SAC
Steel Project

Background Document

Prediction of Seismic Demands for SMRFs with Ductile Connections and Elements

Report No. SAC/BD-99/06

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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Submitted for distribution to
SAC Joint Venture
650-595-1542
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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 structural characteristics on the predicted seismic response of ductile steel moment frame structures. Various approaches for modeling the contributions of beams, panel zones, and elements of the gravity-only portions of the structure were considered. The effects of differing assumptions regarding geometric nonlinearity and viscous damping were also considered. The effect of structural configuration (redundancy) and proportioning (beam to panel zone strength) were studied. This project was performed at Stanford University in California. This task was identified as Task 5.4.3 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.

ABSTRACT

The objective of this work is to improve the knowledge base on the seismic behavior of typical steel moment resisting frame structures, considering regions of different seismicity and sets of ground motions of various intensities and frequency characteristics. The emphasis is on behavior assessment and quantification of global and local force and deformation demands for different hazard levels.

The behavior and response of different height structures in Los Angeles, Seattle, and Boston are studied. Analytical methods and models of various complexities are utilized and evaluated for their ability to predict global and local performance. A sensitivity study is performed on the effects of analysis assumptions on demand predictions. System level behavior characteristics and seismic demands are studied from the perspective of performance at different hazard levels. Local behavior characteristics and element deformation demands are evaluated for various designs, with consideration given to subjective design decisions, variations in material properties, and different types of beam-to-column connections. A simplified procedure for estimation of global and local seismic demands is developed to facilitate decision making in the conceptual design process.

This work is concerned only with the behavior of "ductile" structures. Fracturing of connections and deterioration strength or stiffness of elements are not considered. The results from this study demonstrate that for ductile code conforming structures the global seismic demands, measured in terms of story drifts, are mostly within the range of acceptable performance at the various hazard levels – with one important exception. This exception occurs when a severe ground motion drives a structure into the stability sensitive range, in which case P-delta effects constitute a potential collapse hazard. Local (element) seismic demands are found to be very sensitive to a multitude of factors, which may result in a concentration of plastic deformation demands in either the beams or the panel zones, or in sharing of demands between these two elements and possibly also the columns.

ACKNOWLEDGEMENTS

This report is a slightly modified version of the senior author's Ph.D. dissertation. The work reported herein is part of the FEMA sponsored SAC effort undertaken to understand, quantify, and improve the seismic behavior of steel moment-resisting frame structures with welded connections. Many individuals and research teams have participated in this effort. The cooperate spirit among the team members facilitated coordination and the sharing of information, and made it possible to write individual reports which, in combination, will form a comprehensive knowledge base on SMRF structures.

The authors would like to thank Professor Allin Cornell for his valuable input to the work. The feedback provided by the SAC management team is acknowledged. Several Stanford students, present and former, have provided valuable input. In particular, the help provided by Dr. Pasan Seneviratna and Nicolas Luco is much appreciated.

This work was conducted pursuant to a contract with the Federal Emergency Management Agency (FEMA) through the SAC Joint Venture. SAC is a partnership of the Structural Engineers Association of California, the Applied Technology Council, and the California Universities for Research in Earthquake Engineering. The opinions expressed in this report are those of the authors. No warranty is offered with regard to the results, findings and recommendations contained herein, either by FEMA, the SAC Joint Venture, the individual joint venture partners, their directors, members or employees, or the authors of this publication. These organizations and individuals do not assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any of the information, product or processes included in this publication.

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