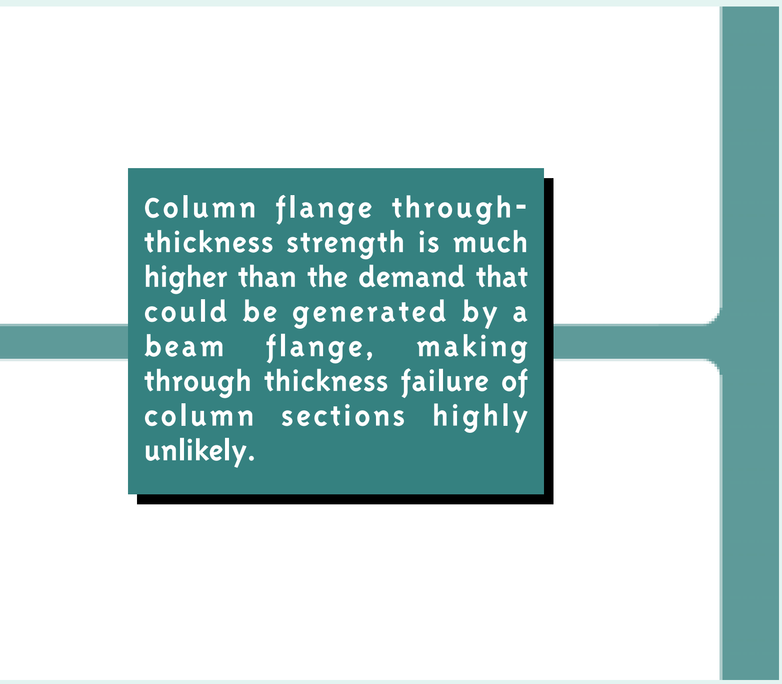
Through-thickness Strength of Column Flanges

By Robert J. Dexter



In the beam-to-column connection used in welded moment frames, the through-thickness strength of the column flange is relied upon to transmit the cyclic forces from the beam flanges to the column. Testing sponsored by the SAC Joint Venture, TradeARBED, and Nucor-Yamato Steel recently performed at Lehigh University and the University of Minnesota has shown that in the constrained configuration of the beam-to-column joint, the column flange through-thickness strength is much higher than the demand that could be generated by a beam flange. The through-thickness failure of column sections is very unlikely in moment connections or other types of T-joints. Therefore, it is recommended that the through-thickness strength does not need to be explicitly checked in the design of welded beam-to-column connections.

Many of the moment connection fractures that occurred in the 1994 Northridge Earthquake and fractures that occurred in subsequent laboratory tests on beam-column joints propagated into the column base metal, including fractures that appeared to scoop out some of the column material, referred to as mouse-ears or divots. Fractography has shown that the primary cause of the fractures was identified as low-toughness weld filler metal combined with the existence of backing-bar notches and lack-of-fusion defects at the weld root. These fractures should not be considered through-thickness failures of the column flange since the cause of the fractures is not related to the column flange properties. Therefore, the fact that some of these cracks propagated into the column material should not be considered a deficiency of the column material.

There are no documented cases where lamellar tearing or inadequate through-thickness strength or ductility was responsible for any of the fractures in the Northridge Earthquake or in subsequent full beam-column joint tests. Ultrasonic testing (UT) has been performed on hundreds of buildings that were loaded significantly by the earthquake. There has been only one documented case of a lamellar separation in the column flange material large enough to require repair. Investigators concluded this separation was probably caused by weld shrinkage during construction and that it did not propagate during the earthquake.

Despite no indications that inadequate through-thickness strength was responsible for any of these fractures, there are lingering questions about the through-thickness strength of the column sections. This lingering doubt is due to a number of factors, including the awareness of many engineers that lamellar tearing is a potential problem with through thickness loading, as described in many textbooks. However, steel produced since 1980 has typically not been susceptible to lamellar tearing because producers have been controlling the large nonmetallic inclusions that used to cause lamellar tearing.

Another reason for the questions about through-thickness strength of column sections may be due to the results of uniaxial through-thickness tensile tests performed in accord with ASTM A770. These results often show a high degree of scatter including some low strength values that may even be below the minimum specified yield strength (MSYS) in the longitudinal direction. In addition, the reduction in area of these through-thickness tests is often less than the reduction of area in the longitudinal tests, indicating the ductility of the material is less in the through-thickness direction.

The uniaxial through-thickness tests are not representative of the highly constrained conditions under which the column flange base metal is loaded in the connection, however. The experiments indicate that under the constrained conditions typical of a beam flange-to-column flange welded tee-joint in a moment connection, the column sections do not yield in the through-thickness direction. Because it is not possible to get yielding in the through-thickness direction, the measured through-thickness yield strength and reduction in area should not be a concern, i.e. the ductility in that direction is never needed.

This behavior was observed in more than 46 tee-joint specimens that were fabricated with high-strength (690 MPa [100 ksi] yield strength) "pull" plates welded transversely to opposite flanges of short 610 mm (24") lengths of heavy column sections. Column shapes were obtained from four steel mills (integrated and electric furnace) and conformed to ASTM A572 Gr. 50, A992, and A913 Gr. 50 and 65. A column section taken from a building that had been damaged in the 1994 earthquake was also tested. The steel included a wide range of chemistry, including some specimens that were intentionally made with an unusually high sulfur content as high as the specification limits of 0.05%. The tee-joint tests were performed at high and low strain rates, with various widths for the simulated beam flange, and with axial and bending loads.

In every case, the through-thickness strength of the column flanges tested exceeded the 690 MPa (100 ksi) yield strength of the pull plates, well above any possible demand that could come from Grade 50 or even Grade 65 beam flanges.

Robert J. Dexter is an associate professor of structural engineering at the University of Minnesota. Professor Dexter is currently conducting two related studies on shape materials and design for AISC.