SAC
Steel Project

Background Document

Parametric Tests on Unreinforced Connections
Volume I – Final Report

Report No. SAC/BD-00/01

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
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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. Issues such as the geometry and size of the access holes, the amount of panel zone deformation, the use of supplemental web fillet welds, the influence of continuity plates, and the effects of concrete slabs were all studies as part of the investigation. The experimental work included six exterior and five interior full scale cyclic connection tests. In addition, this project included detailed nonlinear finite element studies of unreinforced connections subjected to both monotonic and cyclic loading. A low cycle fatigue formulation was developed to evaluate the cyclic ductility of various configurations. The tests and analytical work indicate that unreinforced connections can provide ductility. A recommended design procedure was developed for this class of connections. This project was performed at Lehigh University. This task was identified as part of Task 7.05 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

Parametric tests on unreinforced steel beam-to-column moment connections were conducted in The University of Michigan in order to confirm the reasons of brittle failures observed during the 1994 Northridge earthquake and to determine the performance level of newly detailed unreinforced connection as suggested by the SAC Joint Venture. All test specimens were fabricated by using conventional welded flange-bolted web configuration without any reinforcing elements such as cover plates, flange plates, haunches or ribs.

The pre-Northridge test specimens were designed by using pre-Northridge design criteria, which employed conventional connection details such as adding supplemental welds between the beam web and shear tab and commonly used weld metals. The post-Northridge test specimens were designed by using suggested welding procedures after the Northridge earthquake such as using notch tough weld metal and improved weld details.

The test results of pre-Northridge connection specimens showed similar behavior as observed during the Northridge earthquake and laboratory tests performed during the SAC Phase 1 Program. Those specimens failed in somewhat brittle manner without any significant yielding in the connection. For the post-Northridge connection specimens, some improved connection behavior was achieved. Those specimens achieved some plastic rotation and did not fracture in a brittle manner. Although they showed some improved behavior, they did not achieve the plastic rotations generally required for special moment frames. Beam flange yielding was concentrated in a small region due to localized bending.

Thus, using conventional connection configuration with well detailed and properly managed welding practice was not adequate to achieve the desired ductility level for survival during a major earthquake. It should be accompanied by some scheme of reducing stress levels and minimizing strain concentrations in the connection region.

ACKNOWLEDGEMENT

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