SAC
Steel Project

Background
Document

Cyclic Testing of a Free Flange Moment Connection

Report No. SAC/BD-00/19

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

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Submitted for distribution to
SAC Joint Venture
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DISCLAIMER

This document is one of a series documenting background information related to Phase II of the FEMA-funded SAC Steel Project. It is being disseminated in the public interest to increase awareness of the many factors which contribute to the seismic performance of steel moment frame structures. The information contained herein is not for design use and is not acceptable to specific building projects. This report has not been reviewed for accuracy, and the SAC Joint Venture has not verified any of the results presented. **No warranty is offered with regard to the recommendations contained herein, by the Federal Emergency Management Agency, the SAC Joint Venture, the individual joint venture partners, or the partner's directors, members or employees. These organizations and their employees do not assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any of the information, products or processes included in this publication. The reader is cautioned to review carefully the material presented herein and exercise independent judgment as to its suitability for application to specific engineering projects.** This publication has been prepared by the SAC Joint Venture with funding provided by the Federal Emergency Management Agency, under contract number EMW-95-C-4770.

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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 documents the results of an experimental and analytical investigation of the effects of loading sequence and lateral bracing on the performance of welded web Reduced Beam Section (RBS) moment connections. Four full-scale specimens were tested, two with a standard stepwise increasing loading history and two with a loading history developed to more closely simulate the demands that could be imposed by near field ground motions. All four specimens exceeded 0.03 radians of plastic rotation and avoided brittle fracture of the beam flange groove welds. The specimens with the near field protocol reached 0.05 radians. The specimens tested with the near-field protocol also experienced smaller buckling amplitudes at comparable drift levels of those subjected to the standard protocol. The energy dissipation capacity of the specimens appeared to be insensitive to the type of loading protocol. One of the standard loading protocol tests had lateral bracing added near the RBS region. The additional lateral bracing did not increase the beam maximum strength, but it did reduce the rate of strength degradation. Little change in the energy dissipation characteristics occurred until beyond the 4 per cent drift cycles. Buckling amplitudes were decreased in the specimen with additional lateral bracing. Peak bracing forces were on the order of 7 per cent of the beam flange yield force. In addition, a nonlinear finite element analysis was performed to examine the effect of the axial restraint posed by frame systems (in contrast to the cantilevers typically tested in the laboratory. The analysis indicated that this effect can significantly reduce the local buckling amplitudes and therefore the rate of strength degradation of the connection. This led to the conclusion that adding lateral bracing near the RBS region is not required where these frame conditions exist. This task was identified as part of Task 7.11 of the SAC Phase II program. The testing was performed at the University of California at San Diego.

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.

ABSTRACT

The effectiveness of the Free Flange moment connection details for the seismic application of steel moment frames was investigated through the cyclic testing of a full-scale specimen with a W14×257 column section and a W36×150 beam section. The Free Flange connection was designed to prevent the beam flanges from contributing in shear transfer, thus forcing the shear plate, attached to the beam web, to convey the beam shear into the column. Failure of the specimen occurred during the first cycle of 4% drift when a crack at the upper toe of the shear plate groove weld propagated through the column flange. The location of the fracture coincided with the location of kinks that developed in the column flange due to large panel zone deformations. Scanning Electron Microscope analysis of the fractured surface showed that a defect was present in the weld region. The connection was able to reach a total plastic rotation of about 0.018 radian, with a significant proportion contributed by the panel zone. There was significant yielding in the panel zone, while the beam only experienced minor yielding and buckling. The actual overstrength of the beam ($=1.3$) was higher than the value assumed for design ($=1.2$).

ACKNOWLEDGEMENTS

Funding for this research was provided by the Federal Emergency Management Agency through the SAC Joint Venture. SAC is a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering. This research was conducted as part of Task 7.11 in Phase II of the SAC Joint Venture.

Mr. J.O. Malley was the Project Director of Topical Investigations. Professors S. Goel and B. Stojadinovic at the University of Michigan provided the design of the free flange moment connection. PDM/Strocal's donation of the fabrication of the specimen is gratefully acknowledged. The authors would like to thank the technical staff at the Powell Laboratories at the University of California, San Diego for contributions during the setup and testing of the specimen. Dr. B. Kad performed SEM analysis of the fractured column surface.

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