The ATC-29-1 Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components is the second seminar on this topic conducted by the Applied Technology Council (ATC). Similar to the 2-day ATC-29 seminar, which was held in Irvine, California, in October 1990, the purpose of the 1998 seminar is to present current research, practice, and informed thinking pertinent to seismic design, retrofit, and performance of nonstructural components. The seminar focus includes architectural, electrical, and mechanical components and their supports in buildings, hospitals and other essential facilities, and hazardous material and industrial facilities.

The seminar program has been developed for design professionals, regulators, researchers, manufacturers and contractors, insurers, owners, and facility managers. Included are 38 technical papers addressing the following topics:

- Observed performance in recent earthquakes;
- Seismic design codes, standards, and procedures for commercial and institutional buildings;
- Seismic design issues relating to industrial and hazardous material facilities;
- Design, analysis, and testing;
- Seismic evaluation and rehabilitation of conventional and essential facilities (including hospitals)

ATC gratefully acknowledges the Steering Committee, who planned the seminar, and the numerous professionals, who prepared papers for the seminar. The Steering Committee consisted of Christopher Rojahn and Tsu T. Soong (co-chairs), Christopher Arnold, Robert E. Bachman, Edwin T. Dean (ATC Board Representative), Mircea Grigoriu, Steven P. Harris, Satwant S. Rihal, William E. Staehlin, and Mahendra P. Singh. The affiliations of the Steering Committee members are provided in the list of project participants. Paper authors and their affiliations are included with each paper.

ATC also gratefully acknowledges the financial support provided by the National Center for Earthquake Engineering Research and the National Science Foundation. The seminar logistics and report preparation services of ATC staff are also greatly appreciated.

Christopher Rojahn
Executive Director
## Contents

**PREFACE**


**INTRODUCTION**


**SEMINAR TECHNICAL PAPERS**

- Design Criteria for Nonstructural Components Based on Tri-Services Manuals, Sigmund A. Freeman ....................................................... 15
- The Development of Model Code Provisions to Address System Reliability Following Earthquakes, Gayle S. Johnson, Stephen J. Eder, Robert E. Sheppard, and Steven P. Harris .................. 31
- Simplified Methods for Calculating Seismic Forces for Nonstructural Components, Mahendra P. Singh, Luis M. Morechi, and Luis E. Suarez ......................... 43
- A Critique of Procedures for Calculating Seismic Design Forces for Nonstructural Elements, Brian E. Kehoe and Sigmund A. Freeman .......................................................... 57
- Review of Requirements for Design of Nonstructural Components and Their Anchorage, Orhan Gurbuz, Sheng Wu, and Scott Wittchen ......................... 71
- A Suggested Design Procedure for Piping Systems Defined as Hazardous or Essential by U.S. Building Codes, John D. Stevenson ................................................. 79
- Lessons Learned from the 1994 Northridge Earthquake on the Vulnerability of Nonstructural Systems, William E. Gates and Gary McGavin ................................. 93
- Performance of Nonstructural Components During the January 17, 1994 Northridge Earthquake, Case Studies of Six Instrumented Multistory Buildings, Farzad Naeim and Roy Lobo .......................................................... 107
- Performance and Behavior of Library Shelving and Storage Rack Systems During the 1994 Northridge Earthquake, Satwant S. Rihal and William E. Gates ................. 121
- The Need for Improvement in Post-Earthquake Investigations of the Performance of Nonstructural Components (Invited Paper), Robert Reitherman .................................................. 137
- Frequency Tuning for Spring-Supported Mechanical Components' Protection, George C. Yao and N. Lien .......................................................... 165
Upper-Bound Mass Ratios for the Decoupled Analysis and Design of Building-Equipment System,
Genda Chen, and Jingning Wu ................................................................. 173

Simplified Approach to Account for Nonlinear Effects in Seismic Analysis of Nonstructural Components,
Roberto Villaverde ......................................................................................... 187

Seismic Retrofit of Precast Concrete Connections,
Richard J. Nielsen, Edwin R. Schmeckpeper, and Richard Crossler .................... 201

Simplifying Complex GFRC Cladding Structural Systems in Seismic Hazard Zones: A Case Study,
Michael Krakower, Milford W. Donaldson, and Anthony B. Court .......................... 215

Limit States for Architectural Glass Under Simulated Seismic Loadings,
Richard A. Behr and Christy L. Worrell .......................................................... 229

Robert C. Murray, Stanley Sommer, Fred Loceff, George Antaki, Gary Driesen,
Dan Guzy and Jeffrey Kimball ........................................................................... 241

Computer Tools for Seismic Screening and Evaluation of Equipment and Systems Based on Earthquake Experience Data,
Thomas R. Roche, Phillip S. Burtis and Ronald W. Cushing ................................. 255

Earthquake-Caused Hazardous Materials Incidents at Educational Facilities,
Guna Selvaduray ......................................................................................... 265

City of Los Angeles Proposed Ordinance Changes for Suspended Ceiling Systems Prompted by the 1994 Northridge Earthquake,
Gary L. McGavin, James Lai and Steve Ikkanda .................................................. 277

Seismic Restraints for Piping and Duct Systems,
Robert J. Wasilewski ...................................................................................... 283

Seismic Isolation of Semiconductor Production Facilities,
Hal Amick, Ahmad Bayat and Zoltan A. Kemeny ............................................... 297

The Use of Earthquake Experience Data for Estimates of the Seismic Fragility of Standard Industrial Equipment,
Sam W. Swan and Robert Kassawara ............................................................... 313

Toppling Fragility of Unrestrained Equipment,
Z. Y. Zhu and T. T. Soong ................................................................................. 323

Seismic Reliability and Performance of Nonstructural Systems,
M. Grigoriu and F. Waisman ............................................................................. 337

Demonstration of CERL Equipment Fragility and Protection Procedure by Fragility Testing of a Power Transformer Bushing,
James Wilcoski ............................................................................................... 349

California Wine Industry Seismic Risk Analysis and Experimentation Project,
Joshua M. Marrow, David Weggel, Abraham Lynn and Satwant Rihal ....................... 365

Study of Seismic Resistance of Desktop Computers,
Masami Jin and Abolhassan Astaneh-Asl .......................................................... 379
Appropriate Seismic Reliability for Critical Equipment Systems:
An Approach Based on Regional Analysis of Financial and Life Loss,
Keith A. Porter and Charles Scawthorn ................................................................. 393

Development and Usage of FEMA 74, Reducing the Risks of Nonstructural
Earthquake Damage: A Practical Guide,
Eduardo A. Fierro and Cynthia L. Perry ................................................................. 421

The Requirements for Nonstructural Components for the NEHRP Guidelines
for the Seismic Rehabilitation of Buildings,
Christopher Arnold ................................................................................................ 433

Practical Guidelines for Seismic Retrofitting of HVAC Systems,
Patrick J. Lama ....................................................................................................... 445

Observed Behavior of Italian Hospitals During Severe Earthquakes,
G. Di Pasquale, C. Nuti, G. Orsini, and T. Sano .................................................. 455

Seismic Design and Performance of Nonstructural Components in Hospitals (Invited Paper),
William Staehlin .................................................................................................... 469

Seismic Retrofit of Nonstructural Components in Acute Care Hospitals: Title 24,
Part 2, Chapter 16, Division III-R Requirements,
Charles C. Thiel Jr., Theodore C. Zsutty, Christos Tokas and Patrick Campbell .... 475

The Benefits and Costs of Seismic Retrofits of Nonstructural Components for
Hospitals, Essential Facilities and Schools,
John Eidinger and Kenneth Goettel ...................................................................... 491

ATC-29-1 PROJECT PARTICIPANTS ........................................................................ 505

APPLIED TECHNOLOGY COUNCIL PROJECTS AND REPORT INFORMATION ........ 507