CODE

25.4.2.4 For deformed bars or deformed wires, ℓ_d shall be calculated by:

$$\ell_d = \frac{f_y}{1.1\lambda\sqrt{f_c'}}\frac{\psi_t\psi_e\psi_s\psi_g}{\left(\frac{c_b+K_{tr}}{d_b}\right)}d_b \qquad (25.4.2.4a)$$

in which the confinement term $(c_b + K_{tr})/d_b$ shall not exceed 2.5, and

$$K_{tr} = \frac{40A_{tr}}{sn} \qquad (25.4.2.4b)$$

where n is the number of bars or wires being developed or lap spliced along the plane of splitting. It shall be permitted to use $K_{tr} = 0$ as a design simplification even if transverse reinforcement is present or required.

25.4.2.5 For the calculation of ℓ_d, modification factors shall be in accordance with Table 25.4.2.5.

COMMENTARY

cover of d_b and a minimum clear spacing of d_b are provided along with minimum ties or stirrups, then $\ell_d = 47d_b$. The penalty for spacing bars closer or providing less cover is the requirement that $\ell_d = 71d_b$.

R25.4.2.4 Equation (25.4.2.4a) includes the effects of all variables controlling the development length. In Eq. (25.4.2.4a), c_b is a factor that represents the least of the side cover, the concrete cover to the bar or wire (in both cases measured to the center of the bar or wire), or one-half the center-to-center spacing of the bars or wires. K_{tr} is a factor that represents the contribution of confining reinforcement across potential splitting planes. ψ_t is the reinforcement location factor to reflect the effect of the casting position (that is, formerly denoted as "top bar effect"). ψ_e is a coating factor reflecting the effects of epoxy coating. There is a limit on the product $\psi_t\psi_e$. The reinforcement size factor ψ_s reflects the more favorable performance of smaller-diameter reinforcement. ψ_g is the reinforcement grade factor accounting for the yield strength of the reinforcement. A limit of 2.5 is placed on the term $(c_b + K_{tr})/d_b$. When $(c_b + K_{tr})/d_b$ is less than 2.5, splitting failures are likely to occur. For values above 2.5, a pullout failure is expected, and an increase in cover or transverse reinforcement is unlikely to increase the anchorage capacity.

Many practical combinations of side cover, clear cover, and confining reinforcement can be used with 25.4.2.4 to produce significantly shorter development lengths than allowed by 25.4.2.3. For example, bars or wires with minimum clear cover not less than $2d_b$ and minimum clear spacing not less than $4d_b$ and without any confining reinforcement would have a $(c_b + K_{tr})/d_b$ value of 2.5 and would require a development length of only $28d_b$ for the example in R25.4.2.3.

Before ACI 318-08, Eq. (25.4.2.4b) for K_{tr} included the yield strength of transverse reinforcement. The current expression includes only the area and spacing of the transverse reinforcement and the number of wires or bars being developed or lap spliced because tests demonstrate that transverse reinforcement rarely yields during a bond failure (Azizinamini et al. 1995).

Terms in Eq. (25.4.2.4a) may be disregarded if such omission results in longer and, hence, more conservative, development lengths.

R25.4.2.5 The lightweight factor λ for calculating development length of deformed bars and deformed wire in tension is the same for all types of lightweight concrete. Research does not support the variations of this factor in Codes prior to 1989 for all-lightweight and sand-lightweight concrete (ACI 408R).

The reinforcement grade factor ψ_g accounts for the effect of reinforcement yield strength on required development length. Research has shown that required development length increases disproportionately with increases in yield strength (Orangun et al. 1977; Canbay and Frosch 2005).

The epoxy factor ψ_e is based on studies (Treece and Jirsa 1989; Johnston and Zia 1982; Mathey and Clifton 1976) of