Design Example for Beams with Web Openings

Paper presented by RICHARD L. KUSSMAN and PETER B. COOPER (2nd Quarter, 1976 issue)

Discussion by **R. G. Redwood**

The authors have quoted Ref. 5 to justify placing the reinforcement on one side only of the web, but it should be noted that this reference suggests that this should only be done if $A_r/A_f \leq 0.333$. In two of the authors' designs, this ratio is considerably exceeded, and the writer considers that this cannot be justified on the basis of available knowledge of behavior. It should also be noted that the suggestion regarding one-sided reinforcement was made strictly in the context of plastic design, i.e., in beams conforming to Sect. 2.7 of Ref. 4.

The equations presented in the Appendix cover the general case of a rectangular web hole located anywhere in a beam and reinforced or not reinforced. It should be stressed that the basis of the derivation of these equations is plastic analysis, and it would appear to follow from this that the application should be only to beams conforming to the width-thickness limitations of Sect. 2.7 of the AISC Specification (Ref. 4). Most of the experimental work which has been carried out to verify the plastic analysis of perforated webs has been on sections conforming to these limitations; in fact, very few of the test specimens have had web slenderness ratios near the limit for such sections. Some tests are currently being conducted in Canada with the aim of determining the likelihood of local web buckling and its effect on beam strength. These tests are not yet complete and any conclusions drawn must necessarily be tentative.

R. G. Redwood is Professor and Chairman, Dept. of Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada.

However, it is possible to make some comment on the applicability of the authors' approach to beams with more slender webs and flanges than in any previously reported tests, and in one case at least some caution is necessary.

The Canadian Specification governing the design of steel structures for buildings[6] differentiates between Class 1 (plastic design sections) and Class 2 (compact sections); the former permit attainment of the plastic moment and subsequent redistribution of bending moment, and flange and web slenderness limits for these are close, but not identical, to the AISC requirements[4] of Sect. 2.7. Class 2 sections permit attainment of the plastic moment, but not necessarily subsequent moment redistribution, and for these sections the flange and web slenderness limits for flexural members are, respectively[6]

$$b_f/2t_f \leq 64/\sqrt{F_y}$$

and

$$(d - 2t_f)/t_w \leq 520/\sqrt{F_y}$$

Failure of a beam near a hole has been observed in many tests to involve the development of four plastic hinges located at sections through the hole corners. These hinges form more or less simultaneously, and locally, therefore, no requirement for moment redistribution arises. For this reason, it may appear justified to use results based on plastic analysis, such as those presented by the authors, for Class 2 sections. There are, however, two other factors which should be considered: the first relates to the effect of the free edges of the hole on local buckling within the web, and the second concerns the effect of the forces due to reinforcement anchorage on webs more slender than those specified in Sect. 2.7 of Ref. 4.

The tests referred to above have been on beams with web slenderness ratios approximately equal to the limits specified for Class 1 and Class 2 sections. In the case of holes without reinforcement, it appears that a primary influence on local web buckling is the slenderness of the web of the tee section above or below the hole, and therefore there may be some concern in the case of eccentric holes in Class 1 sections as well as holes in Class 2 sections. Local web buckling for unreinforced holes does not seem to be very sensitive to the overall web slenderness. It is hoped that a specific limitation on the tee section web slenderness ratio can be identified such that the plastic design approach can be applied directly.

If holes are reinforced with horizontal bars, without vertical reinforcement near the hole ends, there is a possibility of web buckling associated with the free vertical ends of the hole, or of the web near the ends of the reinforcement. Neither of these appear to be very critical for Class 1 or Class 2 sections, particularly if the factored shear force at the hole is not high.

The final observation from the test program is that flange slenderness is not a critical factor, providing $b_f/2t_f \leq 64/\sqrt{F_y}$.

REFERENCE

6. Steel Structures for Buildings—Limit States Design *Canadian Standards Association, Standard S16.1-1974.*