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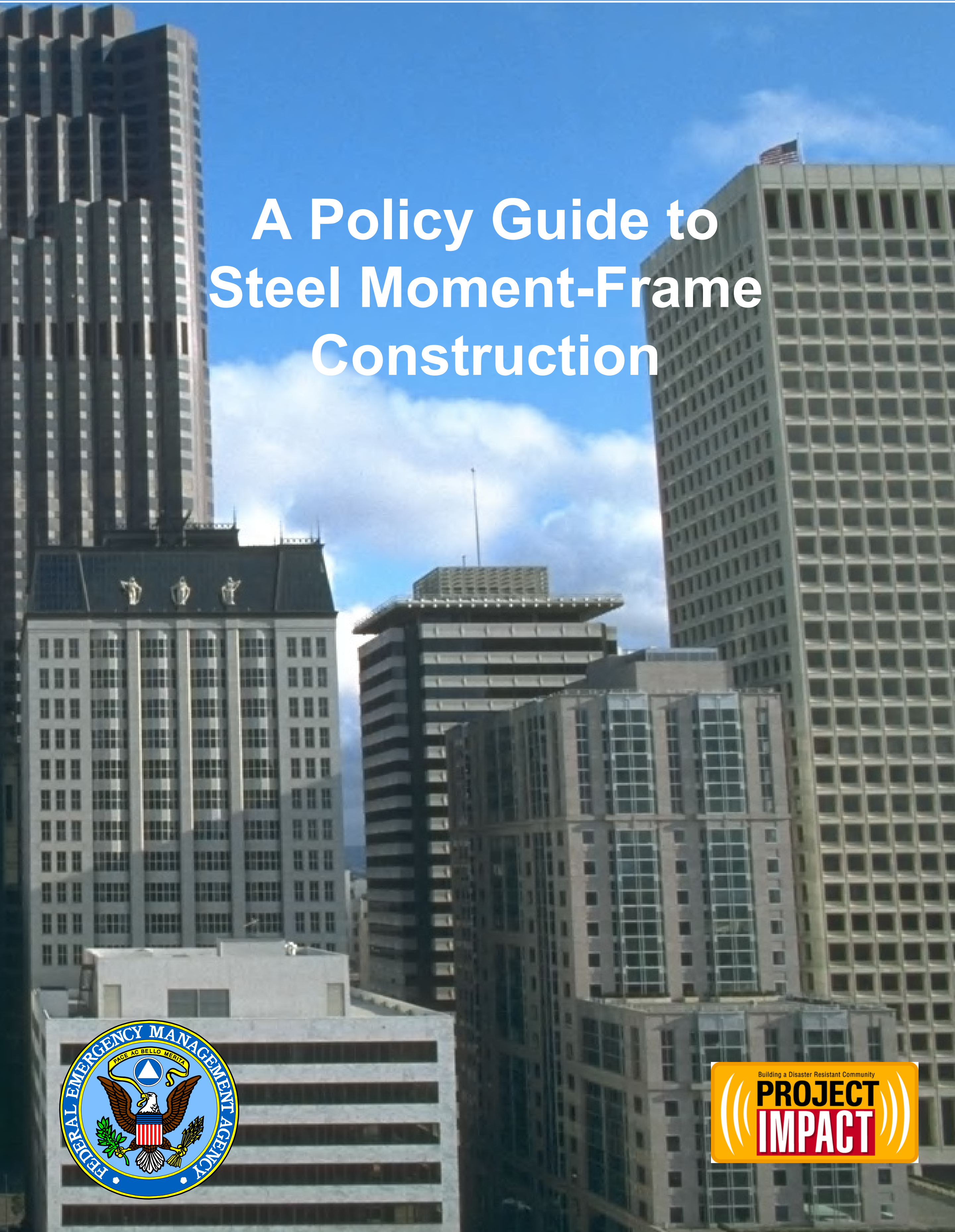
A Policy Guide to Steel Moment-Frame Construction



Building a Disaster Resistant Community
PROJECT IMPACT

DISCLAIMER

Cover Art. The background photograph on the cover of this guide for Policy Makers is a cityscape of a portion of the financial district of the City of San Francisco. Each of the tall buildings visible in this cityscape is a steel moment-frame building. Similar populations of these buildings exist in most other American cities and many thousands of smaller steel moment-frame buildings are present around the United States as well. Until the 1994 Northridge earthquake, many engineers regarded these buildings as highly resistant to earthquake damage. The discovery of unanticipated fracturing of the steel framing following the 1994 Northridge earthquake shattered this belief and called to question the safety of these structures.

A Policy Guide to Steel Moment-frame Construction

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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Project Oversight Committee

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SAC Joint Venture

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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 post earthquake 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 university earthquake research 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 consultants and 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 structures.

ACKNOWLEDGEMENTS

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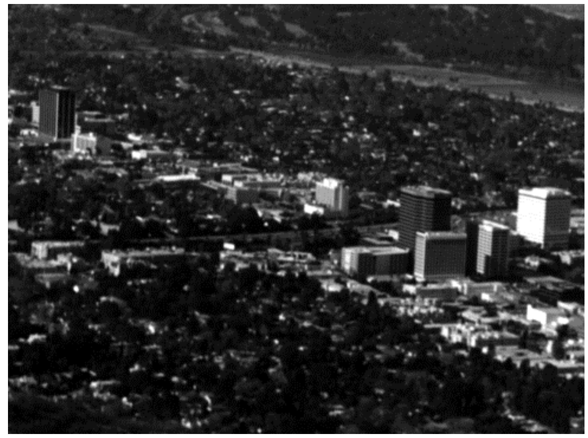
INTRODUCTION

The Northridge earthquake of January 17, 1994, caused widespread building damage throughout some of the most heavily populated communities of Southern California including the San Fernando Valley, Santa Monica and West Los Angeles, resulting in estimated economic losses exceeding $30 billion. Much of the damage sustained was quite predictable, occurring in types of buildings that engineers had previously identified as having low seismic resistance and significant risk of damage in earthquakes. This included older masonry and concrete buildings, but not steel framed buildings. Surprisingly, however, a number of modern, welded, steel, moment-frame buildings also sustained significant damage. This damage consisted of a brittle fracturing of the steel frames at the welded joints between the beams (horizontal framing members) and columns (vertical framing members). A few of the most severely damaged buildings could readily be observed to be out-of-plumb (leaning to one side). However, many of the damaged buildings exhibited no outward signs of these fractures, making damage detection both difficult and costly. Then, exactly one year later, on January 17, 1995, the city of Kobe, Japan also experienced a large earthquake, causing similar unanticipated damage to steel moment-frame buildings.

Following discovery of hidden damage in Los Angeles area buildings, the potential for similar, undiscovered damage in San Francisco and other communities affected by past earthquakes was raised.



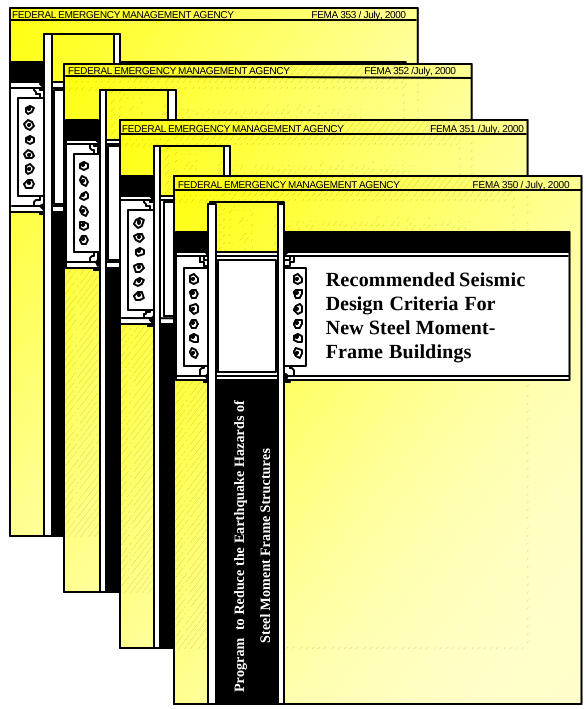
Ventura Boulevard in the San Fernando Valley. Many of these buildings had hidden damage.

Prior to the 1994 Northridge and 1995 Kobe earthquakes, engineers believed that steel moment-frames would behave in a ductile manner, bending under earthquake loading, but not breaking. As a result, this became one of the most common types of construction used for major buildings in areas subject to severe earthquakes. The discovery of the potential for fracturing in these frames called to question the adequacy of the building code provisions dealing with this type of construction and created a crisis of confidence around the world. Engineers did not have clear guidance on how to detect damage, repair the damage they found, assess the safety of existing buildings, upgrade buildings found to be deficient or design new steel moment-frame structures to perform adequately in earthquakes. The observed damage also raised questions as to whether buildings in cities affected by other past earthquakes had sustained similar undetected damage and were now weakened and potentially hazardous. In fact, some structures in the San Francisco Bay area have been discovered to have similar fracture damage most probably dating to the 1989 Loma Prieta earthquake.

In response to the many concerns raised by these damage discoveries, the Federal Emergency Management Agency (FEMA) sponsored a program of directed investigation and development to identify the cause of the damage, quantify the risk inherent in steel structures and develop practical and effective engineering criteria for mitigation of this risk. FEMA contracted with the SAC Joint Venture, a partnership of the Structural Engineers Association of California (SEAOC), a professional association with more than 3,000 members; the Applied Technology Council (ATC), a non-profit foundation dedicated to the translation of structural engineering research into state-of-art practice guidelines; and the California Universities for Research in Earthquake Engineering (CUREe), a consortium of eight California universities with comprehensive earthquake engineering research facilities and personnel. The resulting FEMA/SAC project was conducted over a period of 6 years at a cost of $12 million and included the participation of hundreds of leading practicing engineers, university researchers, industry associations, contractors, materials suppliers, inspectors and building officials from around the United States. These efforts were coordinated with parallel efforts conducted by other agencies, including the National Science Foundation and National Institute of Standards and Technology (NIST), and with concurrent efforts in other nations, including a large program in Japan. In all, hundreds of tests of material specimens and large-scale structural assemblies were conducted, as well as thousands of computerized analytical investigations.

As the project progressed, interim guidance documents were published to provide practicing engineers and the construction industry with important information on the lessons learned, as well as recommendations for investigation, repair, upgrade, and design of steel moment-frame buildings. Many of these recommendations have already been incorporated into recent building codes. This project culminated with the publication of four engineering practice guideline documents. These four volumes include state-of-the-art recommendations that should be included in future building codes, as well as guidelines that may be applied voluntarily to assess and reduce the earthquake risk in our communities.

This policy guide has been prepared to provide a nontechnical summary of the valuable information contained in the FEMA/SAC publications, an understanding of the risk associated with steel moment-frame buildings, and the practical measures that can be taken to reduce this risk. It is anticipated that this guide will be of interest to building owners and tenants, members of the financial and insurance industries, and to government planners and the building regulation community.



FEMA 350 Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings

FEMA 351 Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings

FEMA 352 Recommended Post-earthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings

FEMA 353 Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications