SAC
Steel Project

Background Document

Assessment of the Benefits of Implementing the New Seismic Design Criteria and Inspection Procedures

Report No. SAC/BD-99/12

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
650-595-1542
http://www.sacsteel.org

March 10, 2000

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.

This report describes a limited assessment of the benefits (i.e., reduced losses) resulting from the implementation of the proposed FEMA/SAC Guidelines. Benefits associated with two scenario earthquakes have been estimated for the City of Los Angeles, using the NIBS/FEMA HAZUS earthquake loss estimation software. Default data were replaced with customized building inventories, cost data and steel moment resisting frame fragility curves, resulting in a Level 2 HAZUS analysis. The fragility curves were provided from another study performed for the SAC project. Losses were assessed for two scenario earthquakes; the 1994 Northridge earthquake and a M6.7 event on the Elysian fault. The first earthquake was selected to allow limited validation of building damage and indirect loss estimates, as well as to estimate the impact of retrofit and evaluate the potential losses to damaged structures in a repeat of the 1994 event. The second event was selected because of its expected regional impact and potential significant impact on moment frame buildings within the City of Los Angeles. Inventories for both the 1994 time frame of the Northridge event, and a postulated inventory for 2020 were considered. Resulting benefits, including reduction in building damage, casualties avoided and impact on income were collected for various scenarios, demonstrating the benefits that can be realized from implementation of the various guideline documents.

Numerous individuals helped to review a preliminary version of this report, including members of the Past Performance Team, the Project Oversight Committee and representatives of FEMA. The contributions of these individuals are greatly appreciated.

Assessment of the Benefits of Implementing the New Seismic Design Criteria and Inspection Procedures

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SUMMARY

As part of the on-going FEMA/SAC Phase 2 Steel Project, EQE International has performed a limited assessment of benefits (i.e., reduced losses) resulting from implementation of the new steel moment frame *Seismic Design Criteria* and *Inspection Procedures*. Benefits associated with two scenario earthquakes have been estimated for the City of Los Angeles, using the NIBS/FEMA HAZUS earthquake loss estimation software. Default data were replaced with customized building inventories, cost data and steel moment-resisting frame (SMRF) fragility curves, resulting in a Level 2 HAZUS Analysis. Raw data on more than 540,000 buildings within the City of Los Angeles totaling more than 1.6 billion square feet were aggregated for use in HAZUS. Included within this data were approximately 75 million square feet of SMRF structures, valued by HAZUS at about $6.8 billion.

Losses were assessed for two scenario earthquakes; the 1994 Northridge earthquake and a M6.7 earthquake on the Elysian Park thrust fault. The first earthquake was selected to allow limited validation of building damage and indirect loss estimates, as well as estimate the impact of retrofit and evaluate the potential losses to damaged structures in a repeat of the 1994 event. Actual ground motion data from the USGS were used in lieu of simulating ground motions with HAZUS. The second scenario, a maximum Magnitude earthquake for the Elysian Park fault, was selected because of its expected regional impact and potential significant impact on nearby SMRF structures within the City of Los Angeles.

Two building inventories for the City of Los Angeles were analyzed; the existing inventory in 1994 as developed from County Assessor and other data, and an inventory for the year 2020, developed from the 1994 inventory using growth projections for the population and the economy.

Three sets of SMRF fragility curves were provided by another SAC Contractor (documented in Kircher & Associates, 2000), representing SMRF structures designed under existing codes ("Pre-Northridge design"), SMRF structures designed under the new code requirements ("New code"), and SMRF structures that were damaged in previous earthquakes ("Damaged"). In addition, curves were provided for three geographic regions, Los Angeles, Seattle, and Boston. These regional families of curves may be associated with the various seismic design levels, as

designated within HAZUS. For application to the City of Los Angeles, the Los Angeles curves would best represent structures built according to "High seismic design" and "Moderate seismic design", while the Seattle curves would be appropriate for "Low seismic design" structures.

The damage functions, inventories and scenario earthquakes were combined in twelve HAZUS runs intended to determine three sets of "benefits", as follows:

1. Benefits (reduction in losses) from full retrofit of existing SMRF buildings within the City of Los Angeles, given a M6.7 earthquake on the Elysian Park fault.

2. Benefits (reduction in losses) from full retrofit of existing SMRF buildings within the City of Los Angeles and design of new SMRF structures under the new code requirements, given a M6.7 earthquake on the Elysian Park fault in the year 2020.

3. Benefits (reduction in losses) from repair/retrofit of existing (damaged) SMRF buildings within the City of Los Angeles, given a repeat of the 1994 Northridge earthquake.

In order to estimate these benefits, as well as identify the contribution of SMRF losses to overall direct and indirect losses, a total of twelve HAZUS runs were required. These runs are described in **Table 1**. SMRF-related losses in a given scenario earthquake may be determined as the difference between the selected run and the equivalent "No SMRF" run. For example, to isolate SMRF-related losses in an Elysian Park event (1994), the results from run 3 (no SMRF) should be subtracted from run 2 (Elysian Park 1994 baseline). Similarly, to determine the benefit from full retrofit of existing SMRF structures in an Elysian Park event, the retrofit results (run 4) should be subtracted from the baseline (run 2). Resulting benefits, including reduction in building damage, casualties avoided, and impact on income, are summarized in **Table 2**.

As shown, more than \$345 million (\$1994) in direct damage to SMRF buildings could be avoided by retrofitting, if an Elysian Park event were to occur. (The net impact is reduced slightly by a net loss of \$41 million in economic stimulus to the region.) Similarly, more than 1,700 injuries and almost 300 deaths would also be avoided. These figures grow to more than \$390 million (in constant 1994\$) in damage (less \$69 million in reduced regional economic stimulus), 2,800 injuries and 500 deaths by 2020, following implementation of the new code. In addition, retrofit of existing SMRF structures would result in a benefit of \$346 million (\$1994) in avoided damage to previously damaged structures in a repeat of the 1994 Northridge earthquake, minus a small net loss of \$18 million in regional economic stimuli.

The next step in a true benefit-cost analysis would be to compare the estimated benefits (incorporating probability of occurrence i.e., annualized losses), to potential costs associated with retrofit and code implementation to assess the cost-effectiveness of the mitigation. While detailed estimates of costs associated with retrofit and implementation of the new code are the purview of other SAC researchers, it should be noted that implementation of a complete benefit-cost analysis is left to future research. Nevertheless, preliminary cost estimates for code implementation resulting from the SAC cost study for model buildings can be used to demonstrate potential cost-benefit applications.

Model building costs (Mahin, 1999) associated with new code implementation range from –2% (9 story, RBS connections) to +4% (20 story). For comparison, benefits (losses avoided in a M6.7 earthquake on the Elysian Park fault in the year 2020) associated with new code implementation represent 1.2% of exposed building value (estimated from a projected inventory of new SMRF strutures constructed by the year 2020). It must be noted that no probability of occurrence is considered here (and the probability of occurrence of this large earthquake is small), yet the resulting comparison indicates that the monetary savings from one large postulated earthquake are of the same order of magnitude as the cost of code implementation. While on its own, this is insufficient to justify code implementation, it suggests the merits of completing a true benefit-cost analysis.

TABLE 1: HAZUS RUN LIST

Run No.	Run Description	Hazard	Inventory Data	Fragility Curves
1	Northridge validation	1994 USGS Northridge Earthquake (EQ 1)	1994 building inventory, population and cost data (1994 INVENTORY)	"Pre-Northridge" with SMRF building fragility beta's reduced to reflect reduced uncertainty associated with actual ground motions.
2	Elysian Park 1994 Baseline	Simulated M6.7 Earthquake on Elysian Park thrust fault (EQ 2)	1994 INVENTORY	"Pre-Northridge"
3	Elysian Park 1994, no SMRF	EQ 2	1994 INVENTORY, repair costs for SMRF "zeroed-out"	SMRF medians set to 999, betas set to 0.01 to force all SMRF into damage state "None" ("No SMRF")
4	Elysian Park 1994, full retrofit	EQ 2	1994 INVENTORY	"New Code"
5	Elysian Park 2020 Baseline (no code change, no retrofit)	EQ 2	2020 building inventory, population and cost data (2020 INVENTORY)	"Pre-Northridge"
6	Elysian Park 2020, no SMRF	EQ 2	2020 INVENTORY, repair costs for SMRF "zeroed-out"	"No SMRF"
7	Elysian Park 2020, new code and full retrofit	EQ 2	2020 INVENTORY	"New Code"
8	1994 Northridge – Repeat of Initiating Event	EQ 1	1994 INVENTORY	"Damaged"
9	1994 Northridge, no SMRF	EQ 1	1994 INVENTORY, repair costs for SMRF "zeroed-out"	"No SMRF"
10	1994 Northridge Baseline	EQ 1	1994 INVENTORY	"Pre-Northridge"
11	1994 Northridge, full retrofit	EQ 1	1994 INVENTORY	"New Code"
12	Northridge validation 2	EQ 1	1994 Inventory	"Pre-Northridge", with reduced betas for all model building types

TABLE 2: ESTIMATED BENEFITS (REDUCTION IN LOSSES) ASSOCIATED WITH THE IMPLEMENTATION OF *SEISMIC DESIGN CRITERIA* AND *INSPECTION PROCEDURES*, CITY OF LOS ANGELES

	Benefits from full SMRF retrofit – M6.7 Elysian Park Scenario Earthquake (RUN 2 – RUN 4)	**Benefits from full SMRF retrofit and implementation of new code – M6.7 Elysian Park Scenario Earthquake in 2020 (RUN 5 – RUN 7)**	**Benefits from full SMRF repair/retrofit – repeat of 1994 Northridge Earthquake (RUN 8 – RUN 11)**
DIRECT ECONOMIC LOSSES			
Structural damage ($M, 1994)	260	286	270
Nonstructural Damage ($M, 1994)	86	109	76
Total Building-Related Damage ($M, 1994)	346	395	346
CASUALTIES			
Injuries at 2 a.m. (Severity 1, 2 and 3)	647	888	805
Deaths at 2 a.m. (Severity 4)	22	33	22
Injuries at 2 p.m. (Severity 1, 2 and 3)	1,712	2,849	1,418
Deaths at 2 p.m. (Severity 4)	282	489	228
Injuries at 5 p.m. (Severity 1, 2 and 3)	869	1,435	762
Deaths at 5 p.m. (Severity 4)	127	224	103
INCOME LOSSES			
Total Income Impact – Years 1 – 15 ($M, 1994) (Note: negative impact indicates reduction in net stimulus to local economy from retrofit and implementation of new code)	-41	-69	-18

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