

*Summary of NIST's Activities Related to the
January 17, 1994 Northridge California Earthquake*

RILEY M. CHUNG, BIJAN MOHRAZ, AND JOHN GROSS
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899, USA

SUMMARY

The report summarizes the research activities supported by the National Institute of Standards and Technology (NIST) through the funds appropriated by Congress resulting from the January 17, 1994 Northridge earthquake in California. NIST received \$3.7M which were used to support 28 studies in the following areas: post-Northridge earthquake reconnaissance, fires and lifelines, steel frame buildings, and other related topics such as non-structural components and experimental facilities needs. Some projects are carried out by NIST staff, others externally. Most of the in-house projects are conducted as a team with the participation of external experts. This report presents a summary for each project, including the principal investigator(s), objectives, and status. Many studies have been completed and others are near completion. We are now preparing a more comprehensive summary report that will present the findings, conclusions, and recommendations from these studies. The summary report is expected to be completed by the end of September.

INTRODUCTION

The Congressional emergency appropriation resulting from the January 17, 1994 Northridge earthquake in California provided the National Institute of Standards and Technology (NIST) an unparalleled opportunity to expand its internal effort in earthquake engineering research and development under the National Earthquake Hazards Reduction Program (NEHRP), as well as its collaborative efforts with other organizations in the nation's earthquake hazard mitigation community. This report summarizes the activities, as represented by 28 projects described herein, developed through this emergency appropriation. Reports published by NIST are identified and copies of them are available by contacting the authors through email (riley.chung@nist.gov; bijan.mohraz@nist.gov)

Funding to support the post-Northridge earthquake engineering activities at NIST was provided in two phases. In Phase I, NIST received \$1.5M, transferred through FEMA, as part of the immediate appropriation to support activities for learning lessons from the Northridge earthquake. In Phase II, Congress appropriated NIST \$3.0M directly, assigning NIST to focus on research and development issues in the areas of fires and lifelines. Further, because of the urgent need in examining problems related to the seismic performance of steel frame buildings, NIST added it as another topic to its activity list. It should be noted that the rescission in FY95 resulted in a reduction of approximately \$0.78M from the Phase II funding.

THE 1994 NORTHRIDGE EARTHQUAKE INVESTIGATION

A reconnaissance study was carried out immediately after the earthquake to assess the damage and document the performance of buildings and lifeline systems.

Northridge Earthquake Research Conference, August 20-22, 1997, Los Angeles, CA.
Proceedings, 1997.

Principal Investigator(s): H. S. Lew, Riley M. Chung, Nicholas Carino, Andrew W. Taylor, Diana Todd, and William D. Walton, NIST
James Cooper and Roland Nimis, FHWA/DOT

Objectives: To investigate the performance of structures, lifelines, and fire protection systems following the Northridge earthquake of January 17, 1994. A multi-agency Federal reconnaissance team organized by the Interagency Committee on Seismic Safety in Construction was dispatched to Los Angeles on January 19, 1995 to examine the damage and document the performance of constructed facilities.

Status: Completed.

Publication(s): 1994 Northridge Earthquake: Performance of Structures, Lifelines, and Fire Protection Systems, NIST Special Publication 862, May 1994.

FIRE/LIFELINE

The Fire/Lifeline topic has been identified as one of the most critical areas through post-earthquake reconnaissance in recent devastating earthquakes. NIST, with full participation of the fire and lifeline communities, organized a fire and lifeline workshop in January 1995 that brought together over 40 experts to address issues related to the performance of lifelines and fire protection systems..

FIRE/LIFELINE WORKSHOP

Principal Investigator(s): Nora Jason, Riley M. Chung, Bijan Mohraz, and Doug Walton, NIST
Fred Mowrer, University of Maryland, College Park, MD

Objectives: To assess technology development and research needs that will be used in developing recommendations to reduce the number and severity of post-earthquake fires.

Status: Completed

Publication(s): Post-Earthquake Fire and Lifeline Workshop; Long Beach, California, January 30-31, 1995, Proceedings, NIST Special Publication 889, August 1995.

The workshop participants identified and prioritized 20 R&D projects recommending for NIST support. The following projects were developed using the workshop recommendations as a guide.

NORTHRIDGE POST-EARTHQUAKE MONOGRAPH ON LIFELINE PERFORMANCE

Principal Investigator(s): Anshel Schiff, etc., ASCE/TCLEE, Washington, D. C.
Riley M. Chung, NIST

Objectives: To conduct a follow-up investigation on the performance of lifeline systems resulting from the January 17, 1994 Northridge earthquake and publish a report to document the observations and lessons learned. The report also includes the information collected in the initial investigation conducted immediately following the earthquake.

Status: Completed

Publication(s): Northridge Earthquake; Lifeline Performance and Post-Earthquake Response, ASCE Technical Council on Lifeline Earthquake Engineering Monograph No.8, August 1995. Also published as NIST GCR 97-712.

PROTECTION OF BUILDING ENVELOPE FROM EXTERNAL FIRE SOURCES

Principal Investigator(s): Fred W. Mowrer, University of Maryland, College Park, MD
Doug Walton, NIST

Objectives: To evaluate the fire exposure conditions that cause glass to fall, examine the protection afforded by strategies that could easily be retrofitted, and address the protection of soffit vents from external fire penetration in single family homes.

Status: In Progress.

Publication(s): To be expected by September 1997.

FIRE-RELATED ASPECTS OF THE NORTHRIDGE EARTHQUAKE

Principal Investigator(s): Charles Scawthorn, EQE International, San Francisco, CA
Doug Walton, NIST

Objectives: To investigate and fully document fires, fire spread and fire department operations, and provide analysis of this data in support of future estimation of fires following earthquakes. Summarize lessons learned and insights resulting from this earthquake, in support of loss reduction practices and mitigation of potential conflagrations and large loss of fires following earthquakes.

Status: In progress.

Publication(s): To be expected by September 1997.

ANALYSIS OF FIRE SPRINKLER SYSTEM PERFORMANCE IN THE NORTHRIDGE EARTHQUAKE

Principal Investigator(s): Russell P. Fleming, National Fire Sprinkler Association, Patterson, NY
Doug Walton, NIST

Objectives: To analyze the performance of fire sprinkler systems in the earthquake in relation to the specific earthquake protection measures employed in their design and installation and develop proposed changes to the national installation standard, NFPA 13, which would improve future system performance by bringing brace fastener details up to current levels of technology.

Status: In progress.

Publication(s): To be expected by September 1997.

FIRE HAZARDS AND MITIGATION MEASURES ASSOCIATED WITH SEISMIC DAMAGE OF WATER-HEATERS AND RELATED COMPONENTS

Principal Investigator(s): T. T. Soong, SUNY Buffalo, NY
Bijan Mohraz and Riley M. Chung, NIST

Objectives: To assess seismic damage of nonstructural elements in buildings which may lead to fire hazards; review current codes and provisions related to seismic design of water heaters and related components; develop, through analysis and experiments, mitigation measures which can be effective in minimizing their fire hazards; and recommend specific seismic code provisions and design guidelines for this class of nonstructural components.

Status: In progress.

Publication(s): Report to be expected in August 1997. It will be published as a NIST GCR series.

EVALUATION OF PASSIVE FIRE PROTECTION SYSTEMS FOLLOWING EARTHQUAKES

Principal Investigator(s): Robert Brady Williamson, Lawrence Berkeley National Laboratory
Doug Walton, NIST

Objectives: To conduct a post-earthquake safety evaluation of the passive fire prevention features of buildings and add such evaluation to the ATC-20 document, "Procedures for post-earthquake safety evaluation of buildings," which in its current form lacks procedures for fire protection system evaluation.

Status: In progress.

Publication(s): To be expected by September 1997.

METHODOLOGIES TO EVALUATE FIRE SAFETY OF BUILDINGS FOLLOWING EARTHQUAKES

Principal Investigator(s): William Greene, Calico-Sterling Company, Davis, CA
Doug Walton, NIST

Objectives: To develop a methodology that can be used by fire inspectors to evaluate the condition of building active fire protection features following earthquakes. The study will address automatic fire

sprinklers; fire pumps; fire standpipe systems, dry chemical, liquid, and gaseous fire suppression systems; and fire alarm and detection systems.

Status: In progress.

Publication(s): To be expected by September 1997.

RELIABILITY AND RESTORATION OF WATER SUPPLY SYSTEMS FOLLOWING EARTHQUAKES

Principal Investigator(s): Donald Ballantyne, EQE, Seattle, WA
(formerly with Dames and Moore, Inc., Seattle, WA)
Riley M. Chung and Bijan Mohraz, NIST

Objectives: To assess post-earthquake water supply system reliability, and make recommendations to enhance post-earthquake operability of domestic water supply and/or alternate water supply systems, and enable quick restoration of service following an earthquake.

Status: In progress.

Publication(s): To be expected by July 1997 as a NIST GCR series.

SEISMIC RISK ASSESSMENT OF LIQUID FUEL SYSTEMS

Principal Investigator(s): M. Shinozuka, University of Southern California, Los Angeles, CA
Bijan Mohraz and Riley M. Chung, NIST

Objectives: To review and integrate available methods and procedures of seismic risk assessment and loss estimation, develop a framework for risk assessment that can logically accommodate the state-of-the-art results of research and development effort on the physical and functional performance of the liquid fuel transmission systems subjected to earthquakes, identify and highlight the design issues that must reflect the risk concept in the process of the development of design guides, and develop and draft an outline of design guides.

Status: In progress.

Publication(s): To be expected by July 1997 as a NIST GCR series.

SEISMIC PERFORMANCE OF LIQUID FUEL TANKS

Principal Investigator(s): Tom Cooper, T. W. Cooper, Inc., Torrance, CA
Bijan Mohraz and Riley M. Chung, NIST

Objectives: To document and evaluate the performance of liquid fuel tanks during the past and recent major earthquakes, particularly the Northridge earthquake, assess their performance with respect to the current design and construction practices, and develop recommendations for improving their future performance.

Status: In progress.

Publication(s): To be expected by July 1997 as a NIST GCR series.

THE ASSESSMENT AND MITIGATION OF EARTHQUAKE HAZARD TO ELECTRIC POWER

Principal Investigator(s): Anshel Schiff, etc., ASCE/TCLEE
Riley M. Chung, NIST

Objectives: To develop guides for improving earthquake response of power system substations and emergency power systems, and to study potential effects of ground motion variations at substation sites on design and test standards for selection, installation, and operating of emergency power.

Status: In progress.

Publication(s): A couple of publications are expected by December 1997. Both will be published as NIST GCR reports.

STEEL FRAME BUILDINGS

Over 100 steel framed buildings were damaged by the Northridge earthquake. NIST working with local engineers carried out a survey and assessment of the damaged buildings. Findings from the survey were presented at the September 1994 SAC workshop. Seven problem-focused experimental and analytical studies were initiated by NIST, in collaboration with universities and experts in the private sector to (1) obtain a thorough understanding of the nature of the observed fractures in the welded connections, (2) quantify the seismic demands placed on a steel structure, (3) assess the efficacy of proposed repair/rehabilitation schemes, (4) develop a computer model to account for the potential connection failure and the subsequent loss of both stiffness and strength, and (5) study experimentally three rehabilitation strategies: reduced beam section, welded haunch, and bolted bracket. These studies are coordinated with related FEMA- and NSF-sponsored studies, notably that of the SAC joint venture. Most of these studies have been completed and others are expected to be completed in the next few months. NIST and the American Institute of Steel Construction (AISC) are developing a rehabilitation guidelines for existing welded steel moment frame buildings. These guidelines will be ready for use by the design profession by September 1997.

WORKSHOP ON SEISMIC PERFORMANCE OF STEEL FRAME BUILDINGS

Principal Investigator(s): SAC Joint Venture
H. S. Lew and John Gross, NIST

Objectives: To coordinate related interests and focus on the problems observed in the performance of steel frame buildings in the Northridge earthquake. To develop a research plan and determine the best approach for solving those problems.

Status: Completed

Publication(s): SAC Workshop on Seismic Performance of Steel Frame Buildings, September 1994. (available through SAC Joint Venture)

ENHANCEMENT OF IDARC FOR MODELING INELASTIC BEHAVIOR OF WELDED CONNECTIONS IN STEEL MOMENT-RESISTING FRAMES

Principal Investigator(s): Sashi K. Kunnath, University of Central Florida, Orlando, FL
John Gross and Riley M. Chung, NIST

Objectives: To use the IDARC computational platform as the base program to which necessary modifications are made to enable detailed evaluations of steel moment-resisting frame buildings with or without welded connections.

Status: Completed

Publication(s): Enhancement to Program IDARC: Modeling Inelastic Behavior of Welded Connections in Steel Moment-Resisting Frames," NIST GCR 95-673, May 1995.

FAILURE ANALYSIS OF BUILDING STRUCTURAL DAMAGE SUSTAINED IN THE NORTHRIDGE EARTHQUAKE

Principal Investigator(s): Eric J. Kaufmann, Lehigh University, Bethlehem, PA
John Gross and Riley M. Chung, NIST

Objectives: To identify, document, and arrange for removal of failed sections of beam-column connections, characterize the metallurgical and mechanical properties of the beam flange and column flange and compare appropriate material specifications, characterize the metallurgical and mechanical properties of the weld metal and heat-affected-zones, perform fractographic examinations of the connection fractures to identify and characterize the fracture origin and mechanism, and evaluate the test results.

Status: Completed.

Publication(s): Failure Analysis of Welded Steel Moment Frames Damaged in the Northridge Earthquake, NISTIR 5944, January 1997.

PERFORMANCE OF STEEL FRAME BUILDINGS DURING THE 1994 NORTHRIDGE EARTHQUAKE

Principal Investigator(s): Nabih Youssef, Nabih Youssef & Assoc., Los Angeles, CA
John Gross and Riley M. Chung, NIST

Objectives: To document damage to steel moment frame buildings in the January 17, 1995 Northridge earthquake.

Status: Completed

Publication(s): A Survey of Steel Moment-Resisting Frame Buildings Affected by the 1994 Northridge Earthquake, NISTIR 5625, April 1995.

DETAILED INVESTIGATIONS AND ANALYSES OF TWO STEEL FRAME BUILDINGS WHICH SUFFERED EXTENSIVE DAMAGE IN THE 1994 NORTHRIDGE EARTHQUAKE

Principal Investigators: Nabih Youssef, Nabih Youssef & Associates, Los Angeles, CA
John Gross and Riley M. Chung, NIST

Objectives: To collect and document fully the damaged condition of the selected buildings and conduct analyses of the building systems using various types of analytical tools to assess the applicability of these tools when compared to the observed damage.

Status: Completed.

Publication(s): Analysis of Two Steel Moment-Resisting Frame Buildings Damaged during the Northridge Earthquake, December 1995. (available through Nabih Youssef & Associates)

COMPUTER MODELING FOR ANALYSIS OF THE PERFORMANCE OF STEEL-FRAME BUILDINGS

Principal Investigator(s): James R. Cagley, Cagley & Associates, Rockville, MD
John Gross and Riley M. Chung, NIST

Objectives: To develop modeling assumptions and computer models for analyzing three steel frame buildings, varying from 4 to 6 stories, which suffered extensive damage in the Northridge earthquake.

Status: Completed.

Publication(s): Developed inputs for computer modeling. No report was required.

LARGE SCALE TESTING OF RETROFITTED STEEL MOMENT CONNECTIONS

Principal Investigator(s): Michael D. Engelhardt, University of Texas, Austin, TX
John Gross and Riley M. Chung, NIST

Objectives: To assess the effectiveness of the retrofit technique (the flange cut-outs, or dogbone) for interior moment frame joints, assess the effects of a composite floor slab on the behavior of the retrofitted connections, assess the performance of this retrofit technique using both moderate size and very large size beams, and develop interim guidelines for the design of connection retrofits using flange cut-outs.

Status: In progress.

Publication(s): To be expected by August 1997 as a NIST GCR series.

BOLTED REPAIR FOR STEEL MOMENT CONNECTIONS DAMAGE FROM THE NORTHRIDGE EARTHQUAKE

Principal Investigators: Kazuhiko Kasai, ATLSS Center, Lehigh University, Bethlehem, PA
John Gross and Riley M. Chung, NIST

Objectives: To investigate the effectiveness of the bolted repair method through realistic experimental and analytical simulations as well as to obtain important data needed to formulate a design guide for the bolted connection.

Status: In progress.

Publication(s): To be expected by August 1997 as a NIST GCR series.

CYCLIC TESTING OF STEEL AND COMPOSITE MOMENT CONNECTIONS WITH HAUNCH REINFORCEMENT

Principal Investigator(s): Chia-Ming Uang, University of San Diego, La Jolla, CA
John Gross and Riley M. Chung, NIST

Objectives: To verify the effectiveness of haunched moment connections for seismic resistance, correlate analytical predictions with test results, and develop design and detailing guidelines for this type of moment connection.

Status: In progress.

Publication(s): To be expected by August 1997 as a NIST GCR series.

ESTIMATES OF GROUND MOTIONS EXPERIENCED AT NEAR-FAULT SITES DURING THE NORTHRIDGE EARTHQUAKE

Principal Investigator(s): Woodward-Clyde Federal Services
John Gross and Riley M. Chung, NIST

Objectives: To develop three-component ground motion (acceleration) time histories and associated response spectra for three specific sites. The time histories will be used as input in modeling studies of steel frame buildings.

Status: Completed.

Publication(s): Ground Motion Time Histories of the 1994 Northridge Earthquake at Three Sites, October 1995. (available through Woodward-Clyde, Pasadena, CA)

OTHER STRUCTURAL AND NON-STRUCTURAL TOPICS

WORKSHOP ON ASSESSMENT OF EXISTING EARTHQUAKE TESTING FACILITIES IN THE UNITED STATES (A JOINT EFFORT WITH THE NATIONAL SCIENCE FOUNDATION)

Principal Investigator(s): Earthquake Engineering Research Institute (EERI)
Riley M. Chung, NIST

Objectives: To assess (a) the need for shake tables and other earthquake engineering research and testing facilities in the United States; (b) options to cooperate with countries that have developed complementary earthquake engineering and testing programs and facilities; (c) projected costs for construction, maintenance, and operation of new earthquake engineering research and testing facilities in the United States; and options and recommendations to provide funding for the construction and operation of new earthquake engineering and testing facilities, including the feasibility and advisability of developing a comprehensive earthquake engineering research and testing program within the scope of the Earthquake Hazards Reduction Act of 1977. The study was jointly sponsored by the National Science Foundation.

Status: Completed.

Publication(s): Assessment of Earthquake Engineering Research and Testing Capabilities in the United States, EERI publication no. WP-01, September 1995. (available through EERI)

PERFORMANCE OF REHABILITATED MASONRY BUILDINGS AND DEVELOPMENT OF
PERFORMANCE BASED REHABILITATION GUIDELINES

Principal Investigators: William Holmes, Rutherford and Chekene, San Francisco, CA
Riley M. Chung, NIST

Objectives: To document the performance of rehabilitated unreinforced masonry buildings during the Northridge earthquake, evaluate the effectiveness of current rehabilitation practices, and develop a compendium of rehabilitation techniques with guidance for designers.

Status: Completed.

Publication(s): Development of Procedures to Enhance the Performance of Rehabilitated URM Buildings, March 1997. (will be published as a NIST GCR shortly)

SEISMIC PERFORMANCE OF CLADDING SYSTEMS

Principal Investigators: Julie Cohen, Cladding Research Institute, Emeryville, CA
Andrew W. Taylor and Riley M. Chung, NIST

Objectives: To document the current state-of-practice with respect to the design and fabrication of building cladding systems; to summarize current code provisions; and to summarize past research programs on cladding.

Status: Completed.

Publication(s): Literature Review on Seismic Performance of Building Cladding Systems, NIST GCR-95-681, February 1995. (also available through Cladding Research Institute)

DEVELOPMENT OF ENERGY DISSIPATING CLADDING CONNECTOR HARDWARE SYSTEMS

Principal Investigators: Barry Goodno, Georgia Institute of Technology, Atlanta, GA
Andrew W. Taylor and Riley M. Chung, NIST

Objectives: To develop energy dissipating cladding systems for seismic retrofit and design of new and existing buildings. To document and evaluate the performance of architectural cladding systems during the Northridge and other earthquakes.

Status: In progress

Publication(s): Two NIST GCR reports are planned. Phase I report is expected by September 1996; Phase II by March 1997.

METHODS TO RETROFIT MANUFACTURED HOUSING UNIT ANCHORING

Principal Investigators: Richard D. Marshall and Riley M. Chung, NIST

Objectives: To develop anchorage requirements to prevent toppling of manufactured housing units during earthquakes. Methods to improve the anchorage requirements should reduce the incidence of breakage of gas service connections which result in post earthquake fires.

Status: In progress

Publication(s): To be expected by September 1997.