AASHTO LRFD Bridge Design Specifications: Combined Shear and Torsion

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In the Summer 2016 issue of *ASPIRE*, this column provided an introduction to design for torsional resistance using the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*. This article is a follow-up to that discussing design for combined shear and torsion.

The commentary of the eighth edition of the *AASHTO LRFD Bridge Design Specifications* acknowledges that shear stresses stemming from torsion and those caused by shear are additive on one side of a member and act in opposite directions on the other side of the same member. Naturally, transverse reinforcement is designed for the side where the effects are additive. The commentary states that the loading that causes the highest torsion differs from the loading that causes the highest shear, in most cases. The commentary also indicates that it is only necessary to design for the highest shear and its concurrent torsion, and the highest torsion and its concurrent shear. However, as a design simplification, designers may find it convenient to design for the highest torsion combined with the highest shear, despite the fact that those load effects do not occur concurrently for the same load combination.

With this guiding principle in mind, for solid sections the longitudinal reinforcement shall be proportioned to satisfy *AASHTO LRFD Bridge Design Specifications* Eq. 5.7.3.6.3-1 (with the familiar variables not discussed herein):

$$A_{ps} f_{ps} + A_s f_y \ge \frac{|M_u|}{\phi d_v} + \frac{0.5N_u}{\phi} + \cot\theta \sqrt{\left(\left|\frac{V_u}{\phi} - V_p\right| - 0.5V_s\right)^2 + \left(\frac{0.45 p_h T_u}{2A_o \phi}\right)^2}$$

The transverse reinforcement design for solid sections is also addressed by the AASHTO LRFD specifications. For such sections, considerable redistribution of shear stresses may occur, as stated in the commentary. To make some allowance for this favorable redistribution, the commentary deems it safe to use a root-mean-square approach in calculating the nominal shear stress for solid cross sections. Where torsion is to be considered, the AASHTO LRFD specifications provide Eq 5.7.3.4.2-5 for this purpose:

$$V_{eff} = \sqrt{V_u^2 + \left(\frac{0.9 p_h T_u}{2A_o}\right)^2}$$

In calculating the effective shear force, the 0.9 comes from 90% of the perimeter of the spalled concrete section, an approximation similar to 0.9 times the effective section depth in flexural calculations used to estimate the internal lever arm. For combined shear and torsion, the effective shear V_{eff} replaces the V_u term in Eq. 5.7.3.4.2-4:

$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps} f_{po}\right)}{E_s A_s + E_p A_{ps}}$$

Similar to solid sections, the specifications and commentary include guidance for designing hollow sections subjected to combined shear and torsion.

The specifications also provide an alternative for the designer by stating that, instead of the method discussed previously, the resistance of members subjected to "shear combined with torsion may be determined by satisfying the conditions of equilibrium and compatibility of strains and by using experimentally verified stress-strain relationships for reinforcement and for diagonally cracked concrete." Furthermore, the specifications allow the use of a three-dimensional strut-and-tie model for complex stress states, such as those that exist in combined shear and torsion problems, as well as loading conditions that may induce shear in secondary directions.

Circularity torsion