SAC
Steel Project

Background Document

Cyclic Instability of Steel Moment Connections with Reduced Beam Sections

Report No. SAC/BD-99/19

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

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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.

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 a statistical investigation to evaluate the cyclic instability of Reduced Beam Section (RBS) moment connections. The results of fifty-five full scale test specimens were used in a series of regression analyses to evaluate relationships between response parameters (plastic rotation and strength degradation rate, e.g.) and section slenderness parameters for section instability. These analyses indicated that the web slenderness ratio was a more important parameter than either flange slenderness or lateral-torsion buckling. Based on these analyses, recommendations were made to reduce the allowable web slenderness limit for application in moment frame beam sections. This task was identified as part of Task 7.11 of the SAC Phase II program. The testing was performed at the University of California at San Diego.

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.

ABSTRACT

A statistical study was performed to evaluate the cyclic instability of steel moment connections with reduced beam sections (RBS). Based on test results of 55 full-scale test specimens, regression analyses were performed to evaluate the relationships between response quantities (plastic rotation and strength degradation rate) and slenderness parameters for buckling. Treating each buckling mode as an independent limit state, linear regression showed high dependence between the response quantities and the slenderness ratio (h/t_w) for web local buckling, but not lateral-torsional buckling. Considering that buckling modes are interactive, results from nonlinear regression showed the same trend. Since lateral-torsional buckling did not significantly affect the response quantities, an expression that relates the plastic rotation to the slenderness ratios of both web and flange local buckling modes was developed. When an RBS beam of Grade 50 steel satisfies the AISC seismic requirements for both local and lateral-torsional buckling, the expression shows that a plastic rotation of 0.02 radian can be achieved. To achieve a plastic rotation of 0.03 radian, however, the lower bound h/t_w ratio can be taken as $440/\sqrt{F_y}$. To provide some level of conservatism, a limiting h/t_w ratio of $418/\sqrt{F_y}$ is recommended for seismic design. An expression for evaluating the strength degradation rate was also developed. The presence of a concrete slab was shown to increase both the strength and plastic rotation capacity of the RBS beam under positive bending. Under negative bending, the slab did not enhance the plastic rotation capacity. Therefore, a slab cannot be counted on to brace beam bottom flange.

ACKNOWLEDGEMENTS

Funding for this research (Task 14) was provided by the Federal Emergency Management Agency through the SAC Joint Venture. SAC is a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering.

Dr. C. Roeder is the Team Leader of Connection Performance of the SAC Joint Venture who initiated the study. Mr. J. Malley is the Project Director of Topical Investigations of the SAC Joint Venture. Guidance provided by Dr. Roeder and Mr. Malley was greatly appreciated. Mr. Nestor Iwankiw of American Institute of Steel Construction provided constructive comment.

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