SAC
Steel Project

Background Document

Elastic Models for Predicting Building Performance

Report No. SAC/BD-99/21

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
Xiaojing (Jean) Duan and James C. Anderson
Department of Civil and Environmental Engineering
University of Southern California, Los Angeles, California

Submitted for distribution to
SAC Joint Venture
650-595-1542
http://www.sacsteel.org

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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.

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 the seismic performance of extended end plate moment connections. The objectives of this program were to determine the suitability of the extended end plate connections for seismic moment frame applications, and to develop design procedures for this detail. The experimental program included eleven full scale connection tests. Four bolt extended unstiffened, eight bolt extended stiffened and four bolt wide extended unstiffened configurations were cyclically tested in this project. Specimen design addressed the behavior of both the strong plate (inelastic deformations predominantly in the beams) and weak plate (predominant inelastic action in the plate and bolts). One test was performed with a composite slab to determine the effects of the slab on the behavior on a four bolt extended unstiffened connection. An finite element analytical study was conducted to validate the experimental results and assist in the development of design procedures. The results indicate that both the four bolt extended unstiffened and the eight bolt extended stiffened end plate connections can be designed and detailed for use in seimsic applications. The test results led to the recommendation that the four bolt wide extended unstiffened detail should not be used for seismic loading. The composite slab test demonstrated increased demand on the bottom flange connection bolts that should be considered in the connection design. This project was performed at Virginia Tech. This task was identified as Task 7.10 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.

PREDICTING BUILDING PERFORMANCE USING ELASTIC PROCEDURES

Xiaojing (Jean) Duan and James C. Anderson
UNIVERSITY OF SOUTHERN CALIFORNIA

SUMMARY

The purpose of this study was to evaluate the use of elastic procedures for the seismic analysis and design of building systems in a performance based format. These procedures are practical procedures that are extensions of those currently in use by engineers in design offices. The reliability of these procedures for predicting building behavior for different performance levels is also assessed by comparison with the results of nonlinear dynamic analyses conducted by others. The elastic response is related to the nonlinear response through the use of bias factors. Reference building systems were designed by structural engineering firms in Los Angeles and Seattle and three ensembles of earthquake ground motion time histories representing different probabilities of occurrence were developed by others for evaluating building performance. Each suite of ground motion contained ten time histories of orthogonal acceleration pairs resulting in twenty ground motions. Building response parameters include lateral displacement, interstory drift and story shear. Member response parameters considered include column forces at splice locations and demand/capacity ratios for beams and columns. The number of modes to be considered in modal analysis procedures was also evaluated. Comparisons were made with current codes and recommendations that included the 1997 Uniform Building Code, FEMA 302, and FEMA 273. Both static and dynamic (response spectrum) procedures were considered. The use of smoothed design spectra that were consistent with the three performance levels was evaluated by comparison with the average nonlinear response and the current requirements and recommendations. The ability of elastic dynamic analysis procedures to predict potential damage locations in an actual building were evaluated by conducting a case study of an instrumented building that experienced documented damage during the Northridge earthquake.

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