SAC
Steel Project

Background Document

Effects of Hysteretic Deterioration Characteristics on Seismic Response of Moment Resisting Steel Structures

Report No. SAC/BD-99/18

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
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Department of Civil, Structural, and Environmental Engineering, State University of New York at Buffalo

Submitted for distribution to
SAC Joint Venture
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DISCLAIMER

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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.

This report was carried out as part of the overall efforts of the System Performance team of the SAC Phase II Steel Project. This team was responsible for assessing the likely seismic demands on steel moment frames located in different hazard regions of the US. The team focused primarily on 3, 9 and 20 story steel frame buildings located in Los Angeles, Seattle and Boston (representative of regions of high, moderate and low seismic hazard). Local design professionals designed these structures based on pre-Northridge standards as well as on initial post-Northridge recommendations. System Performance team then carried out a wide range of nonlinear dynamic analyses to assess the sensitivity of seismic response to: the intensity and characteristics of ground motions, fracture of connections, deterioration of the hysteretic characteristics of plastic hinge regions, and the proportions and modeling idealizations utilized. In addition, the team evaluated results of dynamic response of frames incorporating partially restrained connections to assess their applicability to regions of moderate seismic risk. These studies were based on a set of ground motions developed for each city, consistent with current USGS hazard analyses corresponding to 50%, 10% and 2% probability of occurrence in 50 years.

This report focuses on studies undertaken related to the effect of various forms of deterioration that may accompany ductile behavior of plastic hinge regions. This project studied the effects of stiffness softening that may accompany reversed cyclic plasticity, pinching that may be associated with partially restrained connections or various forms of slip, and strength deterioration that may be associated with local and lateral torsional buckling. This project was performed by John A. Martin and Associates in Los Angeles, California. This task was identified as Task 5.4.4 of the SAC Phase II program.

Numerous individuals helped to develop the scope and content of this project and to review a preliminary version of this report. These individuals included members of the Technical Advisory Panel (TAP) for System Performance; the Project Management Committee, and several members of the Project Oversight Committee. The contributions of these individuals are greatly appreciated.

ACKNOWLEDGEMENTS

The funding for this research project was provided by the Federal emergency Management Agency (FEMA) through a contract with the SAC Joint Venture. This is the final report on the SAC Phase II, Task 5.4.4 under the topical area named *Topical Investigation on System Performance*. Several other projects were funded within the same topical area. Professor Helmut Krawinkler of Stanford University headed the team of researchers in this topical area. The title of this project was *Study on the Effect of Seismic Demands of Deterioration of Hysteretic Characteristics*.

The authors wish to express their sincere gratitude and appreciation to FEMA and SAC for funding this research and to Professor Krawinkler, Mr. James O. Malley and the members of the project's Technical Advisory Panel, Professors Mahin, Roeder, Foutch, Mr. Hamburger and Mr. Theiss for their valuable comments and constructive criticisms during the course of this investigation.

Substantial additional funding for this project was provided by John A. Martin and Associates, Inc. The results presented and the opinions expressed in this report are those of the authors and do not necessarily reflect the position of any of the funding agencies.

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