SAC
Steel Project

Background Document

Bolted Flange Plate Connections

Report No. SAC/BD-00/05

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 investigation of the seismic performance of bolted flange plate moment connections. The experimental program included 8 six full scale connection tests. This series of tests attempted o investigate two modes of ductile behavior: hinging of the girder and hinging within the flange plates. The tests demonstrated that both yielding mechanisms could produce stable hysteretic behavior. Net section tearing near the end of the bolted flange plate after substantial inelastic deformation was the ultimate failure mode for some of the early specimens in the test series. Subsequent tests included a clamp plate that improved the ductility of the joint. This report summarizes the results of the test program and compares the strength prediction to actual values obtained from the test results. The results of these tests were used in the development of a design procedure intended to result in ductile performance of this type of connections. This project was performed at the University of Illinois at Champaign-Urbana. This task was identified as Task 7.09 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.

SAC 7.09: Bolted Flange Plate Connections

ABSTRACT

Eight full-scale bolted flange plate connections were tested for the *SAC Joint Venture – Phase II Connection Performance* program. These eight specimens are designated as *BFP 01* through *BFP 08*. This series of tests attempted to investigate two modes of ductile behavior: hinging girder and hinging flange plate mechanisms. This report summarizes the test program, and compares the strength prediction to actual values obtained from the test results.

The *BFP* tests demonstrated that both hinging mechanisms produce stable inelastic cyclic behavior, with plastic rotations at failure of approximately *6%* or more. The amount that each component of the joint contributed to the overall inelastic behavior varied among the tested connections. However, in general, the panel zone generally accommodated *3%* or more plastic distortion, slip and inelastic distortion of the flange plate produced more than *1%* plastic rotation, and girder hinging accommodated over *2%* plastic rotation, and in some cases up to *4%* plastic rotation.

The failure mode for 5 of the 8 *BFP* specimens was by tearing of the net girder section beyond the end of the bolted flange plate connection. These were also specimens that experienced a significant amount of girder hinging. Clamp plates were added to the end of the flange plate connection for two specimens in order to mitigate the potential fracture at the critical net section. For one of these specimens, the clamp plates prevented ductile tearing at the net section. The clamp plates prevented local flange buckling and the imposed deformations eventually tore the flanges and web several inches away from the bolt holes. The clamp plates on the other specimen, however, were not sufficient to shift local buckling away from the critical net section, thus tearing initiated at the last bolt line. Although the clamp plates did not prevent net section tearing of this joint, it was apparent the ductility during failure was larger than that for the companion joint. One specimen failed by fracture of the flange plate near the weld in the heat-affected zone. This was the case even though the net section of the flange plate was less than *2″* from the flange plate fracture. Finally, the hinging flange plate specimen failed by ductile fracture initiation, but sudden fracture propagation through the reduced portion of the flange plate.

ACKNOWLEDGEMENTS

This full-scale test program was funded by *SAC Joint Venture : Phase II* program. The test set-up and an additional bolted flange plate test program were funded by the National Science Foundation Grant CMS-95 01449 with Dr. S.C. Liu as program official. The *Steel Shape Producers Council* provided the structural shapes for the full-scale testing for both test programs. The support from each of these sources is gratefully acknowledged.

The author would like to thank Itthinun Teeraparbwong for his tireless effort in getting these specimens tested. The author would also like to thank Professor Charles Roeder, Leader of the Connection Performance Task Group, for his continued support and guidance on this test program. Prof. Roeder expended significant effort on this test program as well as many other connection projects.

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