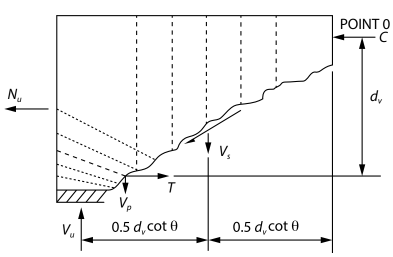
Minimum Longitudinal Reinforcement Revisited

by Dr. Dennis R. Mertz

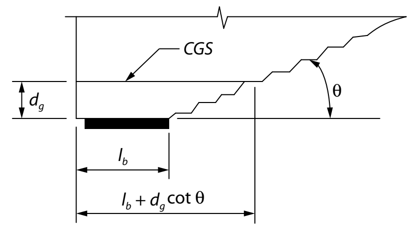
A reader recently raised the issue of the appropriate application of American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* Equation 5.8.3.5-1 in commercially-available computer software when evaluating shear. This equation, reproduced below, was discussed in this column in the Fall 2012 issue of *ASPIRE*.™ The equation mandates the minimum longitudinal reinforcement based upon the interaction of the force effects at a given section.

$$A_{ps}f_{ps}+A_sf_y \ge \frac{|M_u|}{d_v\phi_f}+0.5\frac{N_u}{\phi_c}+\left(\left|\frac{V_u}{\phi_v}-V_p\right|-0.5V_s\right)\cot\theta$$

The variables in the equation are familiar to most designers. Their specific definitions are found in AASHTO LRFD specifications article 5.8.3. The interaction of the force effects is illustrated in the free-body diagram, adapted from the AASHTO LRFD specifications, below.



An important aspect of the application of AASHTO LRFD specifications Equation 5.8.3.5-1 near the end of the beam where shear may be critical, which was not previously discussed, is the consideration of transfer and development lengths. In the figure below, the center of gravity of the longitudinal steel, *CGS*, crosses the hypothetical shear crack at a distance equal to distance, l_b, plus the height of the *CGS* from the bottom of the beam, d_g, times the cotangent of the angle of cracking, θ. Then, at this distance, the appropriate steel stress should be computed considering the variation of steel stress within the transfer and development lengths, instead of f_{ps} or f_y as appropriate for prestressed or nonprestressed steel.



Our concern relative to our reader's comment is the force effects: M_u, the factored moment; N_u, the factored axial force; and V_u, the factored shear force. Are the values of M_u, N_u, and V_u intended to be maximum or concurrent values? As the reader suggests, the equation represents a single point in time. Thus, the force effects should be concurrent values due to a common load condition. The reader's conclusion was also previously addressed in the column of the Winter 2014 issue, wherein the following general conclusion was drawn:

"The various strength limit-state force effects (in other words, the sum of the factored force effects from the governing strength limit-state load combination), M_u, V_u, N_u, and T_u, in the LRFD equations, do not represent the maximums for the section due to varying load conditions. They represent the maximum force effect under consideration along with the other concurrent values for the single governing load condition at each section."

From a design point of view, using the maximum force effects instead of concurrent force effects would be conservative but results in overdesign, perhaps at best a few more stirrups, but an unnecessary overdesign nonetheless.

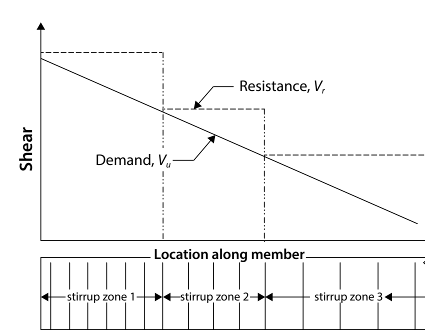
In the case of rating, the evaluator should remember that the Federal Highway Administration *Manual for Bridge Evaluation* states,

"The shear capacity of existing reinforced and prestressed concrete bridge members should be evaluated for permit loads. In-service concrete bridges that show no visible signs of shear distress need not be checked for shear when rating for the design load or legal loads."

In the rare case where a shear rating is required, a lower rating than the intended specified rating will result if maximum force effects are used instead of the more correct concurrent force effects. A reliable bridge could be unnecessarily permit-load restricted. This consequence of using maximum force effects instead of concurrent force effects by rating software was what our reader observed.

Another important consideration in the evaluation of an existing beam such as in rating is the varying spacing of shear reinforcement. In the traditional shear-design approach as shown in the figure below, constant stirrup spacings are chosen to envelope the load or demand curve.

This approach may lead to inaccuracies where several shear stirrup spacings are present within the same zone. Shear failures occur over an inclined plane and a shear crack typically intersects the stirrups within the distance d_v cot θ as shown in the first figure. Each of the stirrups crossing this crack share in resisting the applied shear load and should be included in determining the nominal shear resistance at a section. Using the actual number of stirrups crossing the shear failure plane is the most accurate approach for determining the shear reinforcement resistance, V_s. An example of a Type II AASHTO girder in the *PCI Bridge Design Manual*, 3rd Edition, 2nd Release, illustrates how load rating using the traditional design approach suggests a shear deficiency at a section where the method presented here indicates adequate shear resistance.



Traditional Shear Design

It's important that the user fully understands what the software is doing. Without this understanding, bridges may be overdesigned or underrated. Remember that AASHTO LRFD specifications article 4.4 states, "The Designer shall be responsible for the implementation of computer programs used to facilitate structural analysis and for the interpretation and use of results."