SAC
Steel Project

Background
Document

Parametric Tests on the Free Flange Connections

Report No. SAC/BD-00/02

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
Jaehyung Choi, Bozidar Stojadinovic, and Subhash C. Goel
Department of Civil and Environmental Engineering, The University of Michigan, College of Engineering
Ann Arbor, Michigan 48109-2125

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

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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 a combined experimental and analytical investigation on improving the performance of unreinforced moment connections for use in seismic resistant construction. Extensive finite element studies previously demonstrated that the strain distribution at the moment connections is significantly different from that predicted by classical beam theory, confirming the postulation by St. Venant in the 1850's. A new design concept was developed to reduce the local strains generated in the standard connection approach. The concept has been termed the "free-flange" concept. In this concept, the flange has a "free" length between the column face and the beam web to re-direct the flow of forces within the connection. A heavy web connection is provided to deliver the beam shear to the column flange. The experimental work included five exterior full scale cyclic connection tests. The tests addressed panel zone deformations, beam size and web connection as part of the program. This project also included detailed nonlinear finite element studies of the detail to compare test results to the analytical predictions. A proposed design procedure was also developed for this detail. This project was performed at the University of Michigan. This task was identified as part of Task 7.02 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.

ABSTRACT

Since the 1994 Northridge earthquake, extensive research has been conducted to find the probable causes of premature failures of beam-to-column moment connections, and new concepts have been developed to ensure adequate ductility for use in seismic resistant steel moment frames.

In this report, a new design concept, called the concept of free flange connection, was developed based on the results of analytical studies using finite element analysis and experimental results. The concept of free flange was introduced and detailed design procedure and free flange connection configuration were presented.

The results of the free flange connection tests showed that the free flange connection possessed sufficient ductility and adequate connection stiffness without any major strength degradation before connection failure.

All free flange connection specimens satisfied the minimum required drift based rotation capacity of 4% requirement for special moment resisting frames specified by the new seismic provisions. The test results proved that suggested range of free flange aspect ratio is good for the length of the free flange, showing neither any strength decrease due to free flange local buckling nor severe stress concentration due to beam flange local deformation.

An important factor for free flange connection behavior is strength of column panel zone. Thus, adequate panel zone shear strength can influence the behavior of overall beam-to-column connection system and some yielding in the panel zone can be permitted without causing unduly large shear deformation. Using notch tough weld material and improved weld details are other important factors influencing the connection behavior.

ACKNOWLEDGEMENT

The research work presented in this report was carried out with financial support from the SAC/FEMA Steel Research Program Subtask 7.02a. This financial support is gratefully acknowledged.

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