SAC
Steel Project

Background Document

Test of a Free Flange Connection with a Composite Floor Slab

Report No. SAC/BD-00/18

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
Mark J. Venti and Michael D. Engelhardt
Phil M. Ferguson Structural Engineering Laboratory, The University of Texas at Austin

Submitted for distribution to
SAC Joint Venture
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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.

The primary responsibility of the Connection Performance team in the Phase II Steel Project is to develop straightforward and reliable design and analysis tools for seismic moment resisting connections in steel frame structures. This report describes the results of a single large scale cyclic loading test on an interior beam-column subassemblage constructed with the free flange moment connection. The specimen included a composite slab. The objective of the test was to evaluate the deformation capacity, strength and controlling failure mode for the connection and thereby extend the previous experimental database on the free flange connection. The specimen sustained three full cycles of loading at 0.05 rad drift angle, prior to a fracture in the bottom flange of one of the beams in the base metal region just beyond the groove weld. This specimen sustained large panel distortions which approximately 50 percent of the total plastic rotation. This level of panel zone distortion may have contributed to the fracture by causing localized kinking in the region of the panel zone corners. This project was performed at the University of Texas at Austin. This task was identified as Task 7.06b of the 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 Connection Performance; selected members of the Joining and Inspection TAP; and several members of the Project Oversight Committee. The contributions of these individuals are greatly appreciated.

SUMMARY

This report describes the results of a single large-scale cyclic loading test conducted on a steel beam-column subassemblage constructed with the free flange moment connection. An interior subassemblage, consisting of a W14x398 column and W36x150 beams was tested to destruction. The specimen was provided with an 8-ft. wide composite concrete floor slab. The objective of the test was to evaluate the deformation capacity, strength and controlling failure mode for the connection. This test extended the previous experimental database on free flange connections to larger member sizes and to the case including a composite floor slab.

Overall, this specimen showed very good performance, sustaining three full cycles of loading at 0.05 rad drift angle prior to failure. Failure of this specimen occurred suddenly during the 4th loading cycle at 0.05 rad drift, by complete fracture of the beam bottom flange at one of the connections. The fracture appeared to be contained almost entirely in the beam base metal, in the region just outside of the beam flange groove weld.

The two connections in this specimen sustained total story drift angles of 0.05 rad and plastic rotations of 0.033 rad. Consequently, the connections exhibited excellent deformation capacity. Panel zone yielding played a dominant role in the inelastic response of the test specimen, accounting for approximately 50-percent of the total plastic rotation and energy dissipation of the specimen. Beam yielding accounted for approximately 33-percent of the total plastic rotation. The large panel zone shear distortions observed in this specimen may have contributed to the beam flange fracture by causing localized kinking at the panel zone corners.

The specimen experienced no strength degradation prior to failure. To the contrary, the specimen was still hardening at the point of failure. This very stable hysteretic response may be partially due to the dominant role of panel zone yielding in the overall inelastic response of the specimen. The beams in this specimen experienced bending moments at the face of the column that were well in excess of their plastic moment. Despite these high moments, the beams exhibited very little instability. There were no visible signs of web buckling or lateral torsional buckling. Only very mild flange buckling was observed. The composite slab may have contributed to the stability of the beam. The very heavy and large shear tab may have also assisted in restraining web buckling.

The free flange design appears to have performed in a very effective manner. Some modification may be needed in the design of the shear tab. During testing of the specimen, small fractures were observed at the top and bottom of each shear tab at the face of the column, one of which propagated into the column flange for a distance of approximately 2-inches. For this specimen, however, these small fractures ultimately had no effect on overall performance.

ACKNOWLEDGEMENTS

The work forming the basis for this report was conducted pursuant to a contract with the Federal Emergency Management Agency. The substance of such work is dedicated to the public. The writers gratefully acknowledge funding provided by FEMA. The writers also gratefully acknowledge donations of steel by the Structural Shape Producers Council, donation of fabrication services by W&W Steel Company in Oklahoma City, and donation of stud welding services by Alpha Stud Weld, Inc. of Houston, Texas. The writers thank Ted Winneberger of W&W Steel Company and George Stephenson of Alpha Stud Weld, Inc. for their support.

The writers also thank Tim Wharton of WITS International Inc., Georgetown, Texas for his advice and assistance in welding and welding inspection and for his interest in this work. Welding of the specimens at the Ferguson Laboratory was done by Dwayne Schuessler of S&S Welding, Spicewood, Texas. The writers thank Mr. Schuessler for his advice, interest, and careful workmanship.

Professors Subhash Goel and Bozidar Stojadinovic at the University of Michigan provided the design of the test specimen. Their advice and assistance with this test is gratefully acknowledged. The authors would like to thank the laboratory staff at the University of Texas Ferguson Structural Engineering Laboratory for their extensive assistance with this test. Finally, the writers also thank James Malley of the SAC Joint Venture for support and assistance throughout this research program.

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