Development Length

More Complexity or Saving Grace?

By Jerod G. Johnson, Ph.D., S.E.

For most of us, the provisions for development length and lap splices of reinforcing steel are taken from ACI 318-11, Table 12.2.2. From this, we can surmise that basic development lengths (l_d) follow the form:

$$l_d = \left(\frac{1}{25}, \frac{1}{20}, \frac{3}{50}, \text{ or } \frac{3}{40} \right) \frac{f_y \Psi_t \Psi_e \lambda}{\sqrt{f'_c}} d_b$$

where f_y and f'_c represent steel yield and concrete compressive strengths, respectively; d_b represents bar diameter; Ψ_t and Ψ_e represent bar location and coating factors; and λ accounts for the use of lightweight concrete.

As we examine this relationship and the associated variables, we may find that some simplifications are in order based on rational assumptions. If bars are not epoxy-coated and concrete is normal weight, we can immediately eliminate two variables (Ψ_e and λ), giving them a default value of 1.0. Furthermore, we can eliminate two of the four fractional coefficients listed (3/50 and 3/40) when we confirm that minimum thresholds of bar spacing and cover are established. As a result, the expression for development length may summarily be reduced to the following:

$$l_d = \left(\frac{1}{25}, \text{ or } \frac{1}{20} \right) \frac{f_y \Psi_t}{\sqrt{f'_c}} d_b$$

If we further assume that the material properties (f_y and f'_c) are constant, the only differentiators become the fraction coefficient (which is basically the size factor) and whether more than 12 inches of fresh concrete is cast below the bar (Ψ_t). With this as a basis, the development of standard schedules, details and embedment length versus bar diameter relationships become fairly trivial. This might even be the basis of standard lap splice length schedules used by your office. However, the simplicity introduced within this discussion does come with a price – a conservative design.

Perhaps you have been a party to the following scenario, or something akin to it: You get a call from a contractor planning to place a large volume of concrete the next day. Final inspection of rebar placement has occurred and the inspector has found, due to some unknown error, that the lap splices on a particular size bar in the bottom a mat foundation are short by 6 inches. The contractor is asking for advice. Do you:

a) instruct him to cancel his concrete pour until the problem can be fixed?
b) allow him to continue as planned, but add more bars (excess reinforcement) at the lap splice that will effectively lap with each of the bars in question?
c) tell him that he can proceed if he splices the bars with mechanical couplers?
d) allow him to proceed without changes, since your design was conservative?

Certainly any of these options might be pursued, but the first three are not likely to be favored by the contractor and may be injurious to the good working relationship that you have been striving to foster with him for many years. He would be happy with option D initially, but upon further consideration may wonder how much money is being wasted on the project due to your conservative design. Is there another alternative?

ACI 318 allows for a rational and simple solution. While the provisions of ACI 318 section 12.2.3 are secondary to the aforementioned section 12.2.2, fundamental research led to the development of the following empirical relationship (ACI 318, Equation 12-1):

$$l_d = \left(\frac{3}{40} \frac{f_y}{\sqrt{f'_c}} \frac{\Psi_t \Psi_e \Psi_s \lambda}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$

While this equation has considerable similarity to the equations of ACI 318 section 12.2.2, it also includes a distinct difference: the $(c_b+K_{tr})/d_b$ term offers the potential for explicitly including the benefits of other factors that contribute to development length, specifically bar cover/spacing (c_b) and transverse reinforcement index (K_{tr}). As such, the results of this calculation offer a less conservative result for development length, but with increased complexity of the calculation itself. For this equation, ACI recognizes that, in virtually all cases, the $(c_b+K_{tr})/d_b$ value is at least 1.5. Hence, simply substituting this value offers a conservative result that is reflected in the relationships of ACI 318 section 12.2.2. The positive of this is a simple design; the negative is a conservative design. (As a side note, one wonders if ACI 318 Appendix D might someday offer a similarly simple but conservative approach. We can only hope!)

Consider our contractor's dilemma. If the bar in question is an uncoated #6 bottom bar, with a yield strength of 60 ksi in normal weight concrete (f'_c = 4,000 psi), ACI 318 section 12.2.2 would yield a basic development length (and Class A lap splice length) of 29 inches. Following ACI 318 section 12.2.3, if the bars are spaced at 12-inch on center or greater, and even if there is *no* transverse reinforcement intersecting the bars in question, the $(c_b+K_{tr})/d_b$ value becomes 4.5, which must be truncated to the maximum permissible value of 2.5. The basic development length (and Class A lap splice length) then becomes just over 17 inches – a reduction of over 40%. Hence the saving grace for our contractor in trouble, by qualification, becomes option D. The only drawback is that this calculation requires more consideration and engineering input, the likes of which are probably not practical in every case.

Option D may thus be demonstrated and qualified, as shown here, as the best approach; but a little tact may be required to help the contractor understand the lengths you undertook to qualify the situation as it stands. Furthermore, ACI 318 section 12.2.5 allows for reduction of development length and lap splice in direct proportion to the amount of excess reinforcement provided. Owing to the discreteness of bar sizes, excess reinforcement can usually be quantified such that embedment and lap splicing requirements can be rationally adjusted accordingly.▪

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