1-1-2007

Post-tensioned Steel Structure

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DOI: 10.5703/1288284315797

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Recommended Citation

ECT Team, Purdue, "Post-tensioned Steel Structure" (2007). *ECT Fact Sheets*. Paper 88.
<http://dx.doi.org/10.5703/1288284315797>

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POST-TENSIONED STEEL STRUCTURE

THE NEED

Welded steel Moment-Resisting Frames (MRFs) were long considered as one the most earthquake-resistant types of structures. Numerous factors have contributed to the growth of this market since the 1960s, especially in the Western United States where they were extensively used prior to the 1994 Northridge California earthquake. Four earthquakes in California and Japan (San Francisco, Kanto, Santa Barbara and Long Beach) during the first part of this century gave engineers confidence in this type of steel construction which enforced the engineering communities preference for this earthquake-resistant structural system. During these events, there were typically fewer problems observed in steel structures as compared with concrete and masonry buildings of similar size and scale.

FIGURE 1 THE FAILURE OF THE WELD BETWEEN THE TUBE AND THE CONNECTING PLATE, AS WELL AS A FRACTURE OF THE TUBE, NORTHRIDGE, CA, 1994 (COURTESY OF NISEE, UC BERKELEY)

However, in the 1994 Northridge earthquake where more than 200 buildings of this structural type suffered brittle fractures at connections. None of these steel frame buildings collapsed, but the unexpected type and severity of the damage raised serious questions about the current practice in the design and construction of welded MRFs. In the Kobe, Japan Earthquake, which occurred exactly one year later, damage to steel buildings was even more disturbing: 10% of the steel buildings in Kobe designed to current Japanese building standards suffered extensive damage. Most of these observed fractures occurred at the beam to column connections, and were usually instigated at the level of the full penetration welds.

FIGURE 2 FRACTURE OF STEEL CONNECTIONS IN A MOMENT-RESISTING STEEL-FRAME BUILDING, NORTHRIAGE, CA, 1994

THE TECHNOLOGY

Recently, the idea of applying the post-tensioning technology to achieve moment resistant structural systems has been investigated at the University of California, San Diego. Since 1996, moment-resisting connections using post-tensioning concepts have been developed and tested for precast concrete beam-to-column connections, and concrete shear walls. Professors Constantin Christopoulos' (U of Toronto) and Andre Filiatrault's (UCSD) research has extended the self-centering and energy dissipating connection systems to steel structures using similar post-tensioning concepts. The post-tensioned energy dissipating (PTED) connection system for steel frames incorporates post-tensioned high-strength bars to provide a self-centering response along with energy dissipating bars that are able to develop stable inelastic axial deformations in both axial tension and compression. Numerical and experimental results presented show that this connection is capable of achieving stiffness and strength characteristics comparable to a traditional welded moment-resisting connection.

FIGURE 3 PTED CONCEPT

In addition, the connection can be designed to provide a sufficient amount of energy dissipation per cycle. In the experimental study, a cyclic component test was performed on two energy dissipating bars and a cyclic test was conducted on a large-scale exterior beam-to-column PTED connection. The results of the tests show that the PTED test specimen was able to undergo large inelastic deformations without any damage in the beam or column and without residual drift. From a constructability point of view, post-tensioned steel frames are likely to be faster to erect than an equivalent welded MRFs because they do not require any full penetration welds. The cost of these systems is also expected to be similar to welded MRFs, since only traditional and readily available materials are used for the PTED frames.

FIGURE 4 PTED CONNECTION AT 3% DRIFT

THE BENEFITS

The PTED system offers an alternative to traditional welded MRFs. While the architectural features and their response to service loads of both systems are similar, the PTED system has a highly enhanced response to severe seismic loads, as it limits structural damage to sacrificial bars and assures a full re-centering of the structure at the end of the earthquake.

STATUS

Experimental and analytical work carried out since 1999 has shown that the PTED system is a viable alternative to welded MRFs. Current research efforts are focused on determining the response of these systems when the floor slab and gravity loads are also present during the seismic loading. Additional work is also being carried out to fully assess the dynamic response of systems exhibiting the self-centering hysteresis.

BARRIERS

The lack of the real-world case where the post-tensioned steel structure technology was applied may be a major obstacle. Although the results of the research shows that this technology achieves many strong characteristics for earthquake resistance, there is not enough information how it would work on everyday environments and how it should be applied to actual design such as response to wind, interior design, and fire consideration, etc.

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PUBLISHER

Emerging Construction Technologies, Division of Construction Engineering and Management, Purdue University, West Lafayette, Indiana