SAC
Steel Project

Background Document

Through-Thickness Strength and Ductility of Column Flanges in Moment Connections

Report No. SAC/BD-99/02

SAC Joint Venture
A partnership of
Structural Engineers Association of California (SEAOC)
Applied Technology Council (ATC)
California Universities for Research in Earthquake Engineering (CUREe)

By
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The ATLSS Center, Lehigh University, Bethlehem, PA

Submitted for distribution to
SAC Joint Venture
650-595-1542
http://www.sacsteel.org

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DISCLAIMER

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THE SAC JOINT VENTURE

SAC is a joint venture of the Structural Engineers Association of California (SEAOC), the Applied Technology Council (ATC), and California Universities for Research in Earthquake Engineering (CUREe), formed specifically to address both immediate and long-term needs related to solving performance problems with welded, steel moment-frame connections discovered following the 1994 Northridge earthquake. SEAOC is a professional organization composed of more than 3,000 practicing structural engineers in California. The volunteer efforts of SEAOC's members on various technical committees have been instrumental in the development of the earthquake design provisions contained in the *Uniform Building Code* and the 1997 *National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and other Structures*. ATC is a nonprofit corporation founded to develop structural engineering resources and applications to mitigate the effects of natural and other hazards on the built environment. Since its inception in the early 1970s, ATC has developed the technical basis for the current model national seismic design codes for buildings; the *de facto* national standard for postearthquake safety evaluation of buildings; nationally applicable guidelines and procedures for the identification, evaluation, and rehabilitation of seismically hazardous buildings; and other widely used procedures and data to improve structural engineering practice. CUREe is a nonprofit organization formed to promote and conduct research and educational activities related to earthquake hazard mitigation. CUREe's eight institutional members are the California Institute of Technology, Stanford University, the University of California at Berkeley, the University of California at Davis, the University of California at Irvine, the University of California at Los Angeles, the University of California at San Diego, and the University of Southern California. These laboratory, library, computer and faculty resources are among the most extensive in the United States. The SAC Joint Venture allows these three organizations to combine their extensive and unique resources, augmented by subcontractor universities and organizations from across the nation, into an integrated team of practitioners and researchers, uniquely qualified to solve problems related to the seismic performance of steel moment-frame buildings.

ACKNOWLEDGEMENTS

Funding for Phases I and II of the SAC Steel Program to Reduce the Earthquake Hazards of Steel Moment-Frame Structures was principally provided by the Federal Emergency Management Agency, with ten percent of the Phase I program funded by the State of California, Office of Emergency Services. Substantial additional support, in the form of donated materials, services, and data has been provided by a number of individual consulting engineers, inspectors, researchers, fabricators, materials suppliers and industry groups. Special efforts have been made to maintain a liaison with the engineering profession, researchers, the steel industry, fabricators, code-writing organizations and model code groups, building officials, insurance and risk-management groups, and federal and state agencies active in earthquake hazard mitigation efforts. SAC wishes to acknowledge the support and participation of each of the above groups, organizations and individuals. In particular, we wish to acknowledge the contributions provided by the American Institute of Steel Construction, the Lincoln Electric Company, the National Institute of Standards and Technology, the National Science Foundation, and the Structural Shape Producers Council. SAC also takes this opportunity to acknowledge the efforts of the project participants – the managers, investigators, writers, and editorial and production staff – whose work has contributed to the development of these documents. Finally, SAC extends special acknowledgement to Mr. Michael Mahoney, FEMA Project Officer, and Dr. Robert Hanson, FEMA Technical Advisor, for their continued support and contribution to the success of this effort.

PREFACE

The primary objectives of the FEMA/SAC Phase II Steel Project are to develop guidelines for the seismic evaluation, inspection, repair, design and construction of moment resisting steel frame buildings. A diverse collection of technical investigations is supporting this effort, including the identification of basic material properties in rolled steel sections; development of appropriate welding materials, details, and inspection procedures; specification of anticipated seismic demands imposed on connections as a result of structural response to strong ground motions; and large-scale connection testing to calibrate and verify the design procedures that are ultimately proposed. Tying these activities together is a series of detailed finite element analyses of various connection configurations to quantify the influence of material properties, geometry, and detailing on predicted behavior. In addition, a series of studies have been performed to incorporate the results of the various investigations into a performance based seismic engineering format that can become the basis of the SAC guidelines. Cost and risk studies and investigations into the past performance of this class of structures were also performed to gather valuable information used in the development of the guidelines and other documents.

This report documents part of the work carried out by the Materials and Fracture team of the Phase II FEMA/SAC Steel Project. This team was responsible for characterizing the chemical, stiffness, strength, toughness and other properties that characterize wide flange rolled shape sections that are commonly used in construction of steel moment resisting frames in seismic applications. Over the last ten years, tremendous changes have occurred in the production methods of rolled structural steel shapes. In addition to characterizing a variety of mechanical properties in the longitudinal (or rolling) direction, considerable efforts were made to understand the properties of steel in the through-thickness direction.

The project described in this report focuses on the properties of rolled column sections in the through-thickness direction. Welded test specimens, representing some of the restraint and residual stress conditions present in column flanges in typical beam to column connections, were designed, fabricated and tested. Because the focus of this study was on the ultimate behavior of the column flange, weld and pull plate material was made substantially stronger than the column base material. A variety of member sizes, strain rates, boundary conditions, weld details and properties were studied. This report comprises part of the work completed as part of Task 5.1.2 of the FEMA/SAC Phase II Program.

Numerous individuals helped to develop the scope and content of the project and to review a preliminary version of this report. These individuals included members of the Technical Advisory Panel (TAP) for Materials and Fracture, selected members of the Joining and Inspection TAP; the Project Management Committee, and several members of the Project Oversight Committee. The contributions of these individuals are greatly appreciated.

FORWARD

The tests described in this report were conducted at Lehigh University primarily by Minerva Melendrez under the direction of Robert Dexter. In August 1997, Robert moved from Lehigh University to the University of Minnesota. Robert Dexter continued to direct the project, although the remainder of the testing was still conducted at Lehigh University.

ABSTRACT

More than forty tee joints were fabricated with high-strength (690 MPa yield strength) "pull" plates welded transversely to opposite flanges of short 610 mm lengths of heavy Grade 50 and Grade 65 column sections. The tee-joint specimens were tested in tension through the pull plates. The tests were performed to determine strength, deformation, and fracture behavior of the flanges of wide-flange column sections when loaded in the through-thickness direction under constrained conditions similar those of a welded beam-to-column the connection. (Each pull plate represents a beam tension flange.) The through-thickness strength of the column flanges exceeded 690 MPa in these tests. This result can be explained by the existence of triaxial constraint of the column flange material, which creates hydrostatic tension stresses, raising the apparent through-thickness strength. This effect is an inherent consequence of the Von-Mises and other yield criteria. Three-dimensional finite-element analyses of these specimens using the Von-Mises yield criterion predict this effect and give results consistent with the experiments.

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