SAC
Steel Project

Background Document

Improvement of Welded Connections using Fracture Tough Overlays

Report No. SAC/BD-00/20

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 and Environmental Engineering, University of Southern California
Peter Maranian
Brandow & Johnston Associates

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 experimental and analytical investigation of the seismic performance of moment connections repaired or upgraded with the weld overlay technique. In this technique, high toughness weld material is added to existing welded joints to improve their strength and toughness. A previous investigation of this technique indicated that this technique showed promise in improve the ductility of these connections. The experimental program in this project included five full scale connection tests. This series of tests attempted to extend earlier work on this technique, through using the FCAW-S process for the overlay material for both repair and retrofit applications. The tests indicate that this approach has potential as a means of repair and retrofit of pre-Northridge connections. This report summarizes the results of the test program and a supporting series of finite element analyses to demonstrate the viability of the approach. The results were used in the development of a design procedure intended to result in ductile performance of this type of connections. This project was performed at the University of Southern California. This task was identified as Task 7.07 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.

IMPROVEMENT OF WELDED CONNECTIONS USING FRACTURE TOUGH OVERLAYS

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SUMMARY

Analytical and experimental studies are conducted to investigate the application of fracture tough overlay welds for the repair and/or upgrading on welded steel moment connections. The experimental program consisted of cyclic tests on five exterior connection specimens. Three specimens were fabricated from small size sections and two specimens were fabricated from intermediate size sections. Analytical studies consisted of detailed finite element simulations of the exterior connection using both plate elements and solid elements. Six finite models were developed for the intermediate specimen and included the original configuration and five variations that included the application of weld overlays. The application of weld overlays to the small size specimens definitely improved their cyclic performance. The plastic rotation capacity of all three specimens was either close to or exceeded three percent. The application to the intermediate size specimen requires further study due to the limited number of tests conducted. The first specimen, in an upgrade configuration failed in the parent material away from the weld region at a plastic rotation of 2.7%. The second specimen, in a repair configuration, failed in the weld at a plastic rotation of only 1.7%. Both the analytical and experimental studies indicate that the region around the weld access hole is critical for connection performance.

DEDICATION

This report is dedicated to the memory of Dr. Warner Simon who died on May 24, 2000, at the age of 89. Following the Northridge earthquake, Dr. Simon pioneered the use of weld overlays for the repair of damaged steel moment frame buildings and led the Dynamic Load Weld (DLW) Task group in these endeavors. His early work on small component testing, his hard work, vision and integrity were of great inspiration to the authors of this report. The memory of this exceptional human being, and the legacy of his creative contributions will remain with us always.

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