CODE

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
Confining reinforcement ψ_r	For No. 36 and smaller bars with $A_{th} \geq 0.4A_{hs}$ or s[1] $\geq 6d_b$[2]	1.0
	Other	1.6
Location ψ_o	For No. 36 and smaller diameter hooked bars: (1) Terminating inside column core with side cover normal to plane of hook ≥ 65 mm, or (2) With side cover normal to plane of hook ≥ $6d_b$	1.0
	Other	1.25
Concrete strength ψ_c	For $f_c' < 42$ MPa	$f_c'/105 + 0.6$
	For $f_c' \geq 42$ MPa	1.0

[1]s is minimum center-to-center spacing of hooked bars.

[2]d_b is nominal diameter of hooked bar.

25.4.3.3 The total cross-sectional area of ties or stirrups confining hooked bars A_{th} shall consist of (a) or (b):

(a) Ties or stirrups that enclose the hook and satisfy 25.3.2.

(b) Other reinforcement enclosing the hook, that extends at least $0.75\ell_{dh}$ from the enclosed hook in the direction of the bar in tension, and is in accordance with (1) or (2). For members with confining reinforcement that is both parallel and perpendicular to ℓ_{dh}, it shall be permitted to use the value of A_{th} based on (1) or (2) that results in the lower value of ℓ_{dh}.

(1) Two or more ties or stirrups shall be provided parallel to ℓ_{dh} enclosing the hooks, evenly distributed with a center-to-center spacing not exceeding $8d_b$, and within $15d_b$ of the centerline of the straight portion of the hooked bars, where d_b is the nominal diameter of the hooked bar.

(2) Two or more ties or stirrups shall be provided perpendicular to ℓ_{dh}, enclosing the hooked bars, and evenly distributed along ℓ_{dh} with a center-to-center spacing not exceeding $8d_b$, where d_b is the nominal diameter of the hooked bar.

COMMENTARY

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 location factor ψ_o is based on tests (Johnson and Jirsa 1981; Sperry et al. 2017a,b) demonstrating that the development length of hooked bars anchored within a column core with side cover less than 65 mm or in other members with side cover less than $6d_b$ needs to be 25 percent longer than in similar members with larger cover.

The confining reinforcement factor ψ_r is based on test results reported by Ajaam et al. (2018). A value of 1.0 is used for ψ_r for widely-spaced hooked bars, $s \geq 6d_b$, and for hooked bars with $A_{th}/A_{hs} \geq 0.4$. Where bars are closely spaced or $A_{th}/A_{hs} < 0.4$, the confinement factor is 1.6. Because no test results are available for No. 43 and No. 57 bars, the values of ψ_r for hooked bars larger than No. 36 are the same as those for No. 36 and smaller diameter hooked bars without confining reinforcement. No tests were performed to verify extrapolation to large bars in concrete with strengths greater than 70 MPa. When calculated using 25.4.3.1(a) and the factors in 25.4.3.2, development lengths are, however, as much as 50 percent longer than required by Codes prior to ACI 318-19.

R25.4.3.3 Distribution of confining reinforcement is shown in Fig. R25.4.3.3a and 25.4.3.3b. Figure R25.4.3.3a shows placement of ties or stirrups parallel to the bar being developed along the length of the tail extension of the hook plus bend. This configuration would be typical in a beam-column joint. Tests show that confining reinforcement oriented parallel or perpendicular to the development length of the hooked bar, and located within the regions defined in 25.4.3.3 (a) or (b), contributes to anchorage strength in proportion to the area of the confining reinforcement for both 90- and 180-degree hooks (Sperry et al. 2017b). Figure R25.4.3.3b shows placement of ties or stirrups perpendicular to the bar being developed, spaced along $0.75\ell_{dh}$ of the hook. Tests used to establish these criteria were based on beam-column joints with perimeter ties and stirrups only (Sperry et al. 2017a; Ajaam et al. 2018). Both legs of individual stirrups and individual ties contribute to A_{th}.