



**Background
Document**

**Investigation of Damage to WSMF by
Earthquakes Other Than Northridge**

Report No. SAC/BD-99/09

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

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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.

This report was carried out as part of the overall efforts in the Phase II Steel Project to assess the performance of steel buildings during past earthquakes. Many of these efforts focused on the Northridge earthquake. During Phase I, a number of preliminary damage surveys were performed and detailed investigations of moderately damaged buildings were undertaken. In Phase II, more comprehensive and inclusive surveys were conducted of building performance. Focused investigations were undertaken to characterize the accuracy of damage reports, assess the relation of damage to analysis predictions or proximity to other damage locations within a building, and identify any relations that might exist between the severity and distribution of damage in a structure to the characteristics of the ground motion and structure (age, height, framing system, etc.). In addition, the impact of damage on various service providers (building officials, contractors, inspectors, welders, etc.) in the public and private sectors was assessed. Efforts were also undertaken to assess damage to steel moment frame buildings in other earthquakes, such as the Hyogo-ken Nanbu (Kobe), Loma Prieta, and Landers/Big Bear earthquakes.

This report documents incidents of brittle and other damage to steel moment frame buildings resulting from other California earthquakes. An Appendix to *FEMA-355E – State of the Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes* discusses the extensive damage to this class of structures in Kobe during the Hyogo-ken Nanbu earthquake. This project was performed by Degenkolb Engineers in San Francisco, California. This task was identified as Task 3.1.5 in the SAC Phase II work plan.

Numerous individuals helped to develop the scope and content of this project and to review a preliminary version of this report. These individuals included selected guideline writers, topical investigation team leaders, members of the Social, Economic and Policy Panel, the Project Management Committee, and several members of the Project Oversight Committee. The contributions of these individuals are greatly appreciated.