SAC
Steel Project

Background Document

Cyclic Tests on Simple Connections, Including Effects of the Slab

Report No. SAC/BD-00/03

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 simple shear connections, both with and without composite floor slabs. One objective of this project was to determine the rotation capacity of these connections, in order to determine if the interstory drift capacity would be a controlling design parameter for the seismic design of moment resisting steel frame construction. Another objective was to determine the strength and stiffness of these connections, such that this effect could be included in performance evaluations of such structures. The investigation fulfilled these objectives via the testing of sixteen full scale tests and associated analytical studies. Both past and present design approaches demonstrated ductile behavior and large deformation capacity. The presence of the composite floor slab increased the connection capacity below an interstory drift level of approximately 0.04. Models for both deformation and moment capacity have been developed based on the test reports. This project was performed at the University of California at Berkeley. This task was identified as Task 7.04 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 is the final report for Subtask 7.04 of Phase II of the SAC Steel Project. This subtask was concerned primarily with the cyclic behavior of simple, or shear, connections, including the effects of the floor slab. One objective of this project was to determine if simple connections, with the contribution of the floor slab, might be used to resist seismic loads. With this information, analysis may show the use of shear connections to be a cost-effective alternative for repair or retrofit schemes for damaged welded steel moment-frame buildings. Another objective was to explore the use of the lateral resistance of these composite, partially restrained (PR) connections in new construction. This project fulfilled these objectives through an investigation that included 16 full-scale cyclic tests and associated analytical studies.

The test program consisted of sixteen full-scale cyclic tests on both bare-steel specimens and specimens with slabs. This test program was divided into two series, "A" and "B". Series "A" was based primarily upon current shear tab and other connection details, including a supplemental seat angle connection and a stiffened seat connection. Series "B", partially based upon the results of the first test series, looked at some older shear tab details, the effect of using normal-weight concrete as opposed to lightweight concrete, and other details that were an extension of the efforts of Series "A". These connections included a bolted top-and-bottom-angle connection and a reinforcing scheme for the concrete slab in a typical shear tab connection.

These simple connections showed both considerable moment capacity and ductile behavior to large rotations of drift. Cyclic behavior tended to be characterized by bolt slip, yielding of steel, deformation about the bolt holes, and other ductile mechanisms. The contribution of the floor slab proved important, literally doubling the lateral resistance of the connections tested. For example, the shear tab connections with slabs acted as semi-rigid connections with maximum moment capacities on the order of 30 – 60% of the plastic moment capacities of the tested beams and girders. However, this contribution was typically lost after 4% drift, as the concrete slab at the column was crushed. The connections then continued to act similarly to the bare steel shear tab connections. The continuity of the slab at the column was significant with respect to the cyclic behavior, but the type of concrete and addition of reinforcement around the column were not. Meanwhile, the addition of a supplemental seat angle significantly increased the lateral resistance of the connection.

The older shear tab details, designed to pre-80's standards, also demonstrated ductile behavior, although the deformation tended to be concentrated in the beam web rather than in the shear tab. On average, the bare-steel pre-80's connections demonstrated capacities of 10-20% Mp.

Models for rotation and moment capacity of typical shear tabs have been developed, based upon the experimental observations and data. It is hoped that the use of such information in analyses will give useful information regarding the contribution of simple connections to the lateral resistance of welded steel moment-frame buildings.

ACKNOWLEDGEMENTS

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