SAC
Steel Project

Background
Document

Effects of Strain Hardening and Strain Aging on the K-Region of Structural Shapes

Report No. SAC/BD-98/02

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
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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

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

Several investigations in Phase II of the FEMA/SAC Steel Project are attempting to define the expected material properties of rolled steel sections and the scatter in these properties, and evaluating their influence on the behavior of beam-column moment connections. This work is under the direction of the Materials and Fracture team and involves tests of materials from various producers to evaluate yield point and yield stress, ratio of yield stress to ultimate stress, Charpy V-notch values, through-thickness behavior, etc. The results of these studies will be used to update seismic design criteria for steel moment frame structures and identify desired properties for future generations of steel materials.

One issue which has emerged as particularly important over the course of the Phase II project is the variation in the material properties in the "k-region" of structural steel shapes (the portion of the web adjacent to the fillet transition to the flange). Some have expressed concern that the roller-straightening process which has been employed by some shape producers to bring rolled sections into conformance with AISC tolerances has led to a concentration of plastic strain in this region. Studies funded by SAC and other organizations, including AISC, are focusing on developing an improved understanding of the material properties in the k-region.

Key to the behavior of steels subjected to large plastic strains is the phenomenon of strain aging, in which the assumed yield, tensile, and fracture properties change over time after a plastic strain has been applied and the associated stress removed. The background report presented here summarizes a series of tests on A36 and A572 Grade 50 steel plates with the goal of characterizing the effects of strain aging as a function of both strain amplitude and aging temperature.

Although the magnitude of plastic strain introduced into the k-region due to straightening activities typically is not known precisely, the data presented in this report clarifies the potential for variations in the assumed material properties as a result of strain aging. The summary was written by John M. Barsom and Sjaan A. Korvink and has been provided to SAC for publication and distribution. While the report was not funded as part of the SAC Steel Project, it is being distributed as a service to the engineering community. The contribution of the authors is greatly appreciated.

TABLE OF CONTENTS