K_{tr})/d_b$, whereas ℓ_d from Eq. (25.4.2.3a) is based on the actual $(c_b + K_{tr})/d_b$.

Although there is no requirement for transverse reinforcement along the tension development or lap splice length, research (Azizinamini et al. 1999a,b) indicates that in concrete with very high compressive strength, brittle anchorage failure may occur for bars with inadequate transverse reinforcement. In lap splice tests of No. 25 and No. 36 bars in concrete with an f_c' of approximately 105 MPa, transverse reinforcement improved ductile anchorage behavior.

R25.4.2.2 This provision recognizes that many current practical construction cases use spacing and cover values along with confining reinforcement, such as stirrups or ties, that result in a value of $(c_b + K_{tr})/d_b$ of at least 1.5. Examples include a minimum clear cover of d_b along with either minimum clear spacing of $2d_b$, or a combination of minimum clear spacing of d_b and minimum ties or stirrups. For these frequently occurring cases, the development length for larger bars can be taken as $\ell_d = [f_y\psi_t\psi_e/(1.7\lambda\sqrt{f_c'})]d_b$. In the formulation of the provisions in ACI 318-95, a comparison with past provisions and a check of a database of experimental results maintained by ACI 408.1R indicated that for No. 19 deformed bars and smaller, as well as for deformed wire, the development lengths could be reduced 20 percent using $\psi_s = 0.8$. This is the basis for the *No. 19 and smaller bars and deformed wires* column of Table 25.4.2.2. With less cover and in the absence of minimum ties or stirrups, the minimum clear spacing limits of 25.2.1 and the minimum concrete cover requirements of 20.6.1.3 result in minimum values of c_b equal to d_b. Thus, for "other cases," the values are based on using $(c_b + K_{tr})/d_b = 1.0$ in Eq. (25.4.2.3a).

The user may easily construct simple, useful expressions. For example, in all members with normalweight concrete ($\lambda = 1.0$), uncoated reinforcement ($\psi_e = 1.0$), No. 22 and larger bottom bars ($\psi_t = 1.0$) with $f_c' = 28$ **MPa**, and Grade 420 reinforcement, the expressions reduce to

$$\ell_d = \frac{(420)(1.0)(1.0)}{1.7(1.0)\sqrt{28}}d_b = 47d_b$$

CODE

Table 25.4.2.4—Modification factors for development of deformed bars and deformed wires in tension

Modification factor	Condition	Value of factor
Lightweight λ	Lightweight concrete	0.75
	Lightweight concrete, where f_{ct} is specified	In accordance with 19.2.4.3
	Normalweight concrete	1.0
Epoxy[1] ψ_e	Epoxy-coated or zinc and epoxy dual-coated reinforcement with clear cover less than $3d_b$ or clear spacing less than $6d_b$	1.5
	Epoxy-coated or zinc and epoxy dual-coated reinforcement for all other conditions	1.2
	Uncoated or zinc-coated (galvanized) reinforcement	1.0
Size ψ_s	No. 22 and larger bars	1.0
	No. 19 and smaller bars and deformed wires	0.8
Casting position[1] ψ_t	More than 300 mm of fresh concrete placed below horizontal reinforcement	1.3
	Other	1.0

[1]The product $\psi_t\psi_e$ need not exceed 1.7.

25.4.3 *Development of standard hooks in tension*

25.4.3.1 Development length ℓ_{dh} for deformed bars in tension terminating in a standard hook shall be the greater of (a) through (c):

(a) $\left(\dfrac{0.24 f_y \psi_e \psi_c \psi_r}{\lambda\sqrt{f_c'}}\right) d_b$ with ψ_e, ψ_c, ψ_r, and λ given in 25.4.3.2.

(b) $8d_b$

(c) 150 mm

COMMENTARY

lightweight concrete. Section 25.4.2.4 allows a higher factor to be used when the splitting tensile strength of the lightweight concrete is specified. Refer to 19.2.4.

The epoxy factor ψ_e is based on studies (Treece and Jirsa 1989; Johnston and Zia 1982; Mathey and Clifton 1976) of the anchorage of epoxy-coated bars that show bond strength is reduced because the coating prevents adhesion and lowers the coefficient of friction between the bar and the concrete. The factors reflect the type of anchorage failure likely to occur. If the cover or spacing is small, a splitting failure can occur and the anchorage or bond strength is substantially reduced. If the cover and spacing between bars is large, a splitting failure is precluded and the effect of the epoxy coating on anchorage strength is not as large. Studies (Orangun et al. 1977) have shown that although the cover or spacing may be small, the anchorage strength may be increased by adding transverse reinforcement crossing the plane of splitting, and restraining the splitting crack.

Because the bond of epoxy-coated bars or zinc and epoxy dual-coated bars is already reduced due to the loss of adhesion and lower coefficient of friction between the bar and the concrete, an upper limit of 1.7 is established for the product of the factors for top reinforcement casting position and epoxy-coated reinforcement or zinc and epoxy dual-coated reinforcement.

The reinforcement size factor ψ_s reflects the more favorable performance of smaller-diameter reinforcement.

The reinforcement location or casting position factor ψ_t accounts for the position of the reinforcement in freshly placed concrete. The factor 1.3 is based on research (Jirsa and Breen 1981; Jeanty et al. 1988). The application of the casting position factor should be considered in determination of development lengths for inclined reinforcement.

R25.4.3 *Development of standard hooks in tension*

R25.4.3.1 Study of failures of hooked bars indicate that splitting of the concrete cover in the plane of the hook is the primary cause of failure and that splitting originates at the inside of the hook where local stress concentrations are very high. Thus, hook development is a direct function of bar diameter d_b, which governs the magnitude of compressive stresses on the inside of the hook. Only standard hooks (refer to 25.3.1) are considered, and the influence of larger bend radii cannot be evaluated by 25.4.3.

The hooked bar anchorage provisions give the total hooked bar embedment length as shown in Table 25.3.1. The development length ℓ_{dh} is measured from the critical section to the outside end (or edge) of the hook.

The effects of bar yield strength, excess reinforcement, lightweight concrete, and factors to reflect the resistance to splitting provided from confinement by concrete and transverse ties or stirrups are based on recommendations from ACI 408.1R and Jirsa et al. (1979).

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CODE

25.4.3.2 For the calculation of ℓ_{dh}, modification factors shall be in accordance with Table 25.4.3.2. Factors ψ_c and ψ_r shall be permitted to be taken as 1.0. At discontinuous ends of members, 25.4.3.3 shall apply.

Table 25.4.3.2—Modification factors for development of hooked bars in tension

Modification factor	Condition	Value of factor
Lightweight λ	Lightweight concrete	0.75
	Normalweight concrete	1.0
Epoxy ψ_e	Epoxy-coated or zinc and epoxy dual-coated reinforcement	1.2
	Uncoated or zinc-coated (galvanized) reinforcement	1.0
Cover ψ_c	For No. 36 bar and smaller hooks with side cover (normal to plane of hook) $\geq$ 65 mm and for 90-degree hook with cover on bar extension beyond hook $\geq$ 50 mm	0.7
	Other	1.0
Confining reinforcement ψ_r[2]	For 90-degree hooks of No. 36 and smaller bars (1) enclosed along ℓ_{dh} within ties or stirrups[1] perpendicular to ℓ_{dh} at $s \leq 3d_b$, or (2) enclosed along the bar extension beyond hook including the bend within ties or stirrups[1] perpendicular to ℓ_{ext} at $s \leq 3d_b$	0.8
	For 180-degree hooks of No. 36 and smaller bars enclosed along ℓ_{dh} within ties or stirrups[1] perpendicular to ℓ_{dh} at $s \leq 3d_b$	
	Other	1.0

[1]The first tie or stirrup shall enclose the bent portion of the hook within $2d_b$ of the outside of the bend.

[2]d_b is the nominal diameter of the hooked bar.

COMMENTARY

A minimum value of ℓ_{dh} is specified to prevent failure by direct pullout in cases where a hook may be located very near the critical section.

R25.4.3.2 Unlike straight bar development, no distinction is made for casting position.

The epoxy factor ψ_e is based on tests (Hamad et al. 1993) that indicate the development length for hooked bars should be increased by 20 percent to account for reduced bond when reinforcement is epoxy coated.

The confining reinforcement factor ψ_r is based on tests (Jirsa and Marques 1975) that indicate closely spaced ties at or near the bend portion of a hooked bar are most effective in confining the hooked bar. For construction purposes, this is not always practicable. The cases where the modification factor ψ_r may be used are illustrated in Fig. R25.4.3.2a and R25.4.3.2b. Figure R25.4.3.2a shows placement of ties or stirrups perpendicular to the bar being developed, spaced along the development length ℓ_{dh} of the hook: Figure R25.4.3.2b shows placement of ties or stirrups parallel to the bar being developed along the length of the tail extension of the hook plus bend. The latter configuration would be typical in a beam-column joint.

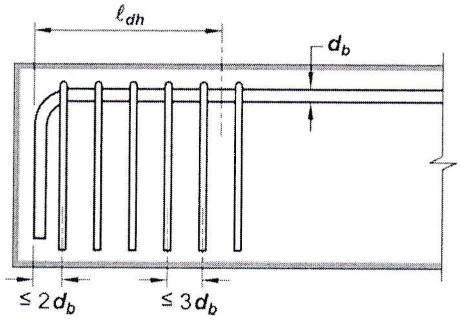


Fig. R25.4.3.2a—Ties or stirrups placed perpendicular to the bar being developed, spaced along the development length ℓ_{dh}.

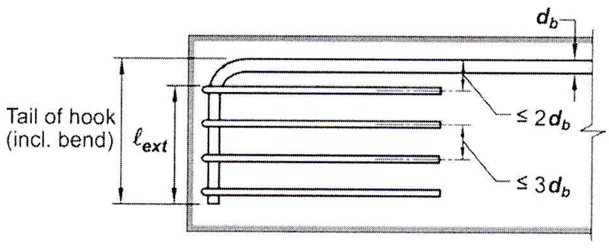


Fig. R25.4.3.2b—Ties or stirrups placed parallel to the bar being developed, spaced along the length of the tail extension of the hook plus bend.

CODE

Table 25.2.4—Minimum center-to-center spacing of pretensioned strands at ends of members

f_{ci}', MPa	Nominal strand diameter, mm	Minimum s
< 28	All	$4d_b$
≥ 28	< 12.7 mm	$4d_b$
	12.7 mm	45 mm
	15.2 mm	50 mm

25.2.5 For pretensioned wire at ends of a member, minimum center-to-center spacing s shall be the greater of $5d_b$ and $[(4/3)d_{agg} + d_b]$.

25.2.6 Reduced vertical spacing including bundling of prestressed reinforcement shall be permitted in the middle portion of a span.

25.3—Standard hooks, seismic hooks, crossties, and minimum inside bend diameters

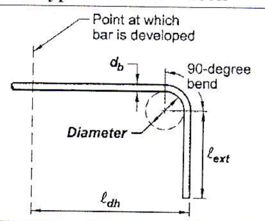
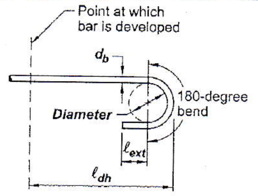
25.3.1 Standard hooks for the development of deformed bars in tension shall conform to Table 25.3.1.

COMMENTARY

R25.3—Standard hooks, seismic hooks, crossties, and minimum inside bend diameters

R25.3.1 Standard bends in reinforcing bars are described in terms of the inside diameter of bend because the inside bend diameter is easier to measure than the radius of bend. The primary factors affecting the minimum bend diameter are feasibility of bending without breakage and avoidance of crushing the concrete inside the bend.

Table 25.3.1—Standard hook geometry for development of deformed bars in tension

Type of standard hook	Bar size	Minimum inside bend diameter, mm	Straight extension[1] ℓ_{ext}, mm	Type of standard hook
90-degree hook	No. 10 through No. 25	$6d_b$	$12d_b$	
	No. 29 through No. 36	$8d_b$		
	No. 43 and No. 57	$10d_b$		
180-degree hook	No. 10 through No. 25	$6d_b$	Greater of $4d_b$ and 65 mm	
	No. 29 through No. 36	$8d_b$		
	No. 43 and No. 57	$10d_b$		

[1]A standard hook for deformed bars in tension includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

25.3.2 Minimum inside bend diameters for bars used as transverse reinforcement and standard hooks for bars used to anchor stirrups, ties, hoops, and spirals shall conform to Table 25.3.2. Standard hooks shall enclose longitudinal reinforcement.

R25.3.2 Standard stirrup, tie, and hoop hooks are limited to No. 25 bars and smaller, and the 90-degree hook with $6d_b$ extension is further limited to No. 16 bars and smaller, as the result of research showing that larger bar sizes with 90-degree hooks and $6d_b$ extensions tend to spall off the cover concrete when the reinforcement is stressed and the hook straightens.

CODE

25.4.9 *Development of deformed bars and deformed wires in compression*

25.4.9.1 Development length ℓ_{dc} for deformed bars and deformed wires in compression shall be the greater of (a) and (b)

(a) Length calculated in accordance with 25.4.9.2
(b) 200 mm

25.4.9.2 ℓ_{dc} shall be the greater of (a) and (b), using the modification factors of 25.4.9.3:

(a) $\left(\dfrac{0.24 f_y \psi_r}{\lambda \sqrt{f_c'}}\right) d_b$

(b) $0.043 f_y \psi_r d_b$

25.4.9.3 For the calculation of ℓ_{dc}, modification factors shall be in accordance with Table 25.4.9.3, except ψ_r shall be permitted to be taken as 1.0.

Table 25.4.9.3—Modification factors for deformed bars and wires in compression

Modification factor	Condition	Value of factor
Lightweight λ	Lightweight concrete	0.75
	Lightweight concrete, if f_{ct} is specified	In accordance with 19.2.4.3
	Normalweight concrete	1.0
Confining reinforcement ψ_r	Reinforcement enclosed within (1), (2), (3), or (4): (1) a spiral (2) a circular continuously wound tie with $d_b \geq 6$ mm and pitch 100 mm (3) No. 13 bar or MD130 wire ties in accordance with 25.7.2 spaced $\leq$ 100 mm on center (4) hoops in accordance with 25.7.4 spaced $\leq$ 100 mm on center	0.75
	Other	1.0

25.4.10 *Reduction of development length for excess reinforcement*

25.4.10.1 Reduction of development lengths defined in 25.4.2.1(a), 25.4.3.1(a), 25.4.6.1(a), 25.4.7.1(a), and 25.4.9.1(a) shall be permitted by use of the ratio $(A_{s,required})/(A_{s,provided})$, except where prohibited by 25.4.10.2. The modified development lengths shall not be less than the respective minimums specified in 25.4.2.1(b), 25.4.3.1(b), 25.4.3.1(c), 25.4.6.1(b), 25.4.7.1(b), and 25.4.9.1(b).

25.4.10.2 A reduction of development length in accordance with 25.4.10.1 is not permitted for (a) through (e).

COMMENTARY

R25.4.9 *Development of deformed bars and deformed wires in compression*

R25.4.9.1 The weakening effect of flexural tension cracks is not present for bars and wires in compression, and usually end bearing of the bars on the concrete is beneficial. Therefore, shorter development lengths are specified for compression than for tension.

R25.4.9.2 The constant 0.043 has units of mm^2/N.

The term λ is provided in the expression for development in 25.4.9.2 recognizing that there are no known test data on compression development in lightweight concrete but that splitting is more likely in lightweight concrete.

R25.4.9.3 The development length may be reduced 25 percent when the reinforcement is enclosed within closely spaced spirals, ties, or hoops.

R25.4.10 *Reduction of development length for excess reinforcement*

R25.4.10.1 A reduction in development length is permitted in limited circumstances if excess reinforcement is provided.

R25.4.10.2 The excess reinforcement factor $(A_{s,required}/A_{s,provided})$, applicable to deformed bars without heads, is not applicable for headed bars where force is transferred through

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