The 1997 T.R. Higgins Lecture: Ductile Concentrically Braced Frames for Seismic Resistance

Subhash C. Goel

Author

Subhash C. Goel is professor of civil engineering at the university of Michigan, Ann Arbor. He received his bachelor's and master's degrees in civil engineering from the University of Roorkee, India, and a Ph.D. from the University of Michigan in 1968.

In 1968, immediately after completing his Ph.D. degree, Dr. Goel joined the faculty of the University of Michigan. He has been involved in carrying out analytical and experimental studies in seismic behavior and design of steel building structures, including braced frames, moment frames, staggered-truss frames, and truss-moment frames. He has studied the application of various steel systems for seismic upgrading of existing steel, reinforced concrete and masonry building structures. Dr. Goel was involved with steel phase of the United States-Japan Cooperative Earthquake Research Program during 1983-1987. His recent research interests have included advanced composite and hybrid structures. Since 1991, he has played a key role in planning of the United States-Japan Cooperative Earthquake Research Program on Composite and Hybrid Structures and is currently serving as the United States Technical Coordinator for that program.

A registered professional engineer, Dr. Goel is a member of the American Society of Civil Engineers, Earthquake Engineering Research Institute, and the Structural Stability Research Council, where he is serving as chairman of the Task Group on Stability Under Seismic Loading. In recent years he has taken an active role through various code committees in bridging the gap between research and practice and codification of research results.

Summary

Concentrically braced frames (CBF) are among the most efficient structural systems in steel for resisting lateral forces due to wind or earthquakes because they provide complete truss action. However, this framing system has not been considered to be very ductile in the past design practice for earthquake resistance. The non-ductile behavior of these structures results mainly from early cracking and fracture of bracing members or connections during large cyclic deformations in the post-buckling range. Instead of requiring the bracing members and their connections to withstand cyclic post-buckling deformations without premature failures (i.e.., for adequate ductility), the codes generally prescribed increased lateral design forces in an attempt to inhibit excessive buckling.

Over more than twenty years of extensive analytical and experimental studies by the author and his graduate students have shown that with proper consideration of post-buckling deformation, concentrically braced frames can possess ductility and reserve strength far in excess of those previously ascribed to this system. Key parameters include width thickness ratios, stitch spacing and strength and detailing of end connections. The research findings formed the basis of major revisions in the code philosophy for seismic design of concentrically braced frames in 1994. The design provisions to ensure ductile behavior were accepted in the 1994 editions of the *Uniform Building Code* and the *NEHRP Recommended Seismic Provisions.*

This paper summarizes the most important findings from a large body of background research work, applications in design of new steel construction, upgrading of existing steel, concrete and masonry buildings.