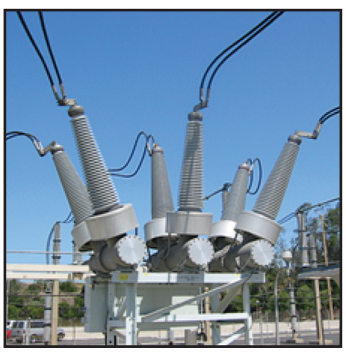
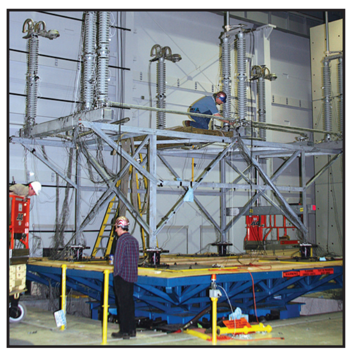
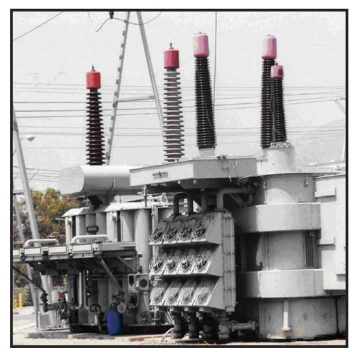
MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

ISSN 1520-295X

Proceedings of the Workshop on Improving Earthquake Response of Substation Equipment

Edited by
Andrei M. Reinhorn



Technical Report MCEER-11-0003

September 19, 2011

This workshop was held in Buffalo, New York, on October 24, 2008. It was sponsored by Bonneville Power Administration under Contract Number 00041295 and the California Energy Commission under Contract Number 500-07-037 (Subcontract TRP-08-03).

NOTICE

Proceedings of the Workshop on Improving Earthquake Response of Substation Equipment

Held in
Buffalo, New York
October 24, 2008

Edited by Andrei M. Reinhorn[1]

Publication Date: September 19, 2011

Technical Report MCEER-11-0003

Bonneville Power Administration Contract Number 00041295
California Energy Commission Contract Number 500-07-037 (Subcontract TRP-08-03)

1 Clifford C. Furnas Professor of Engineering, Department of Civil, Structural and Environmental Engineering, University at Buffalo, State University of New York

MCEER
University at Buffalo, State University of New York
Red Jacket Quadrangle, Buffalo, NY 14261
Phone: (716) 645-3391; Fax (716) 645-3399
E-mail: *mceer@buffalo.edu*; WWW Site: *http://mceer.buffalo.edu*

Preface

MCEER is a national center of excellence dedicated to the discovery and development of new knowledge, tools and technologies that equip communities to become more disaster resilient in the face of earthquakes and other extreme events. MCEER accomplishes this through a system of multidisciplinary, multi-hazard research, in tandem with complimentary education and outreach initiatives.

Headquartered at the University at Buffalo, The State University of New York, MCEER was originally established by the National Science Foundation in 1986, as the first National Center for Earthquake Engineering Research (NCEER). In 1998, it became known as the Multidisciplinary Center for Earthquake Engineering Research (MCEER), from which the current name, MCEER, evolved.

Comprising a consortium of researchers and industry partners from numerous disciplines and institutions throughout the United States, MCEER's mission has expanded from its original focus on earthquake engineering to one which addresses the technical and socio-economic impacts of a variety of hazards, both natural and man-made, on critical infrastructure, facilities, and society.

The Center derives support from several Federal agencies, including the National Science Foundation, Federal Highway Administration, National Institute of Standards and Technology, Department of Homeland Security/Federal Emergency Management Agency, and the State of New York, other state governments, academic institutions, foreign governments and private industry.

The Bonneville Power Administration (BPA) and the California Energy Commission (CEC) are supporting a series of studies on the resilience of electric power substation equipment that focus on the following topics:

- Reducing Disruption of Power Systems in Earthquakes: Advanced Methods for Protecting Substation Equipment
- Analysis of the Seismic Performance of Transformer Bushings

It is envisioned that these studies will result in the development of cost effective seismic protective solutions for transformer–bushing systems and other electrical substation equipment considering inertial effects and dynamic interaction with conductors. Furthermore, new knowledge discovered about the bushing-transformer seismic interaction will be translated into a proposed revision of the IEEE 693 Standard. A series of MCEER reports will document the results of these studies.

This report presents the proceedings of the workshop entitled "Improving Earthquake Response of Substation Equipment," held on October 24, 2008, at the University at Buffalo. The purpose of the workshop was to engage electric power utility representatives, substation equipment manufacturers, and consultants, to solicit their input to help direct MCEER's Research and

Development Plan for advanced methods for protecting substation equipment. Over 30 participants shared their expertise with the research team and provided comment on a draft R&D plan. Specifically, participants helped to identify issues effecting performance of substation equipment during earthquakes, provided perspectives on the use of advanced damping and isolation technologies to improve equipment performance, and contributed their experience and insights on problems caused by interaction of substation equipment during earthquakes.

EXECUTIVE SUMMARY

Past earthquakes have shown that porcelain transformer bushings are very vulnerable to earthquake damage and can contribute to power outages leading to community losses. Although efforts have been made to design and qualify new transformer bushings by computations or by laboratory testing, they may still sustain damage in an earthquake. Furthermore, some evaluations have shown that 230 kV bushings that showed poor earthquake performance may be able to meet current seismic qualification criteria.

A research team, including the editor of this report, engaged in a comprehensive investigation to clarify the reasons for this conflicting behavior. As a first step in the development of a detailed research plan, a workshop was held to help clarify issues on the behavior of transformer bushings while seeking alternative methods of protecting the substation electrical equipment from damage during earthquakes, thus reducing the expected disruptions.

The workshop presented and discussed issues related to: (i) the behavior of bushings, transformers and current application of seismic design and qualification standards, and (ii) the possibility of using base isolation, damping devices, or strengthening of equipment, while considering the influence of conductors that interconnect the equipment.

The workshop raised questions and proposed solutions regarding:

- Behavior of transformer bushings and qualification issues
- Consideration of induced forces in the design of transformers and bushings
- Identification of challenges in current qualification and acceptance procedures
- Seismicity considerations in the behavior of equipment
- Soil structure interaction (SSI) of large equipment
- Suggested protective systems
- Implementation issues of base isolations to electrical equipment
- Conductors and the electrical equipment
- Protective systems for conductors - reduction of dynamic effects of conductors
- Effects to be considered as constraints in the development of protective systems
- Standardization issues for base isolation and other protective systems
- Risk, reliability and resilience of protective systems

The following are some of the recommendations from the workshop:

The research should address the amplification of ground motions at transformer's roof/cover as input to the components connected to it. The influence of the transformer components should be determined by proper modeling of transformers and by the transfer functions between the roof/cover and the base. Moreover, the research should explore the methods to determine the dynamic properties of components connected to the roof /cover (as installed) in order to more accurately determine the expected response.

The research should address the acceptance criteria for qualification by testing and eventually develop new testing techniques using either spectral compatible motions or modulated sine-sweeps. The criteria should simultaneously recognize motion and mechanical quantities which characterize seismic demands and strength capacity of equipment.

In addition, the research should address protective systems that can simultaneously protect the transformer, bushings and conductors. New protective systems such as base isolations, damping systems and simple redesign of connectivity of equipment, such as stiffening or softening, should be investigated.

Among the challenges to be recognized are the contributions of dynamics of conductors to the mechanical functionality of equipment. Further studies, through modeling and testing, should be conducted to determine more realistic effects of conductors.

The use of base isolation, although controversial, would require a well designed study to determine its benefits on the accelerations and forces in the equipment, while considering the limitations and constraints imposed by the conductors and by the constraints imposed by the electrical functionalities (avoidance of acceleration spikes, torsion of equipment, and local seismological demands). Any implementation would require a full experimentation in the field with suitable observation.

Moreover, acceptance criteria would have to be developed to complement current standards for fixed base equipment. Simplified design methodology and modeling guidelines would need to be developed.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support from two major agencies, (i) the Bonneville Power Administration under Contract 00041295 and (ii) the California Energy Commission under Contract 500-07-037 (Subcontract TRP-08-03). In addition, the authors acknowledge the support from the State of New York. Significant support was derived from academic institutions, government and private industry.

The authors like to acknowledge the contributions of workshop participants (names indicated in Appendix A) and their institutions that supported their participation. Their contributions are sincerely appreciated.

Finally, the authors would like to acknowledge the support of MCEER (formerly the Multidisciplinary Center for Earthquake Engineering Research) that initiated, maintained and continues outreach to the community while sponsoring technology transfer and facilitating publication of project materials.

TABLE OF CONTENTS

SECTION 1.
INTRODUCTION

Past earthquakes have shown that porcelain transformer bushings are very vulnerable to earthquake damage and can contribute to power outages leading to community losses. Although efforts have been made to design and qualify new transformer bushings by computations or by laboratory testing, they may still sustain damage in an earthquake. Furthermore, some evaluations have shown that 230 kV bushings that showed poor earthquake performance may be able to meet current seismic qualification criteria.

A research team, including the editor of this report, engaged in a comprehensive investigation to clarify the reasons for this conflicting behavior. A comprehensive research plan was developed and a draft is included in the Appendix C of this report.

The investigation intends to:

1. Solicit advice and prioritize input from the electric power community
2. Establish seismic demands on equipment: Part 1 - Determine behavior of transformers and bushings
3. Establish seismic demands on equipment Part 2 - Determine behavior of transformers-bushings-conductors in-field conditions
4. Evaluate state-of-the-art of protective systems – base isolation (BI), supplemental damping (SD), and passive control systems (PCS)
5. Identify and evaluate protective systems – methods, design guidelines
6. Develop, evaluate and recommend advanced protective solutions and systems
7. Plan full scale field implementations and monitoring
8. Organize workshop(s) for community input and dissemination of results

As a first step in the implementation of a detailed research plan, a workshop was developed as part of tasks 1 and 8, that was intended to clarify issues on the behavior of transformer bushings while seeking alternative methods of protecting the substation electrical equipment from damage during earthquakes to reduce the expected disruptions. The description of the workshop, which was held on October 24, 2008, is the subject of this report.

The agenda of the workshop (see Appendix B) was developed to address issues related to (i) the behavior of bushings, transformers and current application of seismic design and qualification standards, and (ii) the possibility of using base isolation, damping devices, or strengthening of equipment, while considering the influence of conductors connecting equipment and main power lines. Following presentations by leading experts in the areas listed above (see presentation materials in Section 2), the workshop entertained multiple discussions and comments from workshop participants (as presented in Section 3).

The workshop was attended by 31 participants (see list of participants in Appendix A). Two presenters had to cancel their participation, but their work was presented by the moderators of the sessions. The attendees represented a diverse expertise, from utilities, to manufacturers, to designers and modelers of equipment, to experimentalists from universities and other testing labs, consultants and advisors to the project.

The discussions were captured by recorders from the University at Buffalo and are presented in Section 3.

Note that the presentations and discussions recorded in this report represent opinions held at the time of the workshop. Some of these opinions may have changed as the results from more recent research have become available.

SECTION 2.
WORKSHOP PRESENTATIONS

Eight presentations were made to introduce: (i) the background of the planned project, (ii) the objectives of the workshop, (iii) the performance of transformers and bushings and current standards of seismic qualification, (iv) previous studies on base isolation, (v) past and current research on base isolation, (vi) background of base isolation, (vii) comments on base isolation solutions, and (viii) survey of issues of electrical conductors in association with transmission equipment. The following presentations are included in this section:

Reducing Disruption of Power Systems in Earthquakes

Improving Earthquake Response of Substation Equipment

Introduction to Workshop

Andrei M Reinhorn

Background Draft R&D Plan

University at Buffalo, September 15, 2008

Project Participants

- **Andrei M. Reinhorn, PE, PhD**
- **Andre Filiatrault, Eng, PhD**
- **Michael Constantinou, PhD**
- **Anshel Schiff, PhD – Consultant**
- **Roh Hwasung, PhD**
- **Advisory Board**
- **Grad Students**

Tentative Project Plan

Task #1: Solicit advise and prioritize input from the electric power community

Task #2: Establish Seismic Demands on Equipment: Part 1 - Determine behavior of transformers and bushings

Task #3: Establish Seismic Demands on Equipment: Part 2 - Determine behavior of transformers-bushings-conductors in-field conditions

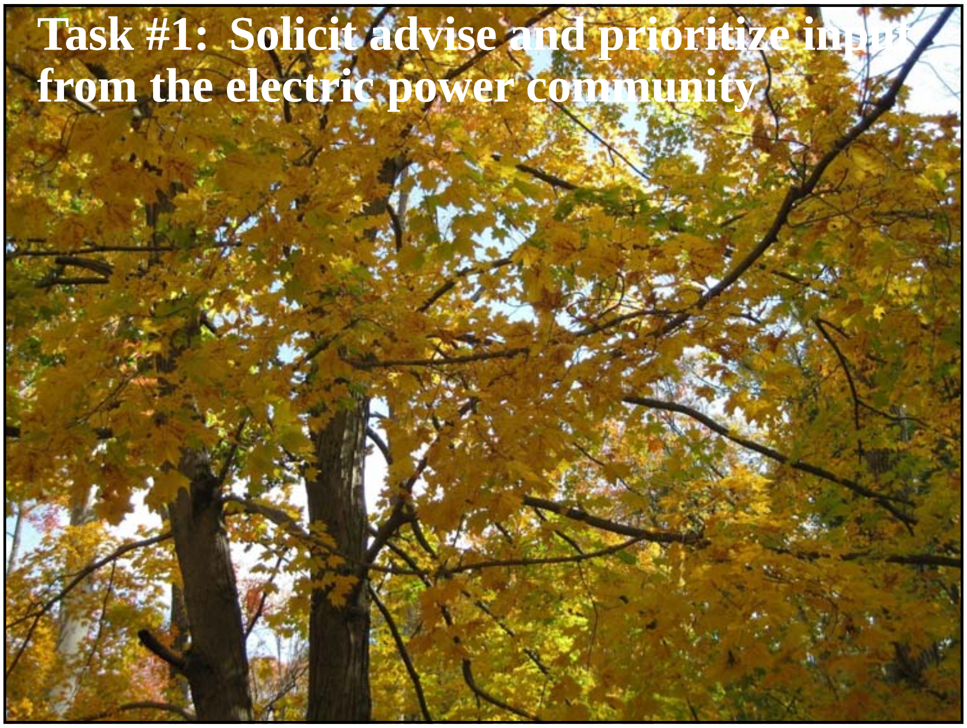
Task #4: Evaluate State-of-the-art of Protective Systems – Base Isolations (BI), Supplemental Damping (SD), Passive Control Systems (PCS)

Task #5: Identify and evaluate protective systems – Methods, Design Guidelines

Task #6: Develop, evaluate and recommend advanced protective solutions and systems

Task #7: Planning Full Scale Field Implementations and Monitoring

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008



Task #1: Solicit advise and prioritize input from the electric power community

- 1.1 Develop a national and international advisory board including North American members to advise on issues and feasibility of implementations. The committee might be enlarged if transpacific partnerships in Japan, New Zealand and Taiwan materialize.
- 1.2 Organize two workshops for (i) initiation of study and (ii) midterm evaluation and monitoring potential implementations (see Task #8)
- 1.3 Layout plan for complimentary proposals (NSF, International-Transpacific, etc)
- 1.4 Engage and integrate multiple funding projects and sources (BPA, CEC, MCEER, EPRI, NSF, Utilities)
- 1.5 Identify manufacturers and/or utilities to donate equipment which can be used in experimental studies (bushings, protective systems, components)

Task #2: Establish Seismic Demands on Equipment: Part 1 - Determine behavior of transformers and bushings

Bank K, Phase B 500 kV/230 kV Transformer

Task #2: Establish Seismic Demands on Equipment: Part 1 - Determine behavior of transformers and bushings

- **2.1 Extend current static analysis modeling methods of transformers used by manufacturers to meet current IEEE 693 standard provision - considering dynamic analysis and modeling of cover and bushings.**
- **2.2 Determine adequacy of current modeling practices used by manufacturers to capture system dynamic properties.**
- **2.3 Perform sensitivity analysis using dynamic models to evaluate the precision needed to meet the needs of IEEE 693 standard.**
- **2.4 Determine influence of bushing-transformer system interaction on the seismic demand on bushings.**
- **2.5 Determine influence of variations in cover stiffness or turret design on bushing-transformer system interactions.**
- **2.6 Estimate uncertainties of system frequencies to be incorporated into the IEEE 693 standard which influence transformer-bushings interactions.**
- **2.7 Develop guidelines for modelers for proper considerations of the above issues**
- **2.8 Classify limit states of functionality (such as failure modes) of transformer-bushing systems in terms of terminal pad displacements, loads on bushings, as-installed bushing frequencies or other engineering parameters.**

Task #2: Establish Seismic Demands on Equipment: Part 1 - Determine behavior of transformers and bushings

500 kV Phase B, bushing leaked oil from shifting of ceramic insulator

Task #3: Establish Seismic Demands on Equipment: Part 2 - Determine behavior of transformers-bushings-conductors in-field conditions

- **3.1 Determine behavior of bushings in transformer installed conditions – through tests and analytical studies**
  - **3.1.1 Determine deformations and movement limits**
  - **3.1.2 Identify apparent functionality limits**
  - **3.1.3 Develop simplified models to allow for quick analyses**
- **3.2 Determine behavior of equipment-bushings-conductor interactions – transformers, or other support structures**
  - **3.2.1 Model and evaluate experimentally bushing terminal displacements**
  - **3.2.2 Model and evaluate flexible conductor configuration issues (conductor shape of interconnections) including vertical drops to equipment**
  - **3.2.3 Evaluate conductors construction issues: flexible and rigid bus**
  - **3.2.4 Evaluate geometrical issues – initial, slacks, deformation see also UCSD and UCB studies and beyond) and equipment interaction loading**
  - **3.2.5 Quantify conductor dynamics and equipment interaction loading**
  - **3.2.6 Determine interaction forces and displacement demands – *design issues and criteria for IEEE 693***
  - **3.2.7 Determine electrical and thermal interactions issues – such as influence of electromagnetic fields.**
- **3.3 Determine allowable maximum displacements and interaction forces (as possible constraints to design of protective systems)**
  - **3.3.1 Determine allowable interaction forces and displacements for bushings-connectors interfaces – identify good practices & make recommendations for IEEE standards**
  - **3.3.2 Evaluate allowable interaction forces and displacements for bushings-tank connections (roof tank or turrets) – identify good practices & make recommendations for IEEE standards**
  - **3.3.3 Define initial constraints for design of advanced protective systems**

Task #4: Evaluate State-of-the-art of Protective Systems – Base Isolations (BI), Supplemental Damping (SD), Passive Control Systems (PCS)

Bank K, Phase B, 500 kV Bushing

Task #4: Evaluate State-of-the-art of Protective Systems – Base Isolations (BI), Supplemental Damping (SD), Passive Control Systems (PCS)

- **4.1 Survey past and current studies of BI, SD and PCS – identify gaps in respect with sub-station equipment (for example: UC/Irvine-NJIT studies)**
- **4.2 Evaluate models and analytical tools of protective systems – i.e. rubber and sliding properties, long term behavior, interaction issues**
- **4.3 Evaluate response of transformers and bushings with BI, SD and PCS**
- **4.4 Determine demands on bushings, conductors, connectors during three dimensional disturbances – compare to systems without protection**
- **4.5 Explore combinations of the above solutions and determine demands without constraints**
- **4.6 Determine interaction issues, interferences – displacements, forces**
- **4.7 Evaluate cost issues of current solutions – feasibility and constructability in new and existing facilities**

Task #5: Identify and evaluate protective systems – Methods, Design Guidelines

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Task #5: Identify and evaluate protective systems – Methods, Design Guidelines

- 5.1 Develop protective solutions: i.e. base isolations and supplemental damping – flexible or sliding, with or w/o damping
- 5.2 Develop cost-effective, feasible alternative for various configurations
- 5.3 Validate experimentally and analytically the solutions in
- 5.4 Develop design procedures and tools to enable evaluation and use of protective technologies
- 5.5 Develop guidelines for design and qualifications based on the innovation and enhancement of current standards and practices used by utilities.
- 5.6 Identify limitations of systems, which require innovative solutions.

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Task #6: Develop, evaluate and recommend advanced protective solutions and systems

?

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Task #6: Develop, evaluate and recommend advanced protective solutions and systems

- 6.1 Evaluate in-line damping for conductor systems
- 6.2 Develop, evaluate and verify new expending cable connections
- 6.3 Evaluate inexpensive innovative base isolations of existing transformer tanks – hybrid solutions with displacement constraints
- 6.4 Develop innovative bushing connectivity and construction (existing and new)
- 6.5 Evaluate retainer rings for bushing to enhance serviceability of new and existing bushings after earthquakes
- 6.6 Verify developments experimentally
- 6.7 Develop design procedures and specifications.
- 6.8 Review and propose practical methods for assessing conductor spacing criteria associated with short circuit and seismic loads

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Task #7: Planning Full Scale Field Implementations and Monitoring

- 7.1 Identify utilities to participate in implementing base isolation of transformers and other equipment
- 7.2 Identify equipment and sites; select solution from the methods researched above
- 7.3 Design and implement a protective solution including equipment, connectors to first conductor support, in situ
- 7.4 Develop plans for instrumentation and monitoring
- 7.5 Assist implementer with design or selection of off-the-shelf solutions (instrumentation, protection, monitoring, etc)
- 7.6 Assist with monitoring and processing

Reducing Disruption of Power Systems in Earthquakes

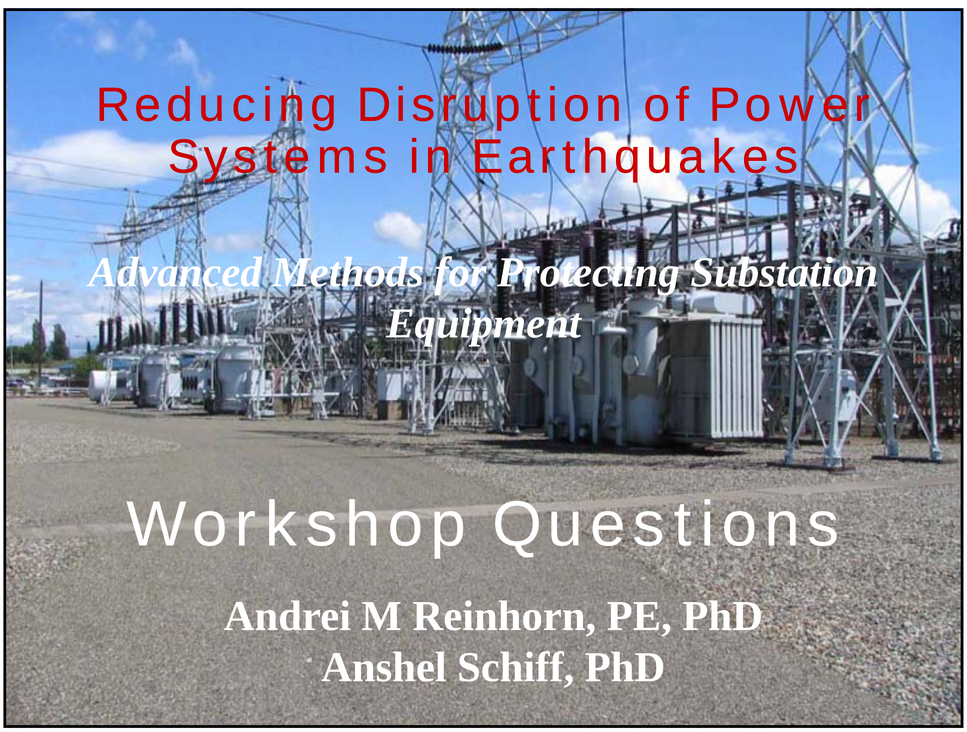
Advanced Methods for Protecting Substation Equipment

Workshop Questions

Andrei M Reinhorn, PE, PhD
Anshel Schiff, PhD

University at Buffalo, September 15, 2008

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008



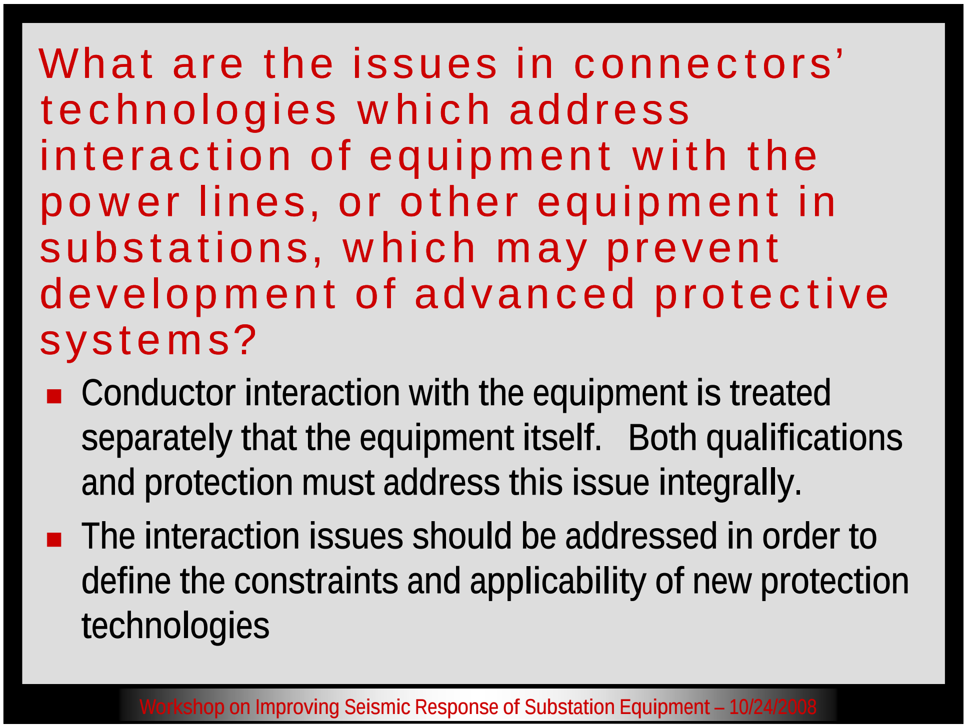
What are the real issues regarding usage and failures during earthquakes of substation equipment and in particular of the high voltage transformer?

- It is understood that the transformers (one of the most complex systems in a substation) are connected to the ground through rigid foundations and to the bus and power lines, or other components in the substations, through bushings and connectors.
- The workshop should try to identify the state of the-art on current construction of equipment, it's qualifications and should try to point out issues which need further development to ensure proper functionality of such equipment

Why are new technologies for seismic protection, such as base isolation and energy dissipation, not used in protection of substation equipment?

- New technologies were developed for very complex structures such as off-shore platforms, liquid natural gas storage tanks, viaducts, bridges, etc., with some measure of success. Such technologies might be adaptable, or new alternatives can be created.
- The workshop should address the current obstacles and possibilities for development of such protective systems.

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008


What are the issues in connectors' technologies which address interaction of equipment with the power lines, or other equipment in substations, which may prevent development of advanced protective systems?
Conductor interaction with the equipment is treated separately that the equipment itself. Both qualifications and protection must address this issue integrally.
The interaction issues should be addressed in order to define the constraints and applicability of new protection technologies
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Workshop on Improving Earthquake Response of Substation Equipment

History of Equipment Performance and Proposed Standard for Qualifying Transformers and their Bushings

Anshel J. Schiff
Precision Measurement Instruments

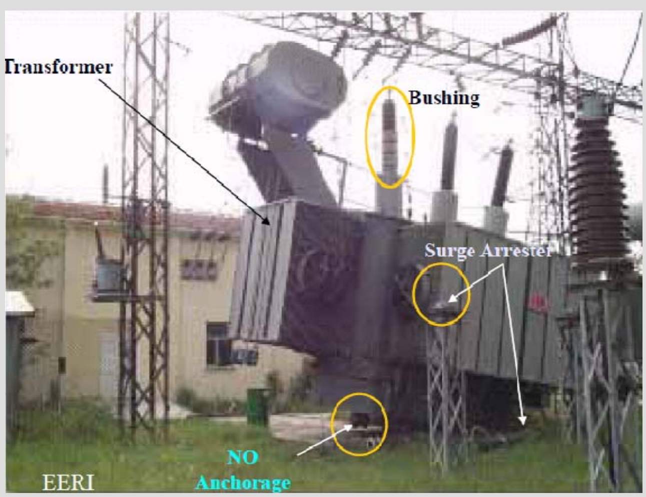
Overview of Presentation

- History of Investigations and Damage
- History of Research Related to the Standard
- Review of Proposed Standard and Related Issues
- Standard Issues
- Feedback

History of Investigations and Damage

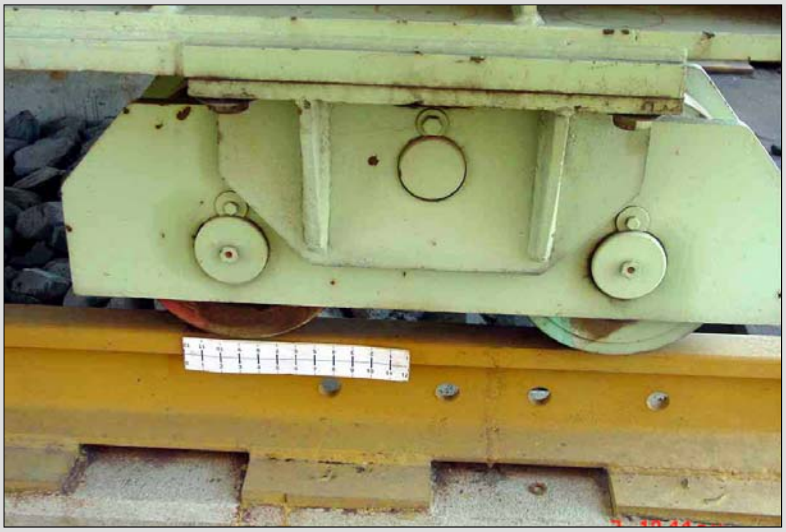
- Earthquake Investigations
- Transformer Anchorage: slipping, rail-mount, connections, bushings, and surge arresters
- Surge Arrestors: base, standoff
- Bushings: leaks, “slipping”, gasket extrusion, cracked porcelain, bent binding post Possible Causes: conductor slack, conductor dynamics, equipment dynamics, interaction with surge arrester, equipment design
- Radiators: leak at top, break at bottom
- Conservators: supports, connections
- Other Damage: LT, bus supports, IT, DS, CS

Unanchored Transformer



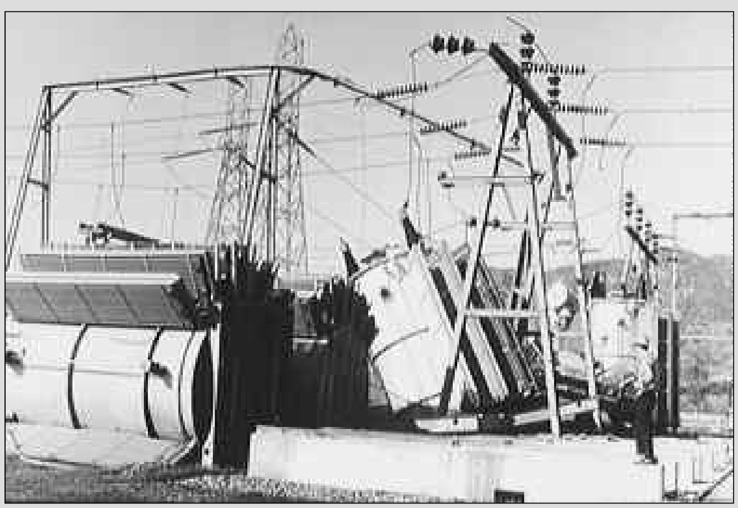
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Rail-Mounted Transformer



Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Formerly Rail-Mounted Transformers

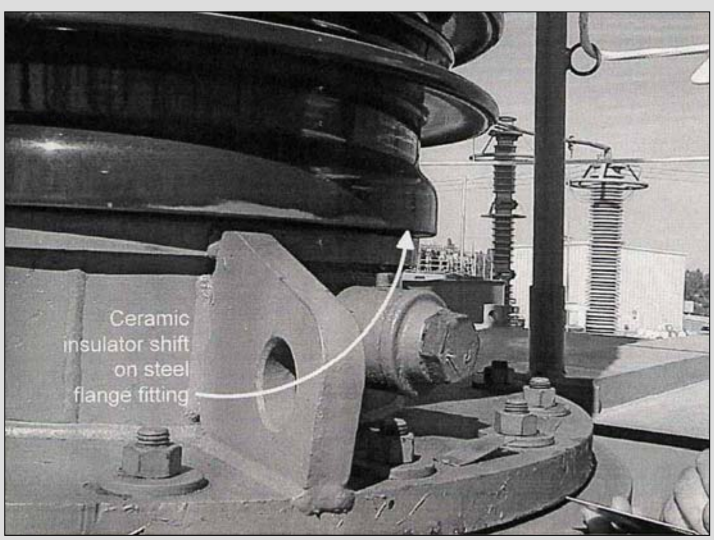


Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Sheared Anchor Bolts

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Slipped 500 kV Bushing



Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Extruded Gasket

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Temporary Patch to Bushing

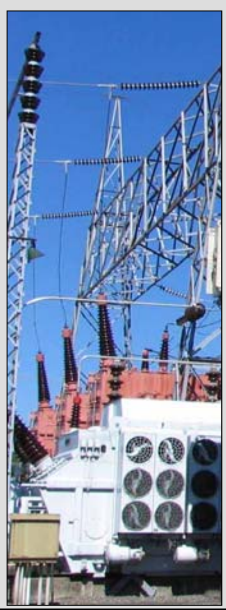
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Cracked Bushing

Cracked Grouted Bushings

Damaged Bushing from Failed Surge Arrester

Possible Conductor Dynamics



Transformer Radiator Leak

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Support Weld Tear

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Weld Tear and Leak

History of Research Related to the Standard

- Problem with Qualification of Bushings
- Qualification of Composites
- Qualification of Bushings
- Orientation of Equipment

Problems with Existing Transformer Qualification

- Assume TR amplification 2 – may be more or less
- Affect of turret and CT neglected
- Conductor interaction (slack & dynamics) neglected
- Current procedure gives poor indication of earthquake performance
- Key Issue: Test bushing on rigid support but in earthquake the as-installed frequency is lower
- Key Issue: Transformer system-bushing interaction

Straw-man Provisions

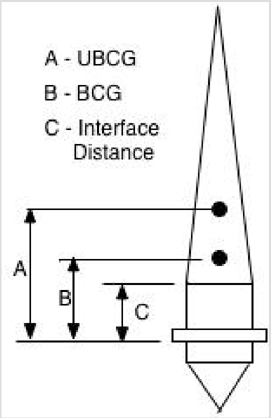
- Bushing Manufacturer Test Requirements
- Bushing Manufacturer to Provide Bushing Modeling Information
- Transformer Manufacturer Requirements
- Determining the Withstand Capacity of the Installed Bushing

Bushing Manufacturer Test Requirements

- Tested in vertical orientation on plate with as-installed frequency in 3.5 Hz to 8 Hz range*
- Tested with TRS shape that is compatible with RRS (no need for vertical)(There is still a question if this should be 1 or 2-D test.)
- Determine excitation fragility or adequacy level
- Determine the instantaneous peak acceleration at the upper CG in test (UBCG)
- This defines the Basis Bushing Acceleration Capacity (BBAC)
- Value of the TRS at the as-installed frequency should be noted (needed if as-installed frequency is above 8 Hz)
- * Porcelain bushing as-installed frequency should be less than 2/3 stiff-mounted frequency
- Note that porcelain and small composite bushings may be responding as rigid bodies

Bushing Manufacturer to Provide Bushing Modeling Information

- Upper bushing CG (UBCG) location
- Upper bushing weight
- Total bushing BCG location
- Total bushing weight
- Flange-Interface distance
- Stiff-mounted bushing frequencies



Transformer Manufacturer Requirements

- Transformers 161 kV and above and bushings to be evaluated with dynamic models
- Modeling guidelines for transformers and their bushings are to be followed
- Subject the transformer base to 1 g RRS (two independent horizontal and 80% vertical)
- Record peak acceleration at the UBCG (in plane of tilt and in perpendicular direction if tilted and instantaneous peak if vertical).
- These accelerations are the Bushing Acceleration Demand (BAD)
- The modeling guidelines will indicate how the model should be changed to account for mode interaction. (The model is modified to take into account uncertainty in model frequencies.)(TR corrective action is possible.)
- The Bushing Acceleration Demand with interaction is called the Corrected Bushing Acceleration Demand (CBAD)

Determining the Withstand Capacity of the Installed Bushing

- If the bushing is installed at an angle, the CBAC in the plane of tilt should be reduced by the affect of the static moment
- If the as-installed bushing frequency, as determined by the transformer model is above 8 Hz, the BBAC should be increased by the ratio of the peak of the 2% RRS at the as-installed frequency during the bushing test divided by the value of the 2% RRS at the as-installed frequency in the transformer model. (This will increase the bushing capacity.)
- These two corrections result in the Final Bushing Acceleration Capacity (FBAC) (Note that tilted bushings will have two values, one in the plane of tilt and one perpendicular to this plane.)
- Compare the CBAD determined from the dynamic model and compare it to the FBAC
- The ratio of the FBAC to the CBAD determines the withstand capacity of the bushing compared to a 1 g RRS.

Model Sensitivity Studies

- Contribute to model guidelines
- Assess the contribution to cover response and bushing response from core/coil, conservator, radiators, and surge arrester responses
- Compare dynamic deflections at ends of bushing to vacuum induced deflections
- Compare response of different bushing
- Evaluate the affect of the bushing core modeled separately
- Evaluate the affect of oil weight distribution
- Evaluate the affect of different surge arresters
- Evaluate the affect on response of anchorage locations

Outstanding Issues with Proposed Provisions

- Adequacy test level for bushing not yet set
- Desire for bushing manufacturer to say it is qualified
- Disconnect between order and assessment dates
- Need for modeling guidelines
- Are two case studies adequate to establish guidelines
- How hard will it be for competent, honest modeler to get it wrong
- Is modeling adequate

Initial Observations about Proposed Standard and from Transformer Modeling Effort

- Currently there are no modeling results
- Large variations in 500 kV porcelain bushings (3500# vs. 6000#)
- One transformer uses polymer (non-composite) surge arresters that are not covered by IEEE 693
- The evaluation of surge arresters in standard questionable for transformer-mounted applications. Should model be used for SAs?
- The testing of 230 kV porcelain bushings will be more severe
- Transformer base isolation may be a method to improve transformer system earthquake performance
- For base isolated system near-field earthquake affects should be considered

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Standard Issues

- Expert opinion
- Proofing procedures
- Testing standard
- Self regulated
- Standard is complex
- Need for convenient method for getting user feedback

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Feedback

- On proposed procedure
- On transformer modeling

On Application of Base-Isolation to Transformers and Other Equipment

M. Ala Saadeghvaziri
Department of Civil and Environmental Engineering

NJIT New Jersey's Science & Technology University

NEWARK COLLEGE OF ENGINEERING

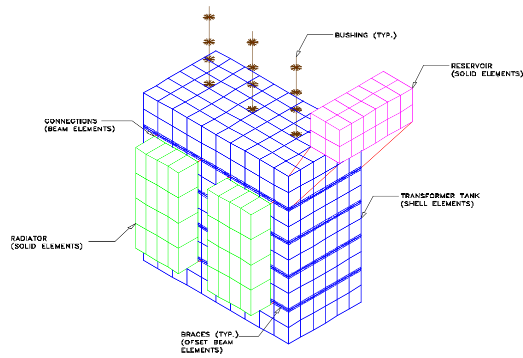
Major Modes of Failure

- Bushing failure.
- Anchorage failure.
- Foundation failure causing rocking and tilting.
- Damage to internal components and longevity.
- Failure of peripheral equipment (e.g., radiators).
- Movement and turn over of transformers.

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

FEA Work

- Finite element analysis of actual transformers using 3-D models (Transformer-Bushing-Interaction).



TRANSFORMER

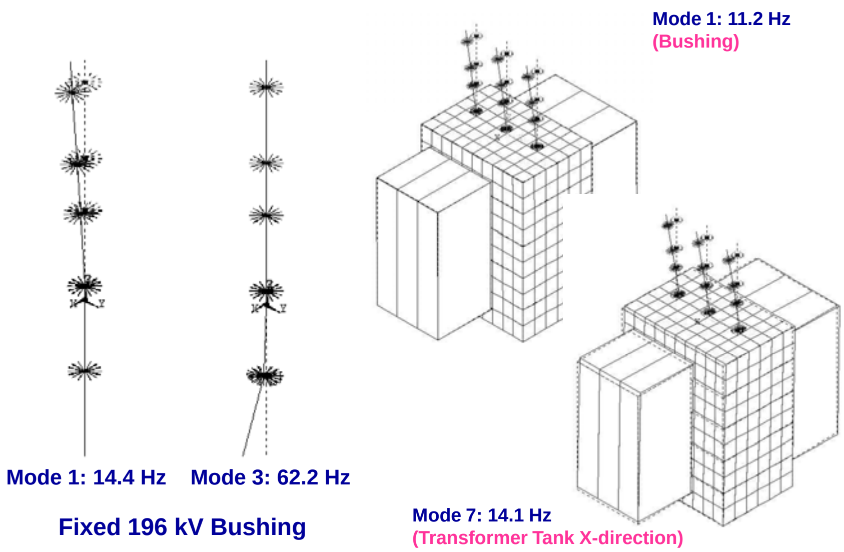
Evaluation Criteria:

- Displacement/acceleration of the bushings
- Gap opening in gaskets
- Prestressing loss in the bushings
- Level of forces and accelerations in the transformer

Note: 3 actual transformer-bushing systems modeled, 4 E.Q. records, Time history and frequency analyses.

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

FEA Results: Frequency Analysis



FEA Results: Transformers

	TT1	TT2	TT3	IEEE 693-1997
Frequency (Hz)	14.1	13.8	11.7	N/A
DAF	2.	2.4	2.5	2.

Filtering of motion has even more effect on bushing response

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

FEA Results: Fixed vs. Transformer Supported Bushing

Case	x-direction		y-direction	
	Disp. (inch)	Acc. (g)	Disp. (inch)	Acc. (g)
Fixed bushing	0.089	1.488	0.084	1.408
Transformer supported bushing	0.550	6.179	0.244	2.967

For TT3 supported bushing displacement and accelerations are even higher (1.2" and 12.4g – x-dir).

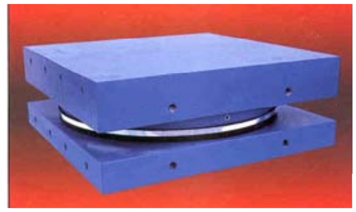
Note: IEEE requires bushing input doubled.

Seismic Isolation

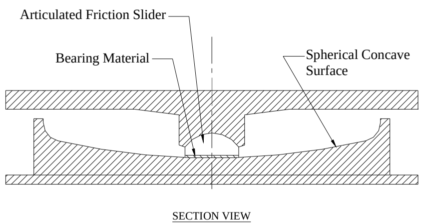
- Friction Pendulum System (FPS) as a rehabilitation measure:
  - Bushing interaction eliminated.
  - Inertia reduction (anchorage design, foundation, internal components, maintenance requirement).
  - Economy: life-cycle cost. Initial cost?
  - Large Displacements: How big a challenge?

FPS Bearing

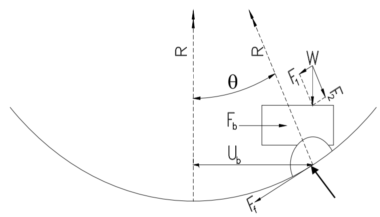
$T = 2\pi\sqrt{R/g}$



A Photograph of FPS

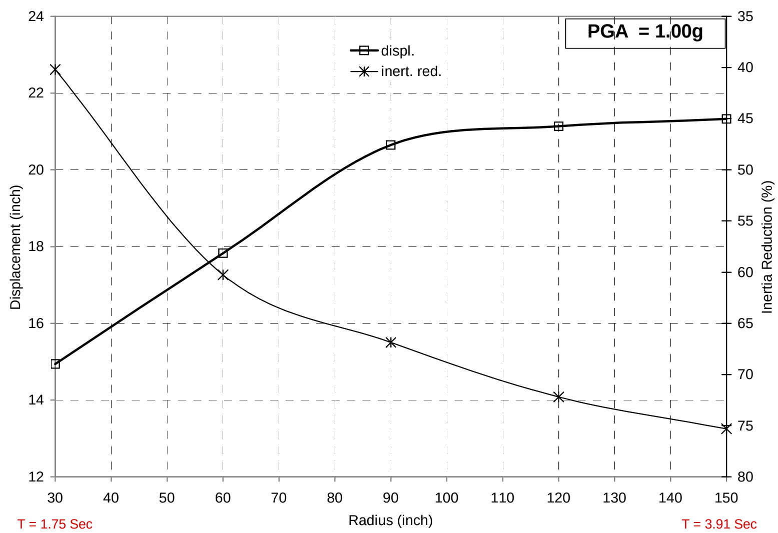


Section View of FPS



F.B. D.

FPS Results: Displ./Accl. Charts

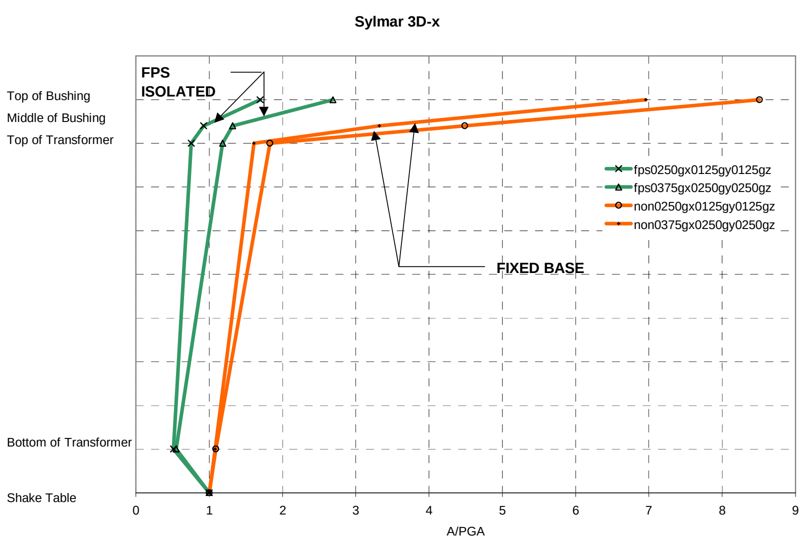


Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Experimental Setup

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Experimental Results

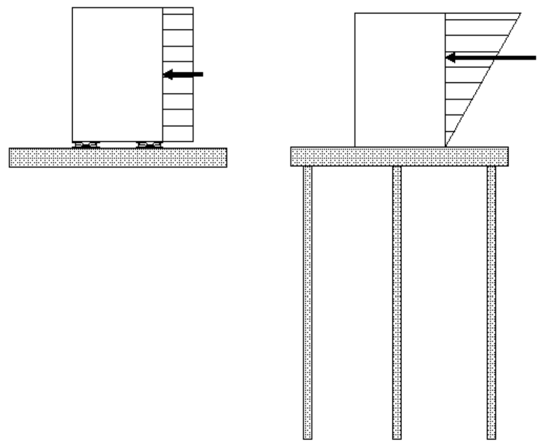


Response Acceleration Map (Sylmar 3D-x)

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Effect of FPS on foundation design

- Isolation reduces the lateral load (as much as 70% or more) compared to PGA. Higher compared to fixed base case.
- Isolation reduces the moment arm for the lateral load, hence reducing the moment



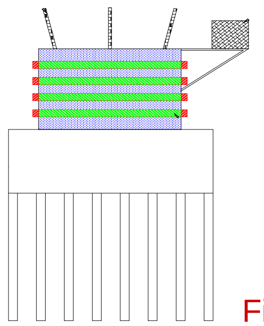
Effect of FPS on foundation design (cont'd)

Case	Support	PL	F_x (kips)	F_y (kips)	F_z (kips)	M_x (k-ft)	M_y (k-ft)
1	Isolated	High	63.0	141.0	327.5	1280.7	572.3
2	Fixed	High	249.0	194.0	315.7	2220.3	2849.8
3	Isolated	Moderate	35.4	45.9	259.0	416.9	321.6
4	Fixed	Moderate	124.5	97.0	246.0	1110.2	1424.9

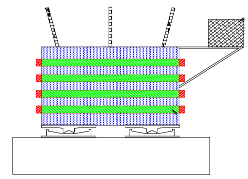
Case	B (ft)	L (ft)	D (ft)	Piles	Pile length (ft)	Pile diameter (ft)
1	24	24	2	-	-	-
2	24	24	2	9	30	3
3	17	17	2	-	-	-
4	24	24	2	9	15	3

- Both fixed cases required piles while isolation eliminated the need for piles even for high seismic performance level.
- Without isolation, footing foundation (i.e., no piles) could sustain an earthquake with maximum PGA of only 0.16g (Compared to 1.0g for isolated foundation).

Initial Cost Comparison



Fixed



Base-isolated

Seismic foundation based on LADWP info.:

"Design/construction of 8 added cast-in-place piles $85,000.

As a range $50,000 to $100,000."

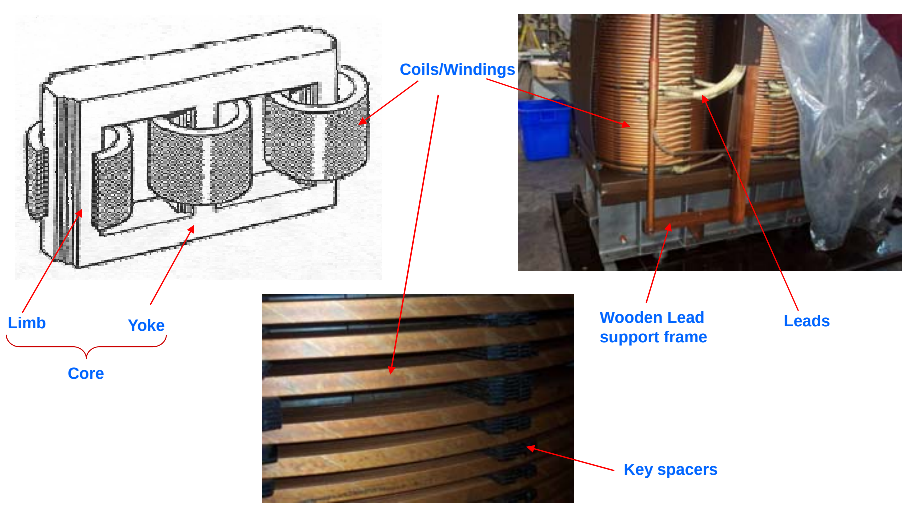
Add to this: anchorage design and construction, and possible removal for maintenance purposes during the life of the system.

Around $15,000. per bearing depending on stroke (max. displacement).

Assuming 4 bearings and construction costs, base-isolation can be competitive even on initial cost basis.

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Internal Components of Power Transformer



Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

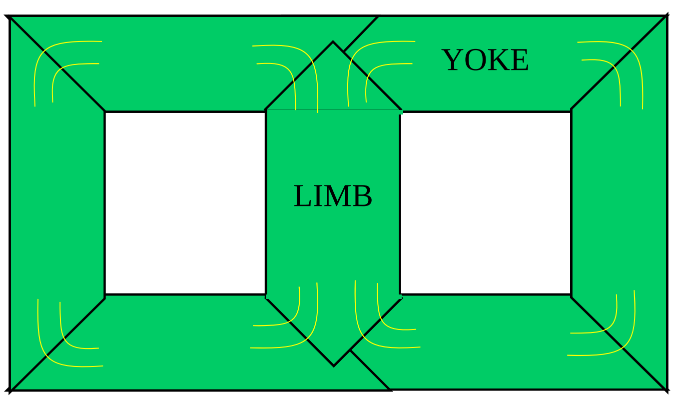
Core-Type 3-Limb Transformer

Frames/Clamps used to hold core together

Thin layer of dielectric steel forming the core (yokes & limbs)

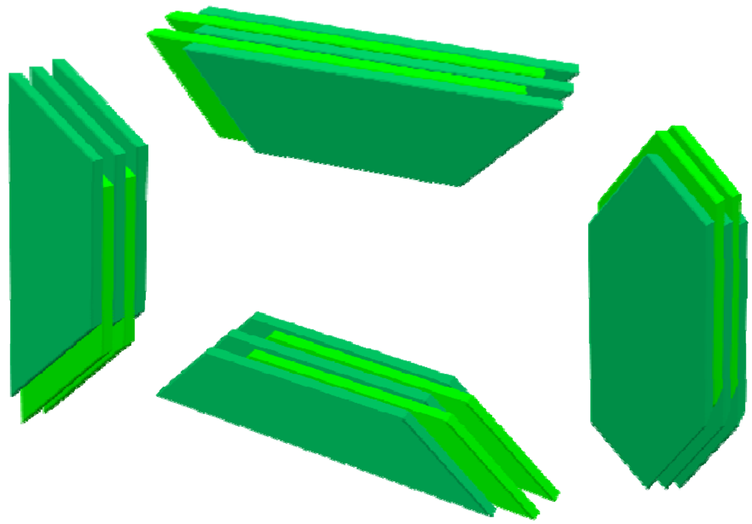
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Core Lamination



Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

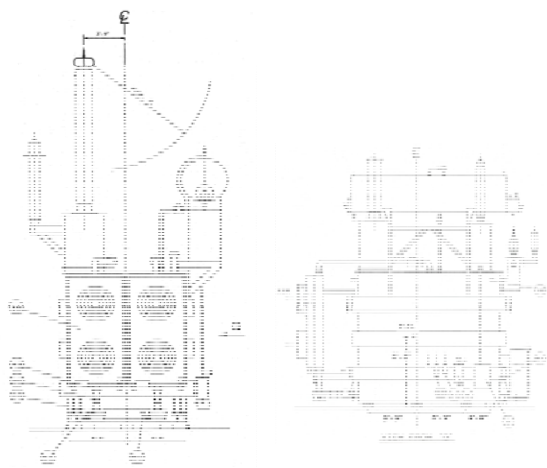
Core Lamination (cont'd)



Possible Modes of Failure/Damage

- Loss of close fitting tolerances between limbs and yokes.
- Flexural and rocking of core-frame system.
- Sliding of key spacers.
- Movement or separation of leads.
- Decrease or loss of safe clearance between layers of conductors due to seismic excitations.
- Rocking of internal segment of bushings.
- Long term impact on prestressing forces

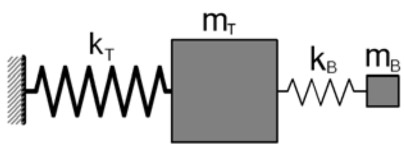
Case Study: Summary of an IEEE paper by Saadeghvaziri, Feizi, Kempner, and Alston

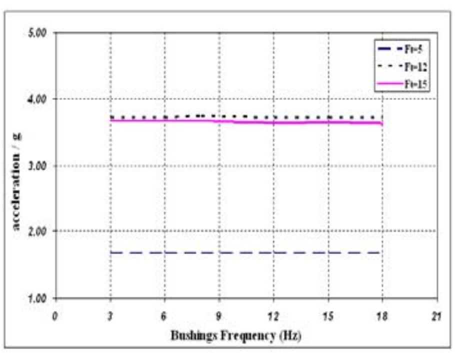


PROPERTIES OF THE TRANSFORMERS AND THE BUSHINGS

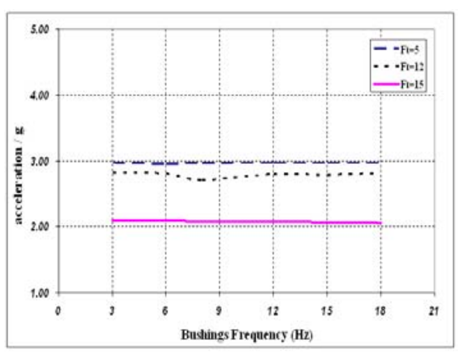
Case Number	Transformer Frequency f_t (Hz)	Transformer Weight (kips)	Bushing Frequency f_b (Hz)	Bushing Weight (lb)
1	5	512.6	3	500
2	5	512.6	6	500
3	5	512.6	8	3740
4	5	512.6	12	770
5	5	512.6	15	1050
6	5	512.6	18	920
7	12	512.6	3	500
8	12	512.6	6	500
9	12	512.6	8	3740
10	12	512.6	12	770
11	12	512.6	15	1050
12	12	512.6	18	920
13	15	512.6	3	500
14	15	512.6	6	500
15	15	512.6	8	3740
16	15	512.6	12	770
17	15	512.6	15	1050
18	15	512.6	18	920

Max Transformer Accelerations: fixed



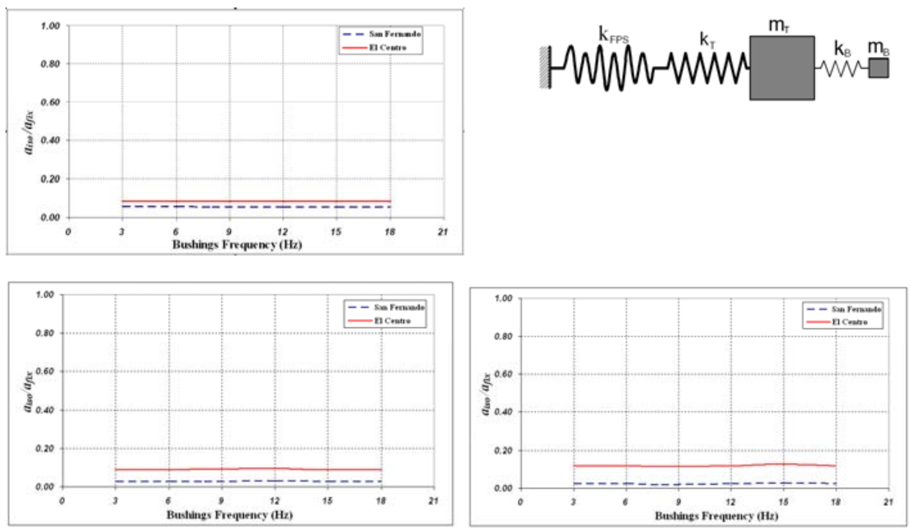


San Fernando (rock)



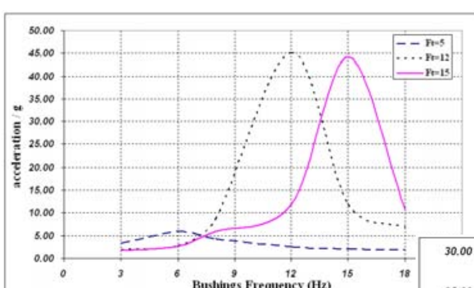
El Centro (soil)

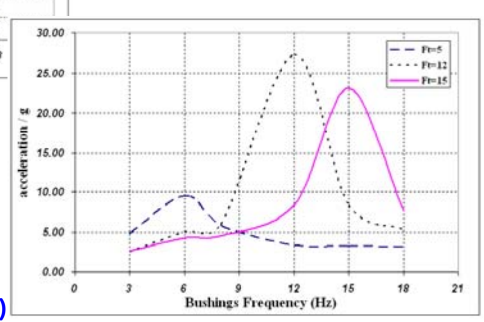
Max. Transformer Acceleration: Fixed vs. Isolated



Max Bushing Accelerations: fixed

San Fernando (rock)

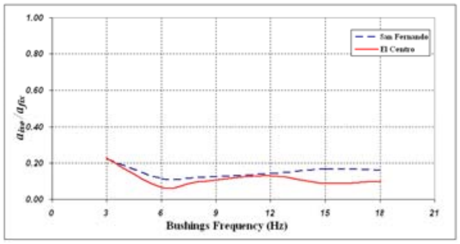




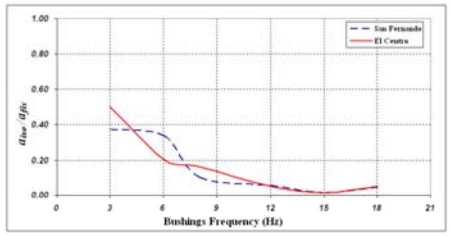
El Centro (soil)

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

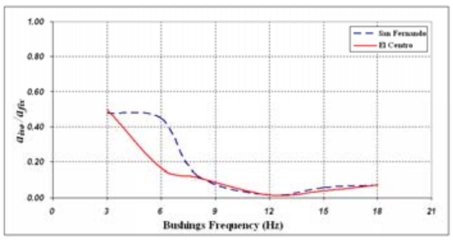
Max. Bushing Accelerations: fixed vs. isolated



Transformer Freq. = 5 Hz



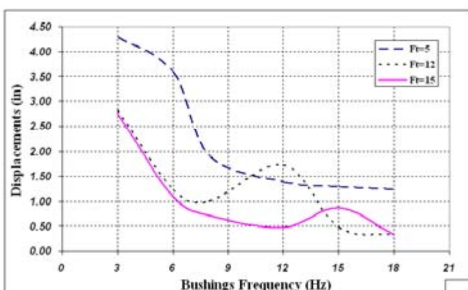
Transformer Freq. = 15 Hz



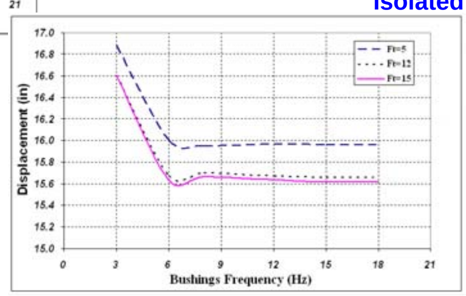
Transformer Freq. = 12 Hz

Bushing Displacements

Fixed



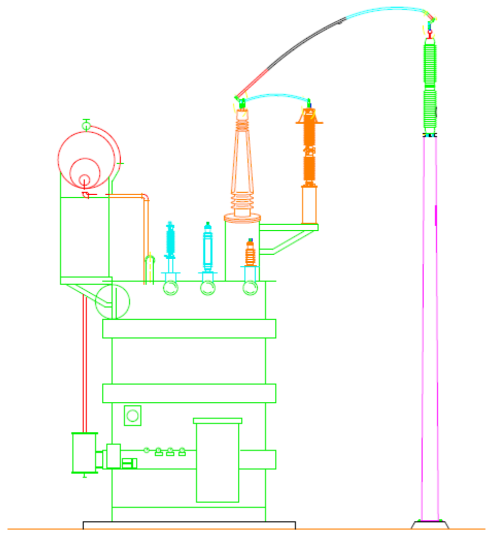
Isolated



The maximum displacement increase as a result of application of base-isolation is about 12.6" (16.9" – 4.3"). That is, additional slack over fixed-base case needs to be provided at 230kV and 550 kV bushing connections to the bus bars.

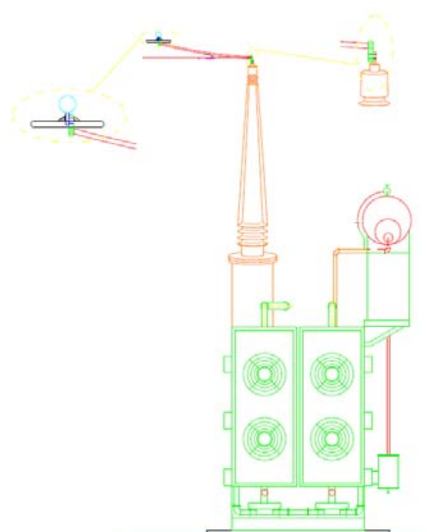
230 kV Bushing to Bus Connection

Detailed measurement of the geometry indicates that it posses more than 20” of slack (> 12.6” required).



500 kV Bushing to Bus Connection

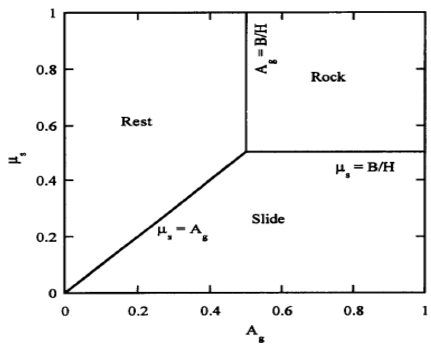
This connection does not have adequate slack and analyses shows that large forces will be developed without additional slack, especially when the transformer is isolated. However, it is possible to provide 2-ft of slack without any electrical implication by increasing cable length on an upward curvature.



Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Turn Over (Uplift)

- Critical issue in application of base-isolation to transformers.
- Equivalent Coeff. of Friction, μ_{eff}, = 1 – IR (where IR is inertia reduction)
- μ_{eff} < B/H to ensure sliding
- μ_{eff} = 0.14
- B/H = 0.62
- Sliding governs OK



Conclusions / Future Research Needs

- Base-isolation is a viable rehabilitation and design option
- Pilot study on application
- Slack requirements
  - Cable vibration and interaction
- Interconnection equipment
- Enhanced bushing modeling particularly gaskets
  - Flexibility of transformer top plate
  - Rotational component of input

Thank You!

Previous Studies of Protection of Substation Equipment

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

SEISMIC PROTECTION OF TRANSFORMER/BUSHING SYSTEMS

Maria Q.FENG
University of California, Irvine

October 24, 2008, SUNY Buffalo

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

CONTENT

- 3-D shaking table tests of base-isolated transformer model
  - Base isolation using sliding bearings
  - Base isolation using HD rubber bearings
  - Energy dissipation at bushing connections
  - Analysis and comparison of different seismic protective systems
- Development of numerical analysis models and simplified design procedures

Tri-axial Simulator Testing of Base-Isolated Transformer with Bushing

- Sliding Bearings -

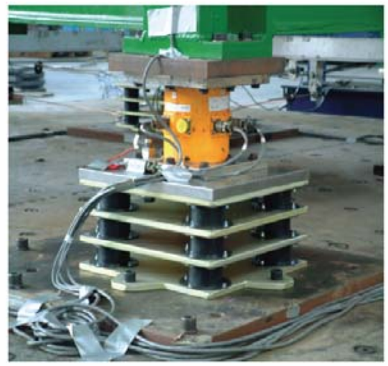
Figure 1. Transformer model and bushing

Figure 2. Isolation system in Phase-1 testing

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Tri-axial Shaking Table Testing of Base-Isolated Transformer with Bushing

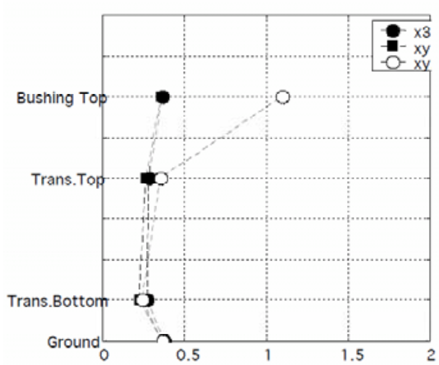
- High-Damping Rubber Bearings -



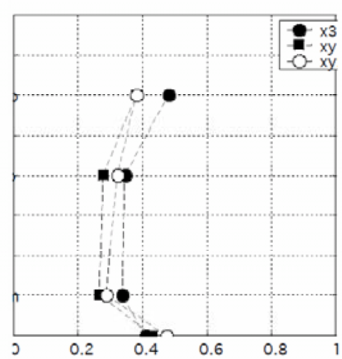
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Comparison between Sliding and HD Rubber Bearing Isolation Systems

Isolation wt. Sliding Bearings



Isolation wt. HD Rubber Bearings

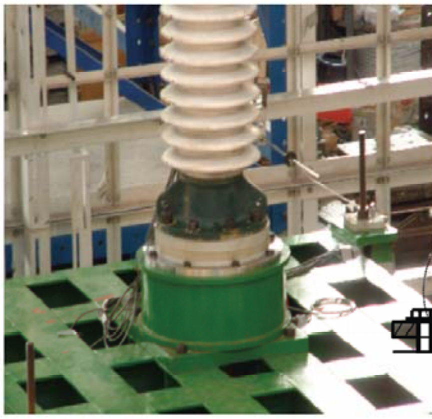


Response Acceleration (g)

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Tri-axial Shaking Table Testing of Base-Isolated Transformer with Bushing

- Rubber Ring at the Bushing Connection -



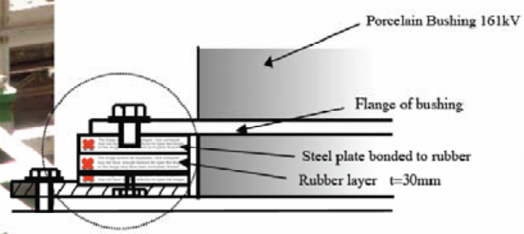
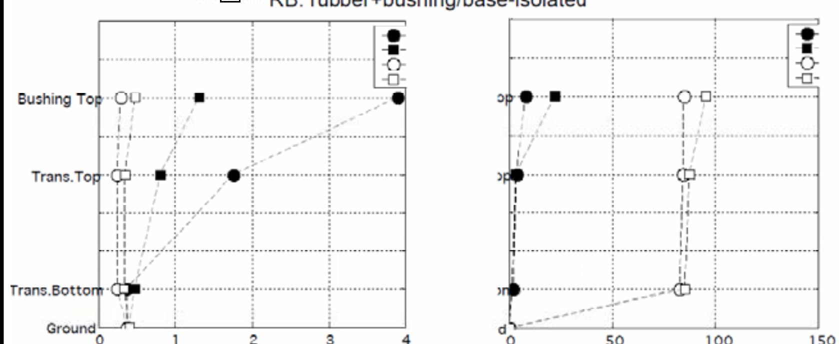


Figure 10. Cross- Section View of a Flexible Rubber Ring

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Comparison among Different Protective Systems

- FF: fixed-bushing/fixed-base
- RF: rubber+bushing/fixed-base
- FB: fixed-bushing/base-isolated
- RB: rubber+bushing/base-isolated



Peak response acceleration (g) Peak response displacement (mm)

Ground motion: Art-693/x375

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

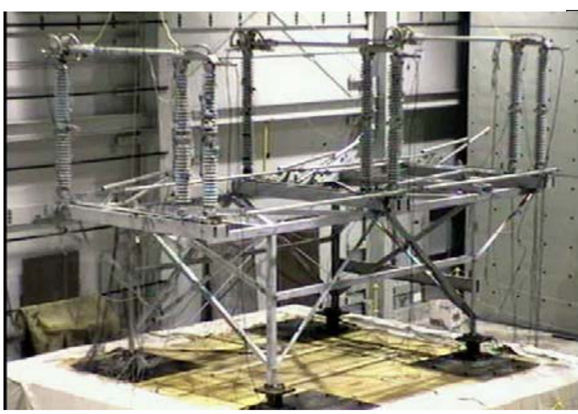
Seismic Isolation of Disconnect Switches

A. M. Reinhorn and D. Kong

Department of Civil, Structural and Environmental Engineering
University at Buffalo (*SUNY)*

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Fixed Base Disconnect 230 KV Switch



Switch:
Pascor Pacific

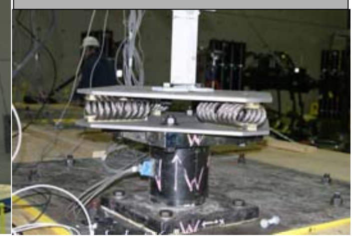
Insulators Fabricator:
LAPP, Rochester NY

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Base Isolated Disconnect Switch

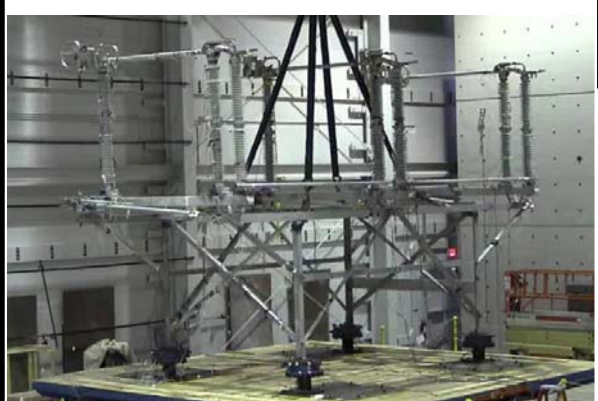
Wire Rope Isolators (WRI)

Fabricator:
Enidine Corp., Buffalo, NY



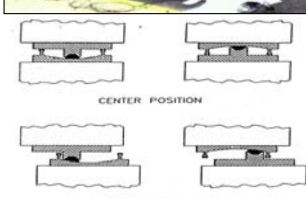
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Base Isolated Disconnect Switch



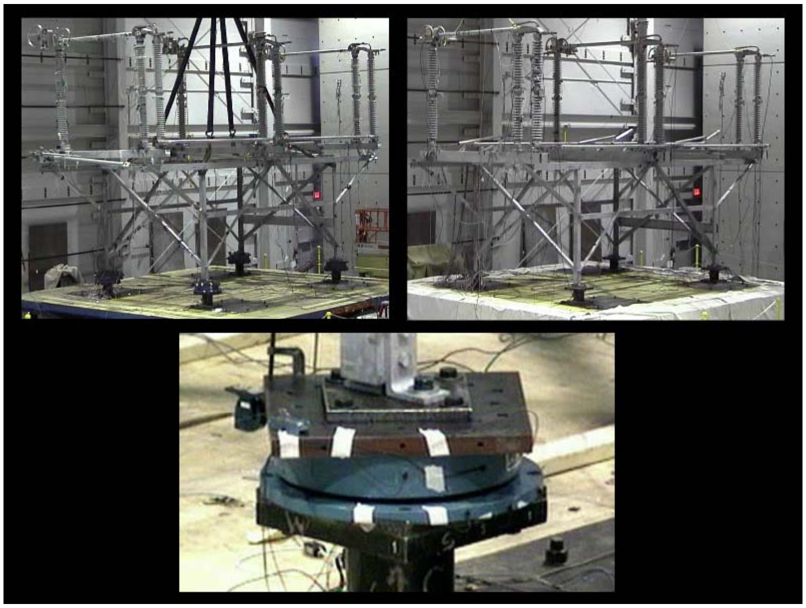
Friction Pendulum System (FPS)

Fabricator:
Earthquake Protection Systems, Inc EPS CA



Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Base Isolated Disconnect Switch



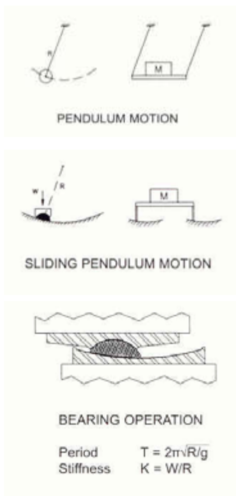
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

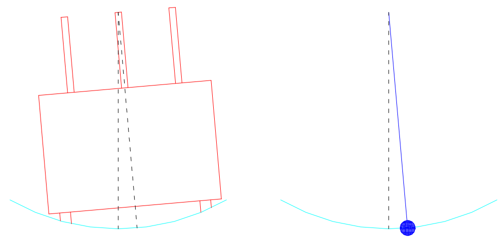
Stresses in Porcelain Posts

		Stresses at Base of Ceramic Post	
Maximum Acceleration of Base Motion		**0.5 g**	**1.0 g**
Fixed Base	StS dir.	28.5	48.4
	FtB dir.	45.6	78.9
Isolated with Wire Rope Isolators (Enidine Corp)	StS dir.	25.2	-
	FtB dir.	37.7	-
Isolated with Friction Pendulum System (EPS)	StS dir.	10.4	15.0
	FtB dir.	9.3	16.8

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Modify FPS Design





Current Design

Proposed Design

Previous Known Applications of Protection of Substation Equipment

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

C. Kircher Report on Application

- 230 kV circuit breaker and support frame - A. D. Edmonston Pumping Plant, California Aqueduct, California Department of Water Resources (DWR)
- Breaker in the same switchyard, was retrofitted by the DWR (after the 1971 San Fernando earthquake) with small (mechanical vibration) isolators under each leg of the support frame (1 phase only).
- Measured dynamic properties, indicated that this type of isolation would not work for earthquakes (the mechanical isolators added a little extra damping, but shifted the period on to, rather than off of, the peak of spectrum)
- Later, in the mid-late 1970's, DWR retrofitted the nearby breaker and support frame (1 phase only), with a much larger displacement - longer period -, seismic-isolation system (GAPEEC system, designed by Del Fosse).
- This isolated breaker subsequently survived a moderate shake due to a nearby earthquake in the Tehachapi mountains, that damaged and knocked off line about one-half of the breakers in the switchyard

Thank You!

SEISMIC ISOLATION HARDWARE

Michael Constantinou
University at Buffalo

ISOLATION HARDWARE

- Isolation bearings
  - Elastomeric
    - Low-damping rubber (NR)
    - High-damping rubber (HDR)
    - Lead-rubber (LR)
  - Sliding
    - Friction Pendulum (FP)
    - Sliding with Restoring Force
    - Sliding with Yielding Devices (Elastoplastic)
- Energy dissipation devices
  - Viscous dampers

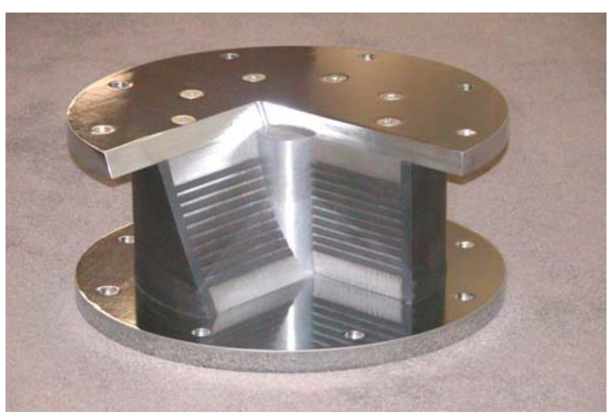
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

ISOLATION HARDWARE

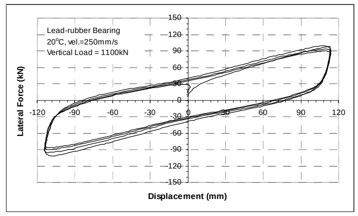
- Elastomeric Bearings for Sakhalin I Orlan Platform
- Tested at University at Buffalo

ISOLATION HARDWARE

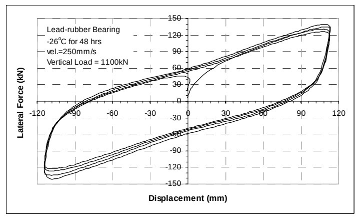
- Lead-rubber bearing



LEAD-RUBBER BEARING



TEMP=20^{O}C

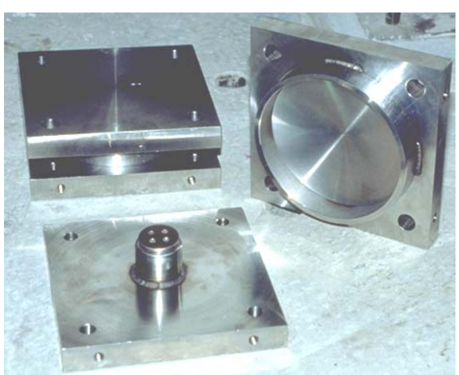


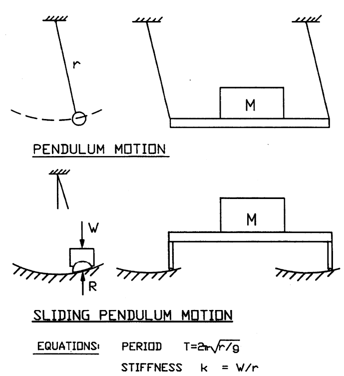
TEMP=-25^{O}C

ROUTE 9W OVER WASHINGTON STREET, ROCKLAND COUNTY, NY
LEAD-RUBBER BEARING, UNIVERSITY AT BUFFALO
LOAD=1100kN, DISPLACEMENT=100mm, VELOCITY=250mm/sec

ISOLATION HARDWARE

- FP bearing





Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

FP BEARING

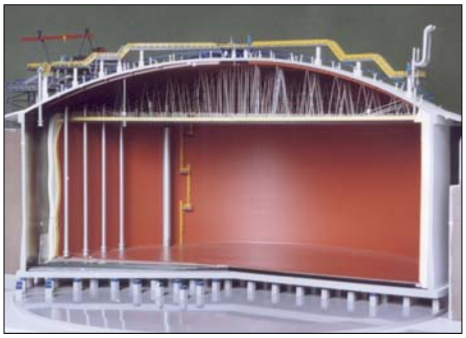
- Salkhalin II bearings
- Largest seismic isolators
- 700mm displacement
- 87,400kN gravity load
- Full-scale testing
- Reduced scale dynamic testing (load of up to 13,000kN, velocity of 1m/sec).

IMPLEMENTATION OF SEISMIC ISOLATORS IN BRIDGES

BENECIA-MARTINEZ BRIDGE
SAN FRANCISCO BAY AREA, RETROFIT 2000
OVER 1200mm DISPLACEMENT CAPACITY

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

IMPLEMENTATION OF SEISMIC ISOLATORS IN LNG TANKS



LNG TANKS, REVITHOUSSA, GREECE, 1996

65,000 m^3 CAPACITY, 75m DIAMETER, 35m HEIGHT (ISOLATOR TO ROOF)

9% NICKEL INNER TANK

PRESTRESSED CONCRETE OUTER TANK

1m PERLITE INSULATION WITH CURTAIN TO ALLOW THERMAL BREATHING

1m INSULATION AT BOTTOM
1m THICK CONCRETE SLAB

UNANCHORED INNER TANK

UNDERGROUND CONSTRUCTION FOR SAFETY REASONS (CONTAINMENT OF SPILLAGE, LOW PROFILE TARGET) AND AESTHETIC REASONS

ISOLATION ALLOWED CONSTRUCTION OF “SLENDER” TANK WITH REDUCED FOOTPRINT AND SMALLER SIZE FOUNDATION

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

IMPLEMENTATION OF SEISMIC ISOLATORS IN LNG TANKS

Inspection, January 2002

LNG TANKS, REVITHOUSSA, GREECE, 1996

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

IMPLEMENTATION OF SEISMIC ISOLATORS IN LNG TANKS

LNG TANKS, REVITHOUSSA, GREECE, 1996

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

IMPLEMENTATION OF SEISMIC ISOLATORS IN LNG TANKS

LNG TANKS, IN-CHON, KOREA, 2006

ELASTOMERIC ISOLATOR

UTILITY LINES REQUIRE FLEXIBILITY TO ACCOMMODATE LARGE DISPLACEMENTS

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

IMPLEMENTATION OF SEISMIC ISOLATORS IN OFFSHORE GAS AND OIL PLATFORMS

SAKHALIN ISLAND, RUSSIA

OFFSHORE GAS PLATFORM WITH CONCRETE GRAVITY BASE

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

SAKHALIN ISLAND GAS/OIL PLATFORMS PILTUN AND LUNSKOYE PLATFORMS

SAKHALIN II PROJECT
LOCATION OF SEISMIC ISOLATION SYSTEM ON TOP OF CONCRETE GRAVITY BASE IN PILTUN AND LUNSKOYE PLATFORMS
GOAL IS TO PROTECT ENTIRE STRUCTURE ABOVE CONCRETE GRAVITY BASE

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

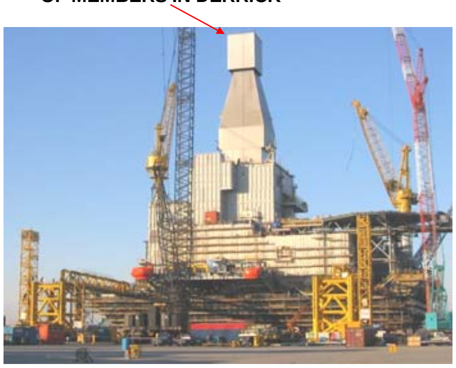
TOPSIDES INSTALLED JUNE 2006

Civil, Structural & Environmental Eng. , University at Buffalo

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

ORLAN PLATFORM

LOCATION OF TUNED MASS DAMPER IN ORLAN PLATFORM GOAL IS TO PREVENT FAILURE OF MEMBERS IN DERRICK



MULTI-STAGE ELASTOMERIC ISOLATORS USED TO ACHIEVE DESIRED FLEXIBILITY WITHOUT STABILITY PROBLEMS AT LARGE DISPLACEMENTS

Civil, Structural & Environmental Eng. , University at Buffalo

IMPLEMENTATION OF SEISMIC ISOLATORS IN STORAGE TANKS

- Case of cryogenic storage tanks near populated seismically active area (Sicily, Italy)
- Demolition and rebuilding not an option-cannot build anything new in that area
- Seismic isolation retrofit an attractive option
- Concept applicable to refineries near populated areas

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

IMPLEMENTATION OF SEISMIC ISOLATORS IN STORAGE TANKS

- Due to close spacing of columns, temporary transfer of load not needed (but support system provided)
- Isolators inserted without need to preload (no use of flat jacks)
- Use of FP bearings with transfer of P-Δ moment on strengthened column below

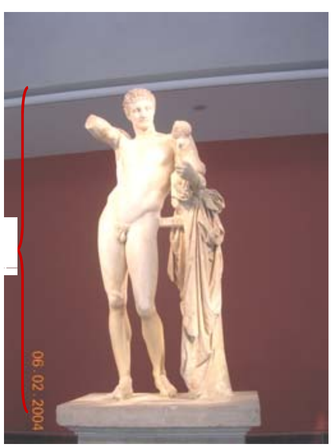
IMPLEMENTATION OF SEISMIC ISOLATORS IN STORAGE TANKS

- Ammonia storage tank, Kentucky
- Supported on four FP isolators

IMPLEMENTATION OF SEISMIC ISOLATORS IN HOSPITALS

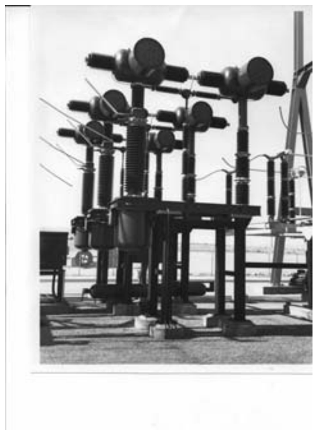
- Erzurum Hospital, Turkey, 2006
- 386 Lead-Rubber Bearings
- Displacement demand in the MCE: 555mm
- Turkey has acted legislation to require seismic isolation for all new hospitals
- Plans for over 15 hospitals to be constructed in the near future

IMPLEMENTATION OF SEISMIC ISOLATORS FOR PROTECTING STATUES



STATUE OF HERMES, 2004
(BY PRAXITELES, 330 BC)
ARCHEOLOGICAL MUSEUM
OLYMPIA, GREECE
4 FP BEARINGS, 320mm DISPLACEMENT

IMPLEMENTATION OF SEISMIC ISOLATORS IN ELECTRICAL EQUIPMENT



- 230kV Circuit Breaker, CA, around 1975
- GAPEC isolators, France, rather stiff low damping elastomeric bearings
- Based on studies and recommendations of Charlie Kircher who, as a graduate student at Stanford, studied the dynamic characteristics of electrical equipment
- Performed well in earthquakes when nearby identical equipment were damaged

APPLICATION OF SEISMIC ISOLATION IN ELECTRICAL EQUIPMENT

- Complexities
  - Very light weight structures so that significant isolation effect cannot be accomplished with elastomeric systems. However, benefits may be realized by relative stiff and damped systems/ concentration of inelastic action in isolators
  - Large displacement demands for size of equipment requires isolators as large as those for buildings or bridges-only gravity load is small
  - Cost is a concern given the size of the isolation hardware as compared to size of equipment
  - Concerns with behavior of cables, etc. that connect equipment to other structures

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

APPLICATION OF SEISMIC ISOLATION IN ELECTRICAL EQUIPMENT

- Challenges
  - Develop generic seismic isolation designs for electrical equipment that can be readily implemented.
  - Verify effectiveness of generic isolation designs.
  - Work with manufacturers of seismic isolation technologies to adapt their technologies for application to electrical equipment. This would require modification of designs due to light weight supported. Concept that deviate from traditional isolation may be most useful.
  - Testing of electrical equipment on shake tables is possible at full scale put capacities of shake tables in terms of displacement and velocity may be insufficient. Verification based only on testing may not be possible.

Thank You!

COMMENTS AND SUGGESTIONS FROM MICHAEL CONSTANTINOU

University at Buffalo (SUNY)

Applications to Electrical Equipment

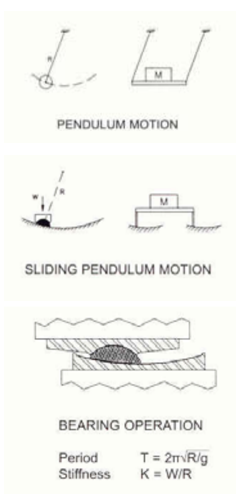
APPLICATION OF SEISMIC ISOLATION IN ELECTRICAL EQUIPMENT

- Complexities
  - Very light weight structures so that significant isolation effect cannot be accomplished with elastomeric systems. However, benefits may be realized by relative stiff and damped systems/ concentration of inelastic action in isolators
  - Large displacement demands for size of equipment requires isolators as large as those for buildings or bridges-only gravity load is small
  - Cost is a concern given the size of the isolation hardware as compared to size of equipment
  - Concerns with behavior of cables, etc. that connect equipment to other structures

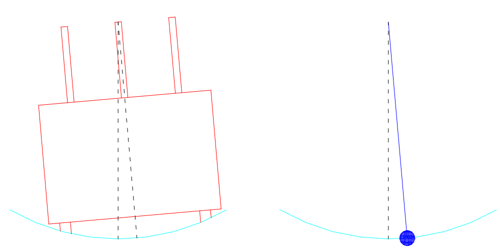
APPLICATION OF SEISMIC ISOLATION IN ELECTRICAL EQUIPMENT

- Challenges
  - Develop generic seismic isolation designs for electrical equipment that can be readily implemented.
  - Verify effectiveness of generic isolation designs.
  - Work with manufacturers of seismic isolation technologies to adapt their technologies for application to electrical equipment. This would require modification of designs due to light weight supported. Concept that deviate from traditional isolation may be most useful.
  - Testing of electrical equipment on shake tables is possible at full scale put capacities of shake tables in terms of displacement and velocity may be insufficient. Verification based only on testing may not be possible.

Modify FPS Design



Current Design



Proposed Design

Thank You!

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Conductor dynamics and equipment loading

Jean-Bernard Dastous
Research Scientist
Hydro Québec
Institut de recherche

Presentation overview

- Overview of research
- Main research results
- Issues on conductors and protective systems

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Overview of research in the field - 1

- First research performed about 25 years ago in Japan after 1978 Miyagi earthquake
  - Shake table testing with 3 sine waves on pair of interconnected equipment and finite element modeling with simplified conductor model
  - Resulted in basic guidelines on necessary slack to provide

> Necessary slack of connecting lead:
> More than maximum value of the following three values
>
> (1)5% of straight distance between two equipment
> (2)1.5 × maximum relative displacement of two equipment
> for 0.3G resonant three cycles sine wave input
> (3)70mm

Overview of research in the field - 2

- Since 1992, various groups in North America have been active:
  - Hydro-Quebec: experimental and numerical (flexible bus)
    - Static and dynamic tests on conductors alone
    - Displacement evaluation of equipment
    - Flexible conductor modeling including variable bending stiffness, with experimental validation
    - Non linear fea modeling on existing installations
    - Guidelines for the design of flexible conductors
  - BC Hydro: experimental (flexible bus)
    - shake table tests on pairs of interconnected equipment

Overview of research in the field - 3

- BPA: experimental (hybrid bus)
  - shake table tests on hydrid connectors
- PEER - UC San Diego: experimental (flexible and rigid bus)
  - shake table tests on pairs of interconnected equipment (rigid/flexible bus)
  - measurements of bending stiffness of conductors and properties of rigid bus connectors
- PEER - UC Berkeley: numerical (flexible and rigid bus)
  - Flexible conductor modeling including variable bending stiffness
  - Rigid bus connector modeling
  - Non linear fea modeling on pairs of interconnected equipment with rigid/flexible bus

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Main research results - 1

- Conductors are dynamic rather than static systems. During motion of equipment, they may generate significant dynamic effects and forces at the terminal pads.
- Significant interaction effects may take place when not enough slack is provided.
- The most significant effects occur when two interconnected equipment have dissimilar natural frequencies
- The generated forces may be an order of magnitude higher than the forces generated by an equivalent static elongation. Level of maximum expected terminal forces for 0.5 g when enough slack provided of the order of 1000 N/conductor.
- Equipment must be designed to take account of those additional forces
- Multi-connected equipment effects may be significant

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Main research results - 2

- Maximum horizontal forces measured when enough slack is provided in flexible conductors

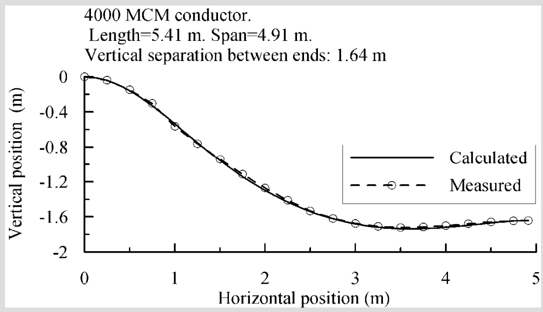
Shape, span, conductor	Type of test	a_{max} (g)	F_{max} (N)	Ref.
catenary, 5 m, 1796 kcmil	harmonic sweep	0.5	750	HQ
catenary, 5 m, 4000 kcmil	harmonic sweep	0.5	1590	HQ
catenary, 3 m, 1796 kcmil	harmonic sweep	0.5	1114	HQ
parabola, 3 m, 1796 kmcil	3 cycles sine	0.5	1040	HQ
parabola, 4 m, 4000 kcmil	3 cycles sine	0.5	1140	HQ
double, 5 m, 4000 kcmil	3 cycles sine	0.5	720	HQ
triple, 5 m, 4000 kcmil	3 cycles sine	0.5	620	HQ
catenary, 4.6 m, 2300 kcmil	shake table	0.5	1060	SD
catenary, 4.6 m, Lupine	shake table	0.5	810	SD
catenary, 4.6 m, 2300 kcmil	shake table	0.5	1330	SD
catenary, 4.6 m, Lupine	shake table	0.5	1430	SD
catenary, 3.2 m, 2300 kcmil	shake table	0.5	693	BCH
catenary, 3.2 m, 2300 kcmil	shake table	0.5	730	BCH
catenary, 3.2m, 2300 kcmil	shake table	0.5	948	BCH

Main research results - 3

- Effect of flexible conductor dynamic loading on equipment
  - Effect of forces translates into an additional static load in the conductor direction at its attachment point that must be part of the equipment standalone design
  - Representative bound value load levels established by numerical studies & experimental results, in accordance with IEEE 693 performance levels :
    - 1000 N/sub-conductor below 0.5 g
    - 2000 N/sub-conductor between 0.5 to 1 g
    - These requirements are now part of IEEE 1527-2006 and in discussion to include in IEEE 693

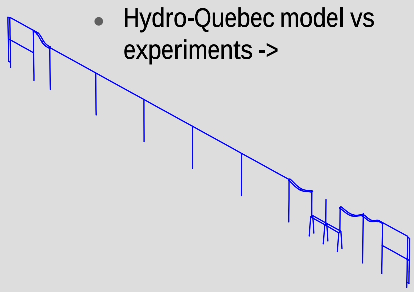
Main research results - 4

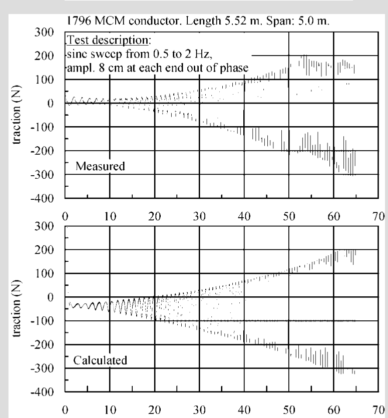
- Modeling - static
  - Finite element method can be used to check electrical clearances prior to design in most cases
  - Exemple: Hydro-Quebec model vs experiments:



Main research results - 5

- Modeling - dynamic
  - Non linear dynamic finite element method provides a representative tool for simulating complex models and doing parametric studies
  - Hydro-Quebec model vs experiments ->





Main research results - 6

- Amount of slack required in flexible conductors
  - The percentage of slackness *s*, defined as: $s = \frac{(L_o - L_1)}{L_1} \times 100$

    with L_1:straight line distance between attachment points and L_o:conductor length between attachment points

    is NEVER a good indicator of the amount of slack needed as it does take into account the demand, that is the amount of the maximum relative motion between equipment during earthquakes
  - A better indicator of the amount of slack needed is given by: $\beta = \frac{e_o}{L_o - L_1}$

    with e_o:maximum relative displacement: the *demand* and $L_o - L_1$: conductor slack: the *availability*

    β values smaller or equal to 1 are recommended to avoid adverse interaction effects

Issues on conductors and protective systems

- Bound value of 1000 N/conductor established with limited amount of experiments / conductor types / studies
- This value may be significant for low voltage equipment
- Rigid bus conductors provide limited amount of availability (cannot accomodate large displacements)
- Flexible conductor may provide more availability but electrical clearances often limit it
- Protective systems must :
  - Allow continuity of electrical current at all times (no disruption permitted – high reliability)
  - Be functional under adverse loading conditions : ice, wind, short-circuit
  - Low or no maintenance over a life expectancy of 40-50 years
  - Cheap and easy to install

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

References - 1

- Experiments on dynamic effects of conductors
  - Dastous, J.B., Pierre, J.R., “Experimental investigation on the dynamic behavior of flexible conductors between substation equipment during and earthquake”, *IEEE Transactions on Power Delivery*, Vol. 11, No. 2, pp. 801-807, April 1996.
- Testing of alternative geometries and generation of tables with universal configurations:
  - Dastous, J.-B., Paquin, J.-Y., "Testing and Development of Alternative Flexible-Bus Geometries for Interconnected Substation Equipment Subjected to Earthquakes," *IEEE Transactions on Power Delivery*, Vol. 18, No.3, pp. 772-780. July 2003.
- Testing on interconnected equipment
  - Filiatrault, A., Kremmidas, S., Elgamal, A. and Seible, F. 1999. “Substation Equipment Interaction – Rigid and Flexible Conductor Studies”, Structural Systems Research Project Report No. SSRP-99/09, Department of Structural Engineering, University of California, San Diego, La Jolla, CA, 218 p.
  - Filiatrault, A. and Kremmidas, S. 2000.“Seismic Interaction Between Components of Electrical Substation Equipment Interconnected by Rigid Bus Conductors”, ASCE Journal of Structural Engineering, 126(10), 1140-1149.
  - Filiatrault, A., Stearns, C., “Electrical Substation equipment interaction – Experimental Flexible Conductor studies,” Report No. SSRP-2002/09, University of California at San Diego, Department of Structural Engineering, Structural Systems Research Project, September 2002

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

References - 2

- Testing on interconnected equipment - continued
  - Filiatrault, A., and Kremmidas, S. 2002.” An Experimental Study on the Dynamic Interaction of Interconnected Electrical Substation Equipment During Earthquakes”, Structural Engineering Institute Specialty Conference on the Design, Maintenance, and Constructability of Electrical Transmission Line and Substation Structures, Omaha, Nebraska, 411-419.
  - Filiatrault, A., and Stearns, C. 2003. “An Experimental Study on the Seismic Response of Electrical Substation Equipment Interconnected by Flexible Conductors”, Sixth U.S. Conference and Workshop on Lifeline Earthquake Engineering, Long Beach, CA, 667-676.
  - Gualifabian, H., Bhuyan, G. et alter, "Seismic Behavior of Flexible Conductors connecting Substation Equipment, Part2: Shake Table Tests," *IEEE Transactions on Power Delivery*, Vol. 19, No. 4, pp. 1680-1687. October 2004
  - Stearns, C. and Filiatrault, A. 2004. “Electrical Substation Equipment Interaction –Experimental Rigid Conductor Studies,” Research Project Report No. SSRP-2003-11 Department of Structural Engineering, University of California, San Diego, La Jolla, CA, 89 p.
  - Filiatrault, A., and Stearns, C. 2004. “Seismic Response of Electrical Substation Equipment Interconnected by Flexible Conductors”, ASCE Journal of Structural Engineering, Vol. 130, No.5, 769-778.

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

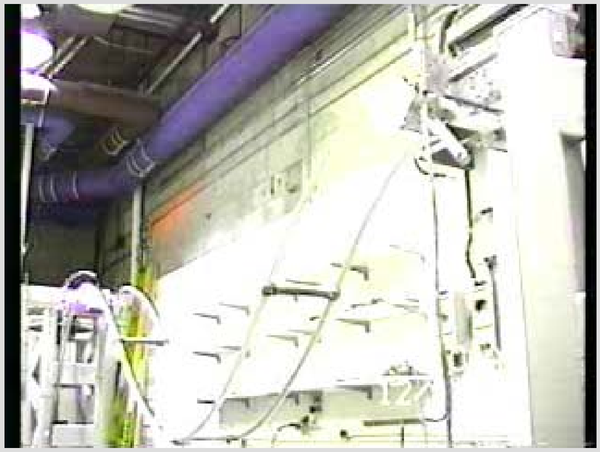
References - 3

- Prediction of equipment standalone displacement
  - Dastous, J-B., and Filiatrault, A. 2003. "Seismic Displacement at Interconnection Points of Substation Equipment", Sixth U.S. Conference and Workshop on Lifeline Earthquake Engineering, Long Beach, CA, 597-606.
  - Dastous, J.-B., Filiatrault, A., Pierre, J.-R., "Estimation of Displacement at Interconnection Points of Substation Equipment Subjected to Earthquakes," *IEEE Transactions on Power Delivery*, Vol. 19, No. 2, pp. 618-628, April 2004.
- Experimental studies and modeling of conductor with variable bending stiffness
  - Filiatrault, A., and Stearns, C. 2005. "Flexural Properties of Flexible Conductors Interconnecting Electrical Substation Equipment", ASCE Journal of Structural Engineering, Vol. 131, No. 1, 151-159.
  - Dastous, J.-B., "Nonlinear Finite Element Analysis of Stranded Conductors with Variable Bending Stiffness Using the Tangent Stiffness Method," *IEEE Transactions on Power Delivery*, Vol. 20, No.1, pp.328-338. January 2005.
  - Hong, K.-J., "Dynamic interaction in cable-connected equipment," *Ph.D. Thesis,* University of California at Berkeley, 2003
  - Hong, K-J., A. Der Kiureghian and J.L. Sackman (2005). Bending behavior of hellically wrapped cables. /J. Engineering Mechanics/, ASCE, *131*(5): 500-511.

References - 4

- Numerical simulations and design methodology
  - Okada, T., Misaki, T. et alter, "Seismic design of connecting leads in open-air type substations," Report 23-04, CIGRE 1986 Session, August/September 1986
  - Der Kiureghian, A., J. L. Sackman and K-J. Hong (1999). Interaction in interconnected electrical substation equipment subjected to earthquake ground motions. /PEER Report 1999/01/, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA , February.
  - Der Kiureghian, A., J. L. Sackman and K-J. Hong (2000). Further studies on seismic interaction in interconnected electrical substation equipment. /PEER Report 2000/01/, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.
  - Der Kiureghian, A., J. L. Sackman and K-J. Hong (2001). Seismic interaction in linearly connected electrical substation equipment. /Earthq. Engrg. Struct. Dyn/., *30*:327-347.
  - Hong, K-J., A. Der Kiureghian and J. L. Sackman (2001). Seismic interaction in cable-connected equipment items. /J. Engineering Mechanics/, ASCE, *127*(11):1096-1105.
  - Dastous, J.-B., Pierre, J.-R., "Design methodology for flexible buswork between substation equipment subjected to earthquakes", submitted for publication in *IEEE Transactions on Power Delivery, 2005*
  - Song, J., A. Der Kiureghian and J. L. Sackman (2006). Seismic response and reliability of electrical substation equipment and system. /PEER Report /to appear/./
  - Dastous, J.-B., "Guidelines for seismic design of flexible buswork between substation equipment", *Earthquake Engng Struct. Dyn., 2007, 36: 191-208*

Video on test at Hydro-Quebec

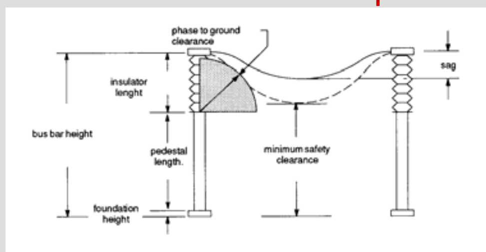


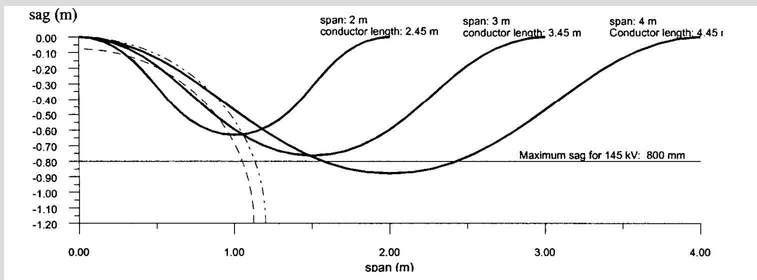
Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Video on test at UCSD

Workshop on Improving Seismic Response of Substation Equipment – 10/24/2008

Electrical clearances requirements





Thank You!

SECTION 3.
COMMENTS AND DISCUSSIONS

The following notes for the subject discussions were recorded in shorthand by Ms. Sofia Tangelos, MCEER, University at Buffalo, State University of New York.

3.1. Comments and Discussions: Base Isolation (Moderator: M. Ala Saadeghvaziri)

KAMRAN KHAN: Most isolation systems do not handle the rotational aspect (meaning rocking) very well in substation equipment.

RON TOGNAZZINI: Who is responsible for the base isolation; the people in the design, or the people who make the implementation in site? The (transformer) box is usually designed by the electrical engineers according to their needs.

KAMRAN KHAN: The base isolation is nonlinear. That will break down the whole spectrum response (approach).

BILL DAROVNY: Adapt the elements coming out of the transformer for big deformations.

LONNIE ELDER: Why do we need base isolation? For the bushing or the transformer?

ALA SAADEGHVAZIRI: For the bushing.

RON TOGNAZZINI: We have to consider alternative load paths when using base isolation.

ERIC FUJISAKI: There is a business case here. Base isolation has to be checked for feasibility, effectiveness and cost first.

SOHRAB ESFANDIARI: How much benefit do you get from a damper that is not in parallel with base isolation? The transformer is not heavy so only FPS will be effective.

ANSHEL SCHIFF: The FPS steel surfaces have to be very well polished or else high frequency effects will arise.

ALA SAADEGHVAZIRI: Is two feet extra slack too much?

RON TOGNAZZINI: Yes it is.

KAMRAN KHAN: There is a program that measures the response of a damped system (Maria Feng).

ALA SAADEGHVAZIRI: Base isolation can also be beneficial in blasts, hurricanes, etc.

ERIC FUJISAKI: The time is right for base isolation because it introduces high reliability.

RON TOGNAZZINI: The customer minutes are the problem. High reliability plays a great role.

JEAN-BERNARD DASTOUS: (Agrees on the matter of reliability).

JOSEPH GRAZIANO: (Says that "load not delivered is money lost" and until an earthquake comes we don’t think much of it). There are indirect costs.

ANDREI REINHORN: The extra cost (in investment) leads to higher quality (in delivery).

RON TOGNAZZINI: Resilience issues.

ANSHEL SCHIFF: The project must target on the design of a system that will implement base isolation from the beginning.

BILL GUNDY: Can we introduce more damping to reduce displacements (with friction)?

ANDRE FILIATRAULT: We should keep friction low and increase damping through viscous devices.

RON TOGNAZZINI: Maintenance cost of fluid dampers might be prohibitive for some people.

ANDREI REINHORN: There are cases where dampers were in salt water for 25 years and continued to perform.

BRIAN KNIGHT: There are issues with great displacements (dampers needed) and overturning moments in FPS.

ANDRE FILIATRAULT: Overturning is not a major issue in FPS (like in bridges as well).

ANDREI REINHORN: Dampers are viscoelastic. They will introduce some elasticity that is (sometimes) undesirable.

RON TOGNAZZINI: There are cases where the dampers were placed wrongly. Therefore we need to have qualified people to place them.

ANDRE FILIATRAULT: How important is the residual displacement for the transformers?

RON TOGNAZZINI: In California there is an issue because of the aftershocks and maintenance will take time to be done.

JOSEPH GRAZIANO: How does base isolation work in a high temperature environment with electric field? The maintenance will be difficult because the electrical engineer will be responsible for it.

ANDREI REINHORN: Longevity is always an issue and is investigated by Constantinou at UB.

ANDRE FILIATRAULT: Bounding analysis (upper and lower bounds of the base isolation values).

JOSEPH GRAZIANO: base isolation is a great idea but you have to have a business and maintenance plan (general concern with the maintenance issues).

KENT MARTIN: Will a leak affect the base isolation?

3.2. Comments and Discussions: Conductors' Issues (Moderator: Andre Filiatrault)

ANDRE FILIATRAULT: Is damping of a vibrating cable desirable? For example, sleeves that will bend with the cable and provide damping, or design of an entirely new special cable with internal damping?

JEAN-BERNARD DASTOUS: The electrical loads will not be a problem in an earthquake.

ANDREI REINHORN: But if you suddenly change the intensity I, you will have serviceability problems.

LONNIE ELDER, **WILLIE FREEMAN**: The problem with insulating the cable is that it will be even hotter than it is.

ANDREI REINHORN: Can we use different cables to detune the system? For example, two stiffer cables at the end and a softer at the middle.

ANSHEL SCHIFF: We have not seen dynamics of a cable yet.

JEAN-BERNARD DASTOUS: However, cables were tested and resonant frequencies were determined (although in 1-D).

ANDRE FILIATRAULT: The greater slackness introduces more damping to the system.

ANDREI REINHORN: Is it possible to use longer buses to accommodate displacements? Because if we need to base isolation, the extra displacement may be as small as 1 in if the cable is very large.

ANDRE FILIATRAULT: Frequencies:

- Rigid Base for bushing: f=10 Hz
- Transformer: f=14-20 Hz
- Bushing on top (as installed f): f=3 Hz

This is a problem because an earthquake has much energy at this frequency. An approach is to stiffen the base of the bushing so much so that $f = f_{RIGID\ BASE}$ for the bushing. Not much acceleration and certainly no problem with the displacements. For example, we can stiffen the top plate.

SOHRAB ESFANDIARI: Some earthquakes give much energy at 10 Hz.

LONNIE ELDER: In the case Andre Filiatrault proposed, we just lower the longitudinal and transverse motion. But the rotational component will be a problem for the bushing.

KENT MARTIN: If we stiffen just the upper plate, there is danger that the transformer will explode.

BILL DAROVNY: It will be better to break at a specific point than exploding.

ANDREI REINHORN: Taking advantage of the rotational motion of the bushing, we can put some appropriate devices to dissipate energy.

ERIC FUJISAKI: The stiffening process should not be abandoned.

3.3. **Comments and Discussions: General Issues (Moderator: Anshel Schiff)**

ANSHEL SCHIFF: There are some comments made from New Zealand:

1) Is it possible that a large turret in combination with a thin plate may drop the as installed frequency? Because if frequency reaches the value f = 3 Hz, there might be a problem.

2) Also the codes do not account for near fault effects, such as

- Very large velocities (fling)
- Directivity phenomena (bad for base isolation, may exceed the design capability of the bushing)

ARTURO DEL RIO:

1) What about the fling motion of the fault? The motion of each side of the fault may be half of the amplitude of the longitudinal motion and at the end result to the same amplitude.
2) High frequency vertical motion near the fault.

BILL GUNDY: What is the effect of base isolation? The base plate has not been designed for base isolation.

ANSHEL SCHIFF: Some plates are designed so that base isolation can be implemented. Others may not be uplifted.

ALA SAADEGHVAZIRI: We can solve the problem by adding a flange at the bottom.

ANDRE FILIATRAULT: Do we really need to drop frequency to 0.5 Hz?

ANSHEL SCHIFF: If we have 3 Hz as installed frequency, we already have a big reduction (by a factor of 4 actually).

KAMRAN KHAN: Do you anticipate for rotational input?

ANSHEL SCHIFF: There has not been a rotational earthquake measurement yet. However, the rotational component of the earthquake exists. It has been accounted for in the model due to the flexibility of the plate.

ANDRE FILIATRAULT: Experiments at MCEER showed significant effect of the flexibility of the top plate (explains the different types of tests involving the bushing).

ANSHEL SCHIFF: In experiments, what is the effect of the turret? A higher turret lowers the acceleration and the moments on the bushing.

ALA SAADEGHVAZIRI: You have to choose the reduction you need. If the as installed frequency gives the desired reduction maybe base isolation is not desirable.

ANDREI REINHORN: If the bushing is in the corner, we have the worst boundary condition (plate stiffer, much rocking). The place of the bushing on the plate plays a significant role on the response.

LONNIE ELDER: How do we measure the rotation?

ANSHEL SCHIFF: With the Krypton™ Visual Sensors (comments on the significance of the direction of excitation and the motion of the bushing. The bushing will move in both directions.).

ANDRE FILIATRAULT: This is due to the flexibility of the top plate. Can we take advantage of the flexibility of the top plate?

WILLIE FREEMAN: (Wants to know about the rotational input on the turret separately.) How can we keep the rotational input out of the bushing? Can we put stiffeners around the turret?

AL MOLNAR: Can we measure damping due to oil using FEM?

ANSHEL SCHIFF: I don't think that we will get much damping from oil.

RON TOGNAZZINI: - What is the behavior of isolated transformers? Need for literature review of failures in general.

1) Soil structure interaction? The foundations tilt: does this happen during the earthquake or not?
2) After the earthquake, we have aftershocks and this is important if we want to put the structure back into its original place promptly.

ANSHEL SCHIFF: Not only that. There is rocking in the transformers that we don't observe, and understand the phenomenon from secondary damage.

SECTION 4.
REMARKS AND SUMMARY

The discussions and the presentations focused on several issues related to the transformers and transformer bushings, protective systems, conductors and connectivity, and methods of design and qualification according to new acceptance criteria. In the following, the issues presented and discussed are grouped along several basic issues and were edited by the author of this report from the public discussions and presentations. Note also that these discussions and presentations took place in October of 2008; more recent research has improved the state-of-art since that time.

4.1. Transformer Bushing Behavior and Qualification Issues

The recent failures of bushings, which may have been previously qualified by current standard procedures, point toward possible flaws in the current practice. Many assumptions were made in the current practice based on engineering intuition, understanding of dynamics and of seismology. The specific issues raised are related to the following:

1. In absence of interaction with other auxiliary devices in the transformer, the dynamic properties and dynamic behavior of the bushings are dependent on the materials and the construction of the bushing first and on the transformer cover, turret and connectors to the cover, second. Moreover, the properties could be influenced by the location of the bushing, on the cover and by the structure of the cover of the transformer.

2. The bushing is excited by the motion of the rooftop/cover of the transformer tank, not directly by the ground motion. The excitation of the bushings is therefore influenced by the dynamics of the tank and its contents - core, oil and conductors - which produce translations and rotations of the rooftop/cover at selected frequencies characterizing the tank. The excitation of the bushing is therefore a modulated ground motion, amplified or damped depending on the tank dynamics. Note that the excitation of the bushings includes translations and rotations as well. Only in case of a rigid tank and rooftop/cover, the bushing is excited by a motion proportional to the ground excitation.

3. Bushings and the auxiliary equipment attached to the roof/cover of the transformer are subjected to a motion which is a result of the ground motion modified by the dynamics of the tank. The roof/cover translates and distorts, providing lateral and rotational motions at the base of the bushings, or other equipment. Current concepts of subjecting the base of the bushing to a constantly amplified ground motion (by a single constant factor over the frequency range) is erroneous, since the dynamics of the transformer may amplify or de-amplify motions with specific frequencies, which can have detrimental effect on the bushings or other equipment.

4. Participants suggested that the contribution of the oil in the tank (to damping) is expected to be significant when the bottom of the bushing is rocking inside the tank. Many participants suggested evaluating and clarifying this expectation by testing.

5. The bushings are also subjected to forces coming from the conductors connected at their tops. These forces can be a result of the dynamics of the conductors, and due to other effects as discussed further in section 4.7.

6. Modeling transformers and bushings by Finite Elements is a suitable method, but if it is not sufficiently detailed or it is too detailed, it tends to provide more questions than answers. Many manufacturers and some researchers have proprietary methods which seem successful to predict behavior in experiments. There is a need ***for more simplified and more direct methods of modeling***, which can provide the main information related to capacity and design. More explicit guidelines are needed for the FE modelers that can help to focus the analyses toward sufficient levels of detailing in order to obtain satisfactory results.

7. Most dynamic analyses use models of damping, which in most cases do not sufficiently represent reality. Equivalent viscous damping models may not be sufficient to address the energy dissipation. The *equivalent viscous damping* models may have to be revisited. Perhaps, as much as possible, damping modeling should be replaced by known hysteretic, or viscoelastic, or viscoplastic models, with a small portion of inherent damping always considered as equivalent viscous damping.

8. Bushings' construction is different, if composite materials, or porcelain, are used. Their failure modes, and their associated strength capacities are different, as well as their rigidity (or stiffness). However, these bushings act like cantilever structures, supported at the base and connected at the free end, through flexible or rigid connectors, to other equipment. The failure modes are different and thus the critical sections are different. However, the shear force or the moment causing the first failure in a critical section defines the *strength capacity of the bushing*, which is a common term (not value) for all bushings.

9. The bushings' dynamic behavior, dominated by the cantilever vibration modes is similar, and dependent on the specific bushing construction. The dynamics of these bushings is substantially affected by the fixity, or lack of it, at the base of the cantilever when mounted on the roof/cover of transformers. The thickness of the roof/cover, the location of the bushing on the roof/cover, the supports of the roof/cover near the bushing locations, in all affect the flexibility of the connection of the cantilevered bushing. The dynamic characteristics of the bushing including its connectivity to the transformer are defined by "as-installed" properties. The dynamic response of bushings is dependent on *as-installed* characteristics and not on the fixed cantilever base properties.

10. Although the differences between the "as-installed" dynamic characteristics and fixed base cantilever properties were not systematically quantified, there are evidences from prior measurements on variability of those characteristics when the same type of bushing is installed on different transformers.

11. The new design and qualification standards should consider (i) better description of the roof/cover motion; (ii) better description of "as-installed" properties of bushings; (iii) the definitions of capacity of bushings in mechanical terms - moments-shears; and (iv) better definition of the acceptance criteria in terms of demands capacity ratios.

4.2. Considering Induced Forces in Design of Transformers and Bushings

Current standards provide acceptance criteria to quantities dependent on motion characteristics such as acceleration and displacement response. Future standards may need to address the mechanical-physical quantities that represent damage. These quantities may be more sensitive. Those may be able to emphasize also the influence of protective systems. These mechanical quantities, forces, moments, torques, etc. can represent *the strength capacity of the bushings* and *the demands* due to the earthquakes and due to interaction of various components. The issues raised by the participants are listed below:

1. Failure modes are usually associated with oil leaks, cracked or broken parts, fracture of anchor bolts and/or slip of bushing components. However, for engineering purposes, these can be associated with the stress resultants, such as shear forces, bending moments or similar in the critical sections in which the damage may occur. Such mechanical quantities can represent **capacity** of bushings or other electrical systems.

2. Determining the capacity requires either analysis or testing by the manufacturer to the level of damage that renders the equipment nonfunctional. The reliable capacity can be determined using statistical evaluations, or reasonable safety factors, or both.

3. When subjecting the equipment to earthquakes or other external disturbances forces, stresses develop in critical sections, generating shear forces, bending moments or similar. These mechanical quantities, dependent on the level of shaking, the mass distributions, and the dynamics of the equipment, are defined as the **seismic demands**. These can be determined by analysis (using exact or code based methods) or by testing provided that the test bed can represent "accurately" (or close) the real conditions of in-field assembly.

4. The suitability check of the equipment should compare *the demands* with *the capacities*. While considering the usual safety factors, the system could and should be declared nonfunctional when the *demand exceeds capacity*.

5. In current practice, equivalent motion characteristics are used to represent demands and the capacities (mostly in terms of peak accelerations). These may not sufficiently represent the demands or the capacities and are definitely not the true demand-capacity ratios. Acceptance criteria (as described in (4) above) should be added to the standards of practice.

6. New experimental set-up(s) may be required for evaluation (qualification) by testing.

7. The evaluation, either by analysis or by testing, when using base isolation or other protective systems, is more sensitive than for the original systems. Therefore in such evaluations, *in addition to the geometric changes* (displacements, velocities acceleration responses) it must include the *forces and moments describing capacity and demands*.

4.3. Identified Challenges in Current Qualification and Acceptance Procedures

The current qualification procedures exaggerate the importance of the dynamic properties of equipment alone and of the ground motions transmitted at the base of the bushings. The issues are that:

1. The dynamic characterization of equipment neglects the "as-installed" conditions in evaluating the dynamic demands. This, in most cases, grossly underestimates the expected response.

2. During qualification, the equipment is subjected to the ground motions, not to the more realistic as expected (modulated) base motion of the equipment. This provides in many instances lower excitations, not sufficiently conservative for the equipment qualified.

4.4. Seismicity Considerations in the Behavior of Equipment

The near fault effect concerned most of the professionals. The cross fault effects, the fling (or velocity pulses) and the high frequencies have the tendency to influence bushings (of high frequencies) and create a wide range of frequencies otherwise. In future research, in design, in qualifications and in implementation, these effects must be considered.

4.5. Soil Structure Interaction (SSI) of Large Equipment

Concerns related to liquefaction and transformer tilting due to interaction of foundations with the surrounding soil was considered important if base isolation is considered. Apparently the SSI effects are recognized by the ASCE standards but not by IEEE 693. Such omission may have to be corrected and addressed in particular when protective systems are considered, such as base isolations.

4.6. Suggested Protective Systems

Various possibilities of protecting the equipment or its components by adding additional systems or modifying components or connectivity, were surveyed. A list of main suggestions is as follows:

1. Base isolation systems including **elastomeric supports, sliding friction systems and combinations** of other supporting materials and composite designs were suggested. Most base isolations suggested have some track record in the construction industry in particular for use in bridges, buildings, reservoirs (Liquid Natural Gas-LNG- tanks), off-shore platforms, nuclear power plants for seismic and water waves protection.

2. One of the suggested isolation systems**, friction pendulum system** (FPS) in its configurations with single, double and triple concave configurations, assures gravity load transfer as well as lateral movement with restoring capabilities. Since the dynamic characteristics are not dependent on the weight of the equipment, it provides a better base for

standardization. Prior research showed good promise. If further investigations are carried out, this system may have a good chance.

3. A new solution was proposed consisting of a series of **inclined isolators** fitting an imaginary sphere with the center at the top of the center bushing of a transformer, and large radius that establishes a small natural frequency pendulum like structure, yet having restoring capacity, was proposed by the editor of this report and two of the project participants (Filiatrault and Constantinou). The suggested solution has the advantage of keeping the top of the center bushing (almost) motionless while reducing forces in the bushings. The concept using flat sliding isolators, or elastomeric or FPS should be further analyzed and qualified, before a cost benefit analysis can be performed.

4. No base isolation could be widely accepted before a full scale **demonstration - pilot - project** will be completed. The pilot project must address severe seismicity, spatial excitations and behavior, connectivity with the other equipment, irregular construction of transformers, installation of isolation systems, service and maintenance issues, cost analyzes, etc. The idea for pilot projects has been suggested for other protective systems, indicating that research alone is not sufficient to prove the concepts and evaluate their viability.

5. Alternative protection of bushings suggested is a modification of flexibility of cantilever base connection, detuning the "as-installed" dynamic characteristics from the amplified effects of bushing's base motion. In many cases, this can be done **by stiffening** (or softening) the roof/cover of the transformer to detune the effects. The benefits of stiffening should be also evaluated from the point of view of decreased force demands that could otherwise damage the structure of the bushings. Feasibility for new designs of roof/covers and of modification of existing ones should also be evaluated as impact on cost benefit and on the interactions with the other auxiliary components.

6. Other alternatives suggested are **hybrid solutions**, including base isolations (of different types) and supplementary dampers for control of excessive displacements.

7. **Dampers** attached to the transformers and bushings were suggested, although many of the utilities and users are concerned with their maintenance and leaks, in particular if oils are involved. However, as presented by some of the proposers of devices, fluid or liquid dampers have been successfully used for four or five decades in military and aerospace equipment, without need of maintenance and malfunctions. However, a thorough documentation of the subject is needed before further considerations can be made for the electrical equipment.

8. Concerns were raised about the oil leak at the flexible bushing connection, rather than the damping device, when such devices are used.

9. A concern was raised related to the isolation of transformers and bushings associated with the increased deflections at the bottom of the bushing and issues associated with slack and electrical clearance in a confined space inside of the transformer. Such behavior, if not evaluated, may produce a disaster in the functionality of the transformer.

4.7. Implementation Issues of Base Isolation to Electrical Equipment

1. Base isolation seems to provide a global solution to protect the whole transformer system. Therefore it must address issues related to (i) the internal construction of transformers (such as the core, core connectors and clamps, conductors, oil filler, etc; (ii) external construction of the transformer tanks; (iii) the bushings and their connectors; (iv) the auxiliary equipment attached to the bushings (radiators, oil conservators, surge arresters, etc); (v) the construction of the base of the transformer and its lifting provisions.

2. Since base isolation provides a global solution, *the spatial behavior (3D*) from the ground excitation to the response of all parts must be addressed. In particular, the effects of vertical excitations and vertical response characteristics, usually neglected, should be considered with the dominant lateral effects.

3. Implementation of base isolation in existing equipment may pose additional challenges. The existing equipment was not designed to support itself in discrete points, therefore the design of the base isolation should collect the distributed weight to a new sub-base construction, or be checked to determine if the lifting points are reinforced enough to carry the weight a long time. Alternatively, the base isolation could be a distributed surface (such as a sliding-friction surface).

4. Base isolation will be affected by the transformer base construction. In many cases, a redesign of the base would be necessary, while changes or additions of anchors, rails or entire support structure must be considered. In many cases however, the base may be able to support part of the self weight, considering that it might be possible to develop simpler design.

5. The participants are concerned with the added impacts of the connectors and other parts inside the transformer tank that may influence the base motion of the bushings. In view of expected large movement when base isolation is used, such behavior should be verified first by analysis and then by testing.

4.8. Conductors in the Electrical Equipment

Conductors that link the electrical equipment to the busses and to other equipment are sources of additional loads and provide additional constraints to the movement of equipment during earthquakes. The environmental influences on the conductors, such as wind, ice, heat, and dynamic behavior, may have substantial influence on equipment. The specific issues raised are:

1. Clearances and loading of electrical conductors, either flexible or rigid, are very important in particular in short conductors. Current standards seem to provide adequate clearances and loads, which can be considered as limits in the design of protective systems.

2. When the equipment is thought to be isolated, the conductors may provide limiting constraints which cannot be satisfied by the design. As such, the conductors may become the *Achilles' heel* in the implementation of protective systems.

3. The dynamics of the conductor cables must be determined and verified, since they are sources of large loads, in particular if the slack is consumed by large movements, while the conductors must extend beyond their cord length. Subjecting the conductors to a controlled cyclic load in plane and out of plane may reveal the dynamic amplifications, accompanied by impulse load, when the conductor tries to extend beyond the cord length.

4. The dynamics are particularly important for multi-connected equipment. Impulse and damping play a significant role in the load evaluations. Current practice for qualifications by adding a fixed size mass to simulate the presence of the conductor is too simplistic and does not always represent the influence of such complex connectors. A more rational approach may be warranted.

5. If base isolation is considered, additional slack may be required. The participants are not optimistic about such an increase since the additional slack may have a detrimental influence on electromagnetic fields interactions, on ground-conductor interaction, and other local effects. The isolations may have to be designed to move equal or less deflection of bushings without isolations. An investigation is necessary.

6. Vertical drops (connecting the bus to the bushings) can develop dynamic loads which may be harmful to the bushings.

7. However, vertical drops are more tolerant to base isolations and may not provide any limitations to horizontal movement. Issue will have to be evaluated.

8. In the development of protective systems, the electrical functions must be considered as constraints which may limit functionality of the equipment. These constraints could be expressed in motion terms (displacements, velocities, accelerations) or in force terms (shears, moments, etc).

4.9. Protective Systems for Conductors - Reduction of Dynamic Effects of Conductors

Conductors can be controlled by modification of connectivity and attachment of devices that can damp the vibrations and reduce dynamic effects. Such dampers need to:

1. In-line coil or friction dampers seem to be promising.

2. Detuning conductors and equipment by smart connectors could be considered.

3. Control slack and clearance through optimization of dampers.

4. Heating of conductors may diminish efficiency of viscoelastic or fluid dampers, and friction.

4.10. Effects to be Considered as Constraints in the Development of Protective Systems

Many of the basic functions of the transformers and other equipment may be affected by heating, shorting, or other such effects. Some of these should be considered in the design providing serious limitations and constraints.

1. Electromagnetic forces develop during shorting. These forces must be addressed in the design, as part of the forces and loads demand.

2. Heating of components change material properties and produce expansion of parts accompanied by releases of pre-tensioning (clamp) forces in bushings. Heating must be considered in electrical equipment as well as in base isolations.

3. Uplift due to rocking of equipment could be allowed as long as overturning stability is satisfied. Such overturning is a constraint that should be applied to base isolations as well.

4. The failure which occurs at the smallest applied load determines the equipment strength capacity in terms of the same load.

4.11. Standardization Issues for Base Isolation and Other Protective Systems

Most electrical industry has standards of practice, which allows commercialization and use of various components and equipment without need of individualized (custom) design of each and single items installed in the substations. Based on the same approach, the industry is interested in the development of suitable standards. Several issues and questions were mentioned although no suggestions were made:

1. Which entity could assume the duties to develop a standard for base isolated equipment? The IEEE 693, or the American Society of Civil Engineers and its specialty Technical Committees could have a role, but this will be a subject for other discussion.

2. Is it going to be necessary that all base isolators will be individually designed, or is it possible to develop standard designs of classes of isolators? Such isolators could be then used "off- the-shelf." Some utilities indicated that the standards must allow the users to make their design based on their justifications.

3. Current standards of practice, such as IEEE 693, must also consider nonlinear behavior of the structural system of the electrical equipment, not only elastic behavior. Such considerations are essential for the introduction of protective systems, which experience nonlinear behavior such as base isolations and many of the viscoelastic and nonlinear dampers.

4. Some of the participants (primarily from the research community) question the focus on bushings and transformers, when the same problems may be present in other types of substation equipment, such as disconnect switches, circuit breakers, instrument transformers, etc., which may be served even better by base isolation and damping.

4.12. Risk, Reliability and Resilience of Protective Systems

The protective systems have an important temporal effect, ensuring in many cases good performance in repetitive events and providing a quick path to recovery in case of some damage. Several issues could be addressed to integrate the solution in the long term resilience of electrical equipment. The associated issues which should be further discussed are:

1. Resilient solutions for equipment itself should consider minimal damage (robust behavior) and quick recovery of functionality.

2. Resilient temporal-geospatial solutions should consider grids and networks of equipment.

3. A probabilistic framework addressing losses and recovery should be used.

4. The associated costs and monetary values would provide a good measure of economics of functionality, including direct and indirect effects on communities.

SECTION 5.
SUGGESTED FURTHER READINGS: BIBLIOGRAPHY

ABB Inc. 2004, - *Seismic Qualification of Transformer Bushing*, Report #1ZUA938501-ACA, Power Technology Products Division USA, Alamo, TN, November 2004.

Abrahamson, N., 1996. *Nonstationary Response-Spectrum Matching*, unpublished paper.

Ala Saadeghvaziri, M., Feizi, B.; Kempner, L.; Alston, D.; 2010, *On Seismic Response of Substation Equipment and Application of Base Isolation to Transformers*, *Power Delivery, IEEE Transactions on* , 25(1)177-186.

Anagnos, T., (1999) *Development of an Electrical Substation Equipment Performance Database for Evaluation of Equipment Fragilities* San Jose State University, PEER 2001/06.

Ashrafi, A., 2003 *Issues of Seismic Response and Retrofit for Critical Substation Equipment*, Master Thesis, New Jersey Institute of Technology, Newark, NJ, August.

Bellorini, S., Bettinali, F., Salvetti, M., and Zafferani, G., 1998. *Seismic qualification of transformer high voltage bushings*, IEEE Trans. Power Deliv. 13 (4), 1208–1213.

Carmona, J S. Zabala, F. Santalucia, J. Sisterna, C. 1992 *Seismic Tests of High Voltage Equipment In Argentine*. A A Balkema, Rotterdam , volume 5, pages 2811-2815.

EERI Newsletter, 1999, *The Izmit (Kocaeli), Turkey Earthquake of August 17, 1999,* 33(10), Oakland, CA.

EERI Suplement, 1995. *Northridge Earthquake Reconnaissance Report*, Vol. 1, *Earthquake Spectra*, Supplement C to Vol. 11, Oakland, CA, April.

Elliott J.J., O'Claire, D.E., Mueller, W.H., Kempner L., 2004, *Seismic Performance of 230kV Transformer Bushings,* Report on Testing, Seismic Testing and Applied Research (STAR) Laboratory, Portland State University, 2004.

Ersoy, S., Saadeghvaziri, M. Ala., (2002). *Seismic Response of Transformer-Bushing Systems*, Report to National Science Foundation, Award No. EEC-9701471.

Ersoy S., and M. A. Saadeghvaziri, (2004), *Seismic Response of Transformer-Bushing Systems*", *IEEE Transactions on Power Delivery,* Power Engineering Society, 19(1), 131-137.

Filiatrault, A. and Matt, H. (2005). "*Seismic Response of High-Voltage Transformer-Bushing Systems*." Earthquake Spectra, 21(4), 1009-1026.

Filiatrault, A. and Matt, H. (2006). "*Seismic Response of High-Voltage Transformer-Bushing Systems*." Journal of Structural Engineering, 132(2), 287-295.

Gilani, A. S. J., Chavez, J. W., Fenves, G. L., and Whittaker, A. S., (1998). "*Seismic Evaluation of 196-kV Porcelain Transformer Bushings"*, *Report No. PEER 98/02*, Pacific Earthquake Engineering Research Center, University of California at Berkeley.

Gilani, A. S. J., Whittaker, A. S and Fenves G. L, (2001), "Seismic Evaluation and Retrofit of Porcelain Transformer Bushings", *Earthquake Spectra* 17(4), 597–616.

Gilani, A. S. J., Whittaker, A. S., Fenves, G. L., and Fujisaki, E., 1999a. *Seismic evaluation of 550-kV porcelain transformer bushings*, *Report No. PEER 99/05*, Pacific Earthquake Engineering Research Center, University of California at Berkeley.

Gilani, A. S. J., Whittaker, A. S., Fenves, G. L., and Fujisaki, E., (1999), "*Seismic Evaluation and Retrofit of 230-kV Porcelain Transformer Bushings*", *Report No. PEER 99/14*, Pacific Earthquake Engineering Research Center, University of California at Berkeley.

Gilani,A., Whittaker, A., Fenves, G. , Chen, C.H., Ho H and Fujisaki, E, 2000, *Seismic Evaluation and Analysis of 230 kV Disconnect Switches Report No. PEER 00/06* Pacific Earthquake Engineering Research Center, University of California at Berkeley.

Gundy, W., (2000). *Seismic Qualification of a 230 kV Power Transformer*," Report 1018-54, W.E. Gundy & Associates, Inc., Hailey, ID.

Gundy, W., (2002). *Seismic Qualification of a 500 kV Power Transformer*, Report 1018-58, W.E. Gundy & Associates, Inc., Hailey, ID.

Institute of Electrical and Electronic Engineers (IEEE), 2006a. *IEEE Standard 693-2005, Recommended Practices for Seismic Design of Substations*, The Institute of Electrical and Electronics Engineers, Inc.3 Park Avenue, New York, NY 10016-5997, USA.

Institute of Electrical and Electronics Engineers, 2006b. *IEEE Standard 693-2005, Recommended Practices for Seismic Design of Substations*, The Institute of Electrical and Electronics Engineers, Department Copyright and Permissions, Piscataway, NJ.

Japanese Society of Civil Engineers (2001), *Dynamic Analysis and Earthquake Resistant Design (Volume 3)*. MCEER Collection.

Jonsson, Lars and Johansson, Rutger- *Perpetual Pioneering - High-Voltage Bushings - ABB* Review 3/2009, ABB Power Products, Ludvika, Sweden, March 2009 Newsletter.

Matt, H. and Filiatrault A. 2004. *Seismic Qualification Requirements for Transformer Bushings*. Report No. SSRP - 2003/12, University of California at San Diego, CA.

Matt, H., and Filiatrault, A, 2006, *Seismic Response of High Voltage Electrical Transformer–Bushing Systems*, *ASCE/Journal of Structural Engineering*, 132(2), February 1, 2006.

National Electrical Manufacturers Association (1983). *ANSI C29.9-1983 American National Standard for Wet-Process Porcelain Insulators - Apparatus, Post-Type*. New York, NY, American National Standard Institute, Inc.

Pardoen, G., Hamilton, C., and Tavares, R., 2009, *Improved Modeling of Electrical Substation Equipment for Seismic Loads*, Slides Presentation to BPA, Jan 4,. 2009, University at California at Irvine, CA.

Pierre, Jean-Robert. 1995, *Damage Caused by the Hanshin-Awaji (Kobe, Japan) Earthquake to the Electrical and Telecommunications Networks and Its Impact on the Implementation of Emergency Measures*, [Québec], Hydro-Québec, Groupe Équipement, Report RE-GEN-95-40.

Reinhorn, A.M. Oikonomou K, Roh H, Schiff A, and Kempner, L, (2010), "*Modeling and Seismic Performance Evaluation of High Voltage Transformers and Bushings*", *MCEER Technical Report –MCEER-10-00xx*, University at Buffalo – the State University of New York (*in press*).

Salvador, W., Vandeleene, J.P. (1991). "Seismic Design of Instrument Transformers."GEC Alsthom Technical Review No. 7, 55-66.

Schiff, A., Ron. O, Dennis. (1995), *Power Systems after the Northridge Earthquake: Emergency Operations and Changes in Seismic Equipment Specifications, Practice, and System Configuration*. *Monograph*, *American Society of Civil Engineers*, New York, August 1995, pages 549-556.

Schiff, A., (1997). *Guide to Post-Earthquake Investigation of Lifelines*, *Technical Council on Lifeline Earthquake Engineering*, *Monograph No. 11*, ASCE, Washington, D.C.

Schiff, A., (1997), "*Northridge Earthquake Lifeline Performance and Post Earthquake Response,*" Technical Council on Lifeline Earthquake Engineering (TCLEE), ASCE Monograph No. 8.

Schiff, A., (1998), "Hyogoken Nabu (Kobe) Earthquake of January 17, 1995 Lifeline Performance," (TCLEE), ASCE Monograph No. 14.

Schiff, A., (1999), *Guide to the Improved Earthquake Performance of Electric Power Systems.* ASCE Manuals and Reports on Engineering Practice No. 96. American Society of Civil Engineers, (A. Schiff, editor), Reston, Virginia; 341 pp.

Schiff, A., Tang A. K. (2000), "Chi Chi, Taiwan Earthquake of September 21, 1999 Lifeline Performance," (TCLEE), ASCE Monograph No. 18.

Schiff, A. and Kempner, J., (2003). *Issues and Guidance for IEEE 693 Equipment Qualification Tests*, PMI, Los Altos Hills, CA.

Schiff, A. (2007), *Seismic Qualification of Transformer/Bushing Systems,* White paper-personal communication, March 4, 2007.

Shih Chieh ,Ti Chen, Kung Ch'eng (2001) *Seismic Reliability Analysis of High-Voltage Transformer*. *World Information on Earthquake Engineering* Volume 17. MCEER Collection.

Shinozuka, M., editor. 1995. The Hanshin-Awaji earthquake of January 17, 1995: Performance of lifelines, *Report No. NCEER-95-0015*, National Center for Earthquake Engineering Research, State University of New York, Buffalo.

Sozen, H., Elwood, K., Whittaker, A. S., Mosalam, K. M., Wallace, J. W., and Stanton, J. F., 2000. Structural engineering reconnaissance of the August 17, *1999 earthquake: Kocaeli, Turkey*, *Report No. PEER 00/09*, Pacific Earthquake Engineering Research Center, University of California at Berkeley.

Togazzini, R., 2002. *Hector Mine EQ. Damage Assessment Investigation*. Los Angeles, CA, Los Angeles Department of Water and Power, Private Communication.

Villaverde R., Pardoen G.C. and Carnalla S., (2001), "*Ground Motion Amplification at Flange Level of Bushings Mounted on Electric Substation Transformers*", Earthquake Engineering and Structural Dynamics, 30(5), 621-632.

Villaverde R., Pardoen G.C. and Carnalla S., (2001), *Ground Motion Amplification at Flange Level of Bushings Mounted on Electric Substation Transformers,* Earthquake Engineering and Structural Dynamics, 30(5), 621-632.

Villaverde, R., Pardoen, G.C. and Carnalla, S., (1999). *Ground Motion Amplification at Base of Bushings Mounted on Electric Substation Transformers*, PEER/PG&E Award No. PGE-09566, University of California, Irvine, CA.

Wilcoski J. and Smith S. J., (1997), "*Fragility Testing of a Power Transformer Bushing*", CERL Technical Report 97/57, US Army Corps of Engineers, Construction Engineering Research Laboratories.

Wilcoski, J., 1998 Demonstration of CERL Equipment Fragility and Protection Procedure by Fragility Testing of a Power Transformer Bushing, *Proceedings [of the] Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components*, San Francisco. MCEER Collection.

Wilcoski, J., and Smith, S.J., 1997. *Fragility testing of a power transformer bushing*, *USACERL Technical Report 97/57*, U.S. Army Corps of Engineers Construction Engineering Research Laboratories, CERL,, Champaign, IL.

Wilcoski, J., Gambil, J. and Smith, S.J., 1997. *The CERL Equipment Fragility and Protection Procedure (CEFAPP)*. Champaign, IL, US Army Corps of Engineering. USACERL Technical Report 97/58.

APPENDIX A: Workshop Participants

IMPROVING EARTHQUAKE RESPONSE OF SUBSTATION EQUIPMENT

October 24, 2008

140 Ketter Hall ■ University at Buffalo





Sponsored by:

Bonneville Power Administration

State of California Energy Commission

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

UB

Terry Burley
Western Area Power Administration
PO Box 281213, 12155 W. Alameda Parkway
Lakewood, CO 80228
Tel: 720-962-7371; Fax: 720-962-7400
Email: aburley@wapa.gov

Cuauhtemoc Cordero
Comision Federal de Electricidad
Rio Mississippi, Piso 7
Col. Cuauhtemoc, Mexico D.F. Mexico
Tel: 52-55-5229-4400; Fax: 52-55-5220-4400
Email: cuauhtemoc.cordero@cfe.gob.mx

Michael C Constantinou* *Research Team*
University at Buffalo
132 Ketter Hall
Buffalo, NY 14260
Tel: 716-645-2469; Fax: 716-645-3733
Email: constan1@buffalo.edu

Bill Darovny *Advisory Committee*
Siemens Canada Limited
1550 Appleby Lane
Burlington ON L7L 6X7 Canada
Tel: 905-315-6868 x7343; Fax: 905-220-8192
Email: bill.darovny@siemens.com

Jean-Bernard Dastous *Advisory Committee*
IREQ/Hydro-Quebec
1800 Blvd. Lionel Boulet
Varennes PQ J3X 1S1 Canada
Tel: 450-652-8341; Fax: 450-652-8309
Email: dastous.jean-bernard@ireq.ca

Arturo Del Rio
Trench Limited
432 Monarch Avenue
Ajax ON L1S 2G7 Canada
Tel: 905-426-2665 x404
Email: arturo.delrio@trench-group.com

Lonnie Elder *Advisory Committee*
ABB Inc.
1128 S. Cavalier Drive
Alamo, TN 38001
Tel: 731-696-5326; Fax: 731-696-5318
Email: lonnie.elder@us.abb.com

Keith Ellis *Advisory Committee*
Trench Limited
641 Kingsway Drive
Old Hickory, TN 37138
Tel: 615-847-2147; Fax: 615-847-2462
Email: Keithcota@aol.com

Sohrab Esfandiari
Enova Engineering Services
39 Quail Court, Suite 100
Walnut Creek, CA 94596
Tel: 925-947-6880; Fax: 925-947-6881
Email: se@enovaengineering.com

Maria Feng *
University of California, Irvine
EG 4139 Henry Samueli School of Engineering
Irvine, CA 92697
Tel: 949-824-2162
Email: mfeng@uci.edu

Andre Filiatrault *Research Team*
University at Buffalo
134 Ketter Hall
Buffalo, NY 14260
Tel: 716-645-2114 x2434; Fax: 716-645-3733
Email: af36@buffalo.edu

Willie Freeman
ABB, Inc.
100 Distribution Circle
Mt. Pleasant, PA 15666
Tel: 724-696-1550; Fax: 724-696-1550
Email: willie.freeman@us.abb.com

Eric Fujisaki *Advisory Committee*
PG&E
1919 Webster Street, Room 283
Oakland, CA 94612
Tel: 510-874-4034; Fax: 510-874-4034
Email: emf1@pge.com

Adelana Gilpin-Jackson
BCTC Asset Program Definition
Ste. 1100, Four Bentall Centre, 1055 Dunsmuir St.
Vancouver BC V7X 1V5 Canada
Tel: 604-699-7503; Fax: 604-699-7451
Email: lana.gilpin-jackson@bctc.com

Joseph Graziano *Advisory Committee*
Tennessee Valley Authority
1101 Market Street (SP5D-C)
Chattanooga, TN 37402
Tel: 423-751-7500; Fax: 423-751-2463
Email: jagraziano@tva.gov

Bill Gundy *Advisory Committee*
W.E. Gundy & Associates
PO Box 2900
Hailey, ID 83333
Tel: 208-788-5989; Fax: 208-788-5990
Email: wegai@mindspring.com

Philip Hoby
AC Consulting Group, Ltd.
PO Box 2934
Wellington New Zealand
Tel: 64-4-472-3377; Fax: 64-4-472-3423
Email: Philiph@acconsulting.co.nz

Leon Kempner, Jr. *Research Sponsor*
Bonneville Power Administration
PO Box 61409 (TNFC-TPP3)
Vancouver, WA 98666
Tel: 360-619-6556; Fax: 360-619-6984
Email: lkempnerjr@bpa.gov

Kamran Khan
Trench Group
71 Maybrook Drive
Scarborough ON M1V 4B6 Canada
Tel: 416-298-8108 x315; Fax: 416-298-2209
Email: kamran.khan@trench-group.com

Brian Knight
Miyamoto International, Inc.
700 Washington Street, Suite 204
Vancouver, WA 98660
Tel: 360-696-9818; Fax: 360-696-9816
Email: bknight@miyamotointernational.com

Kent Martin
Transpower NZ Ltd.
09 TH, 96 The Terrace, PO Box 1021
Wellington New Zealand
Tel: 04-495-7076; Fax: 04-494-7387
Email: kent.martin@transpower.co.nz

Al Molnar
Alstom/EAD
127 Belleau Wood Boulevard
Trafford, PA 15085
Tel: 412-856-7040; Fax: 412-856-7041
Email: kbabthomas@adelphia.net

Andrei Reinhorn *Chair/Research Team*
University at Buffalo
135 Ketter Hall
Buffalo, NY 14260
Tel: 716-390-8857; Fax: 716-645-3733
Email: reinhorn@buffalo.edu

Andy Ruehs *Advisory Committee*
Waukesha Electric Systems, Inc.
400 S. Prairie Avenue
Waukesha, WI 53186
Tel: 262-547-0121 x1525; Fax: 262-524-2044
Email: andy.ruehs@waukesha.spx.com

Ala Saadeghvaziri
New Jersey Institute of Technology
260 Colton, University Heights
Newark, NJ 07102
Tel: 973-596-5813
Email: saadeghvaziri@adm.njit.edu

Anshel Schiff *Research Team*
Precision Measurement Instruments
27750 Edgerton Road
Los Altos Hills, CA 94022
Tel: 650-941-9233
Email: schiff@stanford.edu

Casey Scoggins
Tennessee Valley Authority
1101 Market Street MR4K
Chattanooga, TN 37402
Tel: 423-751-7500; Fax: 423-751-2463
Email: jcscoggins@tva.gov

George Shott
ABB, Inc.
100 Distribution Circle
Mt. Pleasant, PA 15666
Tel: 724-696-1550; Fax: 724-696-1550
Email:

Ron Tognazzini *Advisory Committee*
Tognazzini and Associates
433 N. Knapman Avenue
Sequim, WA 98382
Tel: 360-681-6010
Email: tognazzini@earthlink.net

Pedro Zazueta
Comision Federal de Electricidad
Rio Mississippi, Piso 7
Col. Cuauhtemoc, Mexico D.F. Mexico
Tel: 52-55-5229-4400; Fax: 52-55-5220-4400
Email: pedro.zazueta@cfe.gob.mx

Maria D. Cortes-Delgado *RecorderResearch Team*
University at Buffalo
212 Ketter Hall
Buffalo, NY 14260
Tel: 716-390-2114; Fax: 716-645-3733
Email: mdc24@buffalo.edu

Kostis Oikonomou *RecorderResearch Team*
University at Buffalo
212 Ketter Hall
Buffalo, NY 14260
Tel: 716-390-2114; Fax: 716-645-3733
Email: mdc24@buffalo.edu

Hwasung Roh, PhD *RecorderResearch Team*
University at Buffalo
212 Ketter Hall
Buffalo, NY 14260
Tel: 716-390-2114; Fax: 716-645-3733
Email: mdc24@buffalo.edu

Sofia Tangalos *RecorderResearch Team*
Senior Program Officer
MCEER Information Service
304 Capen Hall
Buffalo, New York 14260
Tel: (716) 645-1157; Fax: (716) 645-3399
E-mail: mailto:mceeris@mceermail.buffalo.edu
tangalos@buffalo.edu

** Participation cancelled in the last moment, however presentations were made in their behalf by moderators of specific sessions*

APPENDIX B: Workshop Agenda

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Improving Earthquake Response of Substation Equipment

October 24, 2008

140 Ketter Hall ▪ University at Buffalo

Agenda

7:30 am	**Continental Breakfast**
8:00	**Introduction** *Andrei Reinhorn, University at Buffalo, Workshop Co-Chair* *Anshel Schiff, Consultant, Workshop Co-Chair*
8:15	**Background and Formulation of Problems** *Andrei Reinhorn / Anshel Schiff* *Anshel Schiff, Precision Measurement Systems, Moderator*
8:30	**Survey of Issues Related to Transformers and Bushings: Failure Modes, History, Modeling, Proposed Qualifying Procedure for IEEE 693, etc.** *Anshel Schiff* *Leon Kempner, Bonneville Power Administration, Moderator*
9:15	**Survey Issues in Base Isolation of Transformers and Other Substation Equipment** *Ala Saadeghvaziri, New Jersey Institute of Technology* *Maria Feng, Andrei Reinhorn, Charlie Kircher - Saadeghvaziri/ Presenter* *Michael Constantinou - Reinhorn/Presenter* *Andrei M Reinhorn - University at Buffalo, Moderator*
9:45	**Survey Issues Related to Conductor Dynamics and Equipment Loading** *Jean-Bernard Dastous, IREQ/Hydro-Quebec* *Andre Filiatrault, University at Buffalo, Moderator*
10:15	*Break*
10:30	**Discussion: Base Isolation and Future Implementation** *Ala Saadeghvaziri, Moderator*
11:30	**Discussion: Cable Interaction Issues and Approaches** *Andre Filiatrault, Moderator*
12:30 pm	*Luncheon* *Tour of Structural Engineering and Earthquake Simulation Laboratory (SEESL)*
1:30	**Discussion: Special Solutions for Protection of Transformers and Bushings** *Andrei M Reinhorn, Moderator*
2:30	**Open Discussion** *Anshel Schiff, Moderator*
3:00	**Workshop Resolutions** *Andrei Reinhorn and Anshel Schiff, Moderators*
3:30	**Workshop Adjourns**

Bonneville Power Administration

REDUCING DISRUPTION OF POWER SYSTEMS IN EARTHQUAKES

ADVANCED METHODS FOR PROTECTING SUBSTATION EQUIPMENT

RESEARCH AND DEVELOPMENT PLAN

Andrei M. Reinhorn, PE, Ph.D.
Andre Filiatrault, Eng, Ph.D.
Michael Constantinou, Ph.D.
University at Buffalo, The State University of New York

Anshel Schiff, Ph.D.
Consulting Engineer
Los Altos Hills, California

MCEER
Buffalo, New York
September 15, 2008

Expected Research Tasks

1 Solicit advise and prioritize input from the electric power community

1.1 Develop a national and international advisory board including North American members to advise on issues and feasibility of implementations. The committee might be enlarged if transpacific partnerships in Japan, New Zealand and Taiwan materialize.

1.2 Organize two workshops for (i) initiation of study and (ii) midterm evaluation and monitoring potential implementations (see Task #8).

1.3 Layout plan for complimentary proposals (NSF, International-Transpacific, etc)

1.4 Engage and integrate multiple funding projects and sources (BPA, CEC, MCEER, EPRI, NSF, Utilities).

1.5 Identify manufacturers and/or utilities to donate equipment which can be used in experimental studies (bushings, protective systems, components).

2 Establish Seismic Demands on Equipment: Part 1 - Determine behavior of transformers and bushings

<First focus: high voltage transformers>
<Interaction of bushings and tank, core/coil, conservators, radiators, surge arresters,>
<Validate Proposed IEEE 693 method for seismic qualification of transformers and bushings considering in-field conditions>

2.1 Extend current static analysis modeling methods of transformers used by manufacturers to meet current IEEE 693 standard provision to considering dynamic analysis and modeling of cover and bushings.

2.2 Determine adequacy of current modeling practices used by manufacturers to capture system dynamic properties.

2.3 Perform sensitivity analysis using dynamic models to evaluate the precision needed to meet the needs of IEEE 693 standard.

2.4 Determine influence of bushing-transformer system interaction on the seismic demand on bushings.

2.5 Determine influence of variations in cover stiffness or turret design on bushing-transformer system interactions.

2.6 Estimate uncertainties of system frequencies to be incorporated into the IEEE 693 standard which influence transformer-bushings interactions.

2.7 Develop guidelines for modelers for proper considerations of the above issues

2.8 Classify limit states of functionality (such as failure modes) of transformer-bushing systems in terms of terminal pad displacements, loads on bushings, as-installed bushing frequencies or other engineering parameters.

3 Establish Seismic Demands on Equipment: Part 2 - Determine behavior of transformers-bushings-conductors in-field conditions

<Perform a combined literature search, analytical modeling, testing and evaluations>

3.1 Determine behavior of bushings in transformer installed conditions – through tests and analytical studies.

3.1.1 Determine deformations and movement limits.

3.1.2 Identify apparent functionality limits.

3.1.3 Develop simplified models o allow for quick analyses.

3.2 Determine behavior of equipment-bushings-conductor interactions – transformers, or other support structures.

3.2.1 Model and evaluate experimentally bushing terminal displacements.

3.2.2 Model and evaluate flexible conductor configuration issues (conductor shape of interconnections) including vertical drops to equipment.

3.2.3 Evaluate conductors construction issues: flexible and rigid bus.

3.2.4 Evaluate geometrical issues – initial, slacks, deformation see also UCSD and UCB studies and beyond) and equipment interaction loading.

3.2.5 Quantify conductor dynamics and equipment interaction loading.

3.2.6 Determine interaction forces and displacement demands – *design issues and criteria for IEEE 693*.

3.2.7 Determine electrical and thermal interactions issues – such as influence of electromagnetic fields.

3.3 Determine allowable maximum displacements and interaction forces (as possible constraints to design of protective systems).

3.3.1 Determine allowable interaction forces and displacements for bushings-connectors interfaces – identify good practices & make recommendations for IEEE standards.

3.3.2 Evaluate allowable interaction forces and displacements for bushings-tank connections (roof tank or turrets) – identify good practices & make recommendations for IEEE standards.

3.3.3 Define initial constraints for design of advanced protective systems.

4 Evaluate State-of-the-art of Protective Systems – Base Isolations (BI), Supplemental Damping (SD), Passive Control Systems (PCS)

4.1 Survey past and current studies of BI, SD and PCS – identify gaps in respect with sub-station equipment (for example: UC/Irvine-NJIT studies).

4.2 Evaluate models and analytical tools of protective systems – i.e. rubber and sliding properties, long term behavior, interaction issues.

4.3 Evaluate response of transformers and bushings with BI, SD and PCS.

4.4 Determine demands on bushings, conductors, connectors during three dimensional disturbances – compare to systems without protection.

4.5 Explore combinations of the above solutions and determine demands without constraints.

4.6 Determine interaction issues, interferences – displacements, forces.

4.7 Evaluate cost issues of current solutions – feasibility and constructability in new and existing facilities.

5 Identify and evaluate protective systems – Methods, Design Guidelines

<Challenges: meet current constraints from #1, #2, #3>

5.1 Develop protective solutions: i.e. base isolations and supplemental damping – flexible or sliding, with or w/o damping.

5.2 Develop cost-effective, feasible alternative for various configurations.

5.3 Validate experimentally and analytically the solutions in 5.2.

5.4 Develop design procedures and tools to enable evaluation and use of protective technologies.

5.5 Develop guidelines for design and qualifications based on the innovation and enhancement of current standards and practices used by utilities.

5.6 Identify limitations of systems, which require innovative solutions.

6 Develop, evaluate and recommend advanced protective solutions and systems

<*Challenges: suggest innovative solutions for protective systems, and constraints modifications*>
<*Methodology: modeling, proof of concept testing, analysis, design solutions*>

6.1 Evaluate in-line damping for conductor systems.

6.2 Develop, evaluate and verify new expending cable connections.

6.3 Evaluate inexpensive innovative base isolations of existing transformer tanks – hybrid solutions with displacement constraints.

6.4 Develop innovative bushing connectivity and construction (existing and new).

6.5 Evaluate retainer rings for bushing to enhance serviceability of new and existing bushings after earthquakes.

6.6 Verify developments experimentally.

6.7 Develop design procedures and specifications.

6.8 Review and propose practical methods for assessing conductor spacing criteria associated with short circuit and seismic loads.

7 Planning Full Scale Field Implementations and Monitoring

<*Challenges: identify full-scale equipment that can be base isolated, incorporate conductor connections to a dressed transformer, design and implement monitoring instrumentation*>

7.1 Identify utilities to participate in implementing base isolation of transformers and other equipment.

7.2 Identify equipment and sites; select solution from the methods researched above.

7.3 Design and implement a protective solution including equipment, connectors to first conductor support, in situ.

7.4 Develop plans for instrumentation and monitoring.

7.5 Assist implementer with design or selection of off-the-shelf solutions (instrumentation, protection, monitoring, etc).

7.6 Assist with monitoring and processing.

8 Organize workshop(s) for community input:

8.1 First workshop to be organized in conjunction with IEEE 693 committee meeting on October 24, 2008 in Buffalo.

8.1.1 Duration and components: One day (eight hours total including breaks) with two parts:

8.1.1.1 Presentations on motivation, state of the art, areas of uncertainty, and challenges.

8.1.1.2 Moderated subject discussions by experts on subjects along the task lines.

8.1.2 Outline for R&D submitted before the workshop – based on the tasks indicated above – with formulated questions and tentative resolutions.

8.1.3 Formulate and consider resolution related to research objections and needs.

8.1.4 Stirring committee: Kempner, Schiff, Filiatrault and Reinhorn.

8.1.5 Organization done by MCEER (including location, announcements, hospitality, etc.).

8.2 Second workshop to be organized in midterm of project for progress evaluation of advanced solutions and code developments.

Possible Funding:

1) Current BPA contract (modeling of transformers –current - -three months).
2) Expected CEC contract (for bushings evaluations and remedial solutions- 18 months – contracting in progress).
3) Expected BPA contract for innovative solutions for transformers and in-house /in-field monitoring - 36 months –contracting in progress).
4) Possible NEESR-GC (for innovative protective systems for electrical equipment - 48 months-to be submitted by February 2009).

Current Project Duration (including the expected contracts):

Total duration 36 months from Oct 1, 2008.

MCEER Technical Reports

MCEER publishes technical reports on a variety of subjects written by authors funded through MCEER. These reports are available from both MCEER Publications and the National Technical Information Service (NTIS). Requests for reports should be directed to MCEER Publications, MCEER, University at Buffalo, State University of New York, 133A Ketter Hall, Buffalo, New York 14260. Reports can also be requested through NTIS, P.O. Box 1425, Springfield, Virginia 22151. NTIS accession numbers are shown in parenthesis, if available.

NCEER-87-0001 "First-Year Program in Research, Education and Technology Transfer," 3/5/87, (PB88-134275, A04, MF-A01).

NCEER-87-0002 "Experimental Evaluation of Instantaneous Optimal Algorithms for Structural Control," by R.C. Lin, T.T. Soong and A.M. Reinhorn, 4/20/87, (PB88-134341, A04, MF-A01).

NCEER-87-0003 "Experimentation Using the Earthquake Simulation Facilities at University at Buffalo," by A.M. Reinhorn and R.L. Ketter, to be published.

NCEER-87-0004 "The System Characteristics and Performance of a Shaking Table," by J.S. Hwang, K.C. Chang and G.C. Lee, 6/1/87, (PB88-134259, A03, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0005 "A Finite Element Formulation for Nonlinear Viscoplastic Material Using a Q Model," by O. Gyebi and G. Dasgupta, 11/2/87, (PB88-213764, A08, MF-A01).

NCEER-87-0006 "Symbolic Manipulation Program (SMP) - Algebraic Codes for Two and Three Dimensional Finite Element Formulations," by X. Lee and G. Dasgupta, 11/9/87, (PB88-218522, A05, MF-A01).

NCEER-87-0007 "Instantaneous Optimal Control Laws for Tall Buildings Under Seismic Excitations," by J.N. Yang, A. Akbarpour and P. Ghaemmaghami, 6/10/87, (PB88-134333, A06, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0008 "IDARC: Inelastic Damage Analysis of Reinforced Concrete Frame - Shear-Wall Structures," by Y.J. Park, A.M. Reinhorn and S.K. Kunnath, 7/20/87, (PB88-134325, A09, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0009 "Liquefaction Potential for New York State: A Preliminary Report on Sites in Manhattan and Buffalo," by M. Budhu, V. Vijayakumar, R.F. Giese and L. Baumgras, 8/31/87, (PB88-163704, A03, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0010 "Vertical and Torsional Vibration of Foundations in Inhomogeneous Media," by A.S. Veletsos and K.W. Dotson, 6/1/87, (PB88-134291, A03, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0011 "Seismic Probabilistic Risk Assessment and Seismic Margins Studies for Nuclear Power Plants," by Howard H.M. Hwang, 6/15/87, (PB88-134267, A03, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0012 "Parametric Studies of Frequency Response of Secondary Systems Under Ground-Acceleration Excitations," by Y. Yong and Y.K. Lin, 6/10/87, (PB88-134309, A03, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0013 "Frequency Response of Secondary Systems Under Seismic Excitation," by J.A. HoLung, J. Cai and Y.K. Lin, 7/31/87, (PB88-134317, A05, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0014 "Modelling Earthquake Ground Motions in Seismically Active Regions Using Parametric Time Series Methods," by G.W. Ellis and A.S. Cakmak, 8/25/87, (PB88-134283, A08, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0015 "Detection and Assessment of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 8/25/87, (PB88-163712, A05, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0016 "Pipeline Experiment at Parkfield, California," by J. Isenberg and E. Richardson, 9/15/87, (PB88-163720, A03, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0017 "Digital Simulation of Seismic Ground Motion," by M. Shinozuka, G. Deodatis and T. Harada, 8/31/87, (PB88-155197, A04, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0018 "Practical Considerations for Structural Control: System Uncertainty, System Time Delay and Truncation of Small Control Forces," J.N. Yang and A. Akbarpour, 8/10/87, (PB88-163738, A08, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0019 "Modal Analysis of Nonclassically Damped Structural Systems Using Canonical Transformation," by J.N. Yang, S. Sarkani and F.X. Long, 9/27/87, (PB88-187851, A04, MF-A01).

NCEER-87-0020 "A Nonstationary Solution in Random Vibration Theory," by J.R. Red-Horse and P.D. Spanos, 11/3/87, (PB88-163746, A03, MF-A01).

NCEER-87-0021 "Horizontal Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by A.S. Veletsos and K.W. Dotson, 10/15/87, (PB88-150859, A04, MF-A01).

NCEER-87-0022 "Seismic Damage Assessment of Reinforced Concrete Members," by Y.S. Chung, C. Meyer and M. Shinozuka, 10/9/87, (PB88-150867, A05, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0023 "Active Structural Control in Civil Engineering," by T.T. Soong, 11/11/87, (PB88-187778, A03, MF-A01).

NCEER-87-0024 "Vertical and Torsional Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by K.W. Dotson and A.S. Veletsos, 12/87, (PB88-187786, A03, MF-A01).

NCEER-87-0025 "Proceedings from the Symposium on Seismic Hazards, Ground Motions, Soil-Liquefaction and Engineering Practice in Eastern North America," October 20-22, 1987, edited by K.H. Jacob, 12/87, (PB88-188115, A23, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0026 "Report on the Whittier-Narrows, California, Earthquake of October 1, 1987," by J. Pantelic and A. Reinhorn, 11/87, (PB88-187752, A03, MF-A01). This report is available only through NTIS (see address given above).

NCEER-87-0027 "Design of a Modular Program for Transient Nonlinear Analysis of Large 3-D Building Structures," by S. Srivastav and J.F. Abel, 12/30/87, (PB88-187950, A05, MF-A01). This report is only available through NTIS (see address given above).

NCEER-87-0028 "Second-Year Program in Research, Education and Technology Transfer," 3/8/88, (PB88-219480, A04, MF-A01).

NCEER-88-0001 "Workshop on Seismic Computer Analysis and Design of Buildings With Interactive Graphics," by W. McGuire, J.F. Abel and C.H. Conley, 1/18/88, (PB88-187760, A03, MF-A01). This report is only available through NTIS (see address given above).

NCEER-88-0002 "Optimal Control of Nonlinear Flexible Structures," by J.N. Yang, F.X. Long and D. Wong, 1/22/88, (PB88-213772, A06, MF-A01).

NCEER-88-0003 "Substructuring Techniques in the Time Domain for Primary-Secondary Structural Systems," by G.D. Manolis and G. Juhn, 2/10/88, (PB88-213780, A04, MF-A01).

NCEER-88-0004 "Iterative Seismic Analysis of Primary-Secondary Systems," by A. Singhal, L.D. Lutes and P.D. Spanos, 2/23/88, (PB88-213798, A04, MF-A01).

NCEER-88-0005 "Stochastic Finite Element Expansion for Random Media," by P.D. Spanos and R. Ghanem, 3/14/88, (PB88-213806, A03, MF-A01).

NCEER-88-0006 "Combining Structural Optimization and Structural Control," by F.Y. Cheng and C.P. Pantelides, 1/10/88, (PB88-213814, A05, MF-A01).

NCEER-88-0007 "Seismic Performance Assessment of Code-Designed Structures," by H.H-M. Hwang, J-W. Jaw and H-J. Shau, 3/20/88, (PB88-219423, A04, MF-A01). This report is only available through NTIS (see address given above).

NCEER-88-0008 "Reliability Analysis of Code-Designed Structures Under Natural Hazards," by H.H-M. Hwang, H. Ushiba and M. Shinozuka, 2/29/88, (PB88-229471, A07, MF-A01). This report is only available through NTIS (see address given above).

NCEER-88-0009 "Seismic Fragility Analysis of Shear Wall Structures," by J-W Jaw and H.H-M. Hwang, 4/30/88, (PB89-102867, A04, MF-A01).

NCEER-88-0010 "Base Isolation of a Multi-Story Building Under a Harmonic Ground Motion - A Comparison of Performances of Various Systems," by F-G Fan, G. Ahmadi and I.G. Tadjbakhsh, 5/18/88, (PB89-122238, A06, MF-A01). This report is only available through NTIS (see address given above).

NCEER-88-0011 "Seismic Floor Response Spectra for a Combined System by Green's Functions," by F.M. Lavelle, L.A. Bergman and P.D. Spanos, 5/1/88, (PB89-102875, A03, MF-A01).

NCEER-88-0012 "A New Solution Technique for Randomly Excited Hysteretic Structures," by G.Q. Cai and Y.K. Lin, 5/16/88, (PB89-102883, A03, MF-A01).

NCEER-88-0013 "A Study of Radiation Damping and Soil-Structure Interaction Effects in the Centrifuge," by K. Weissman, supervised by J.H. Prevost, 5/24/88, (PB89-144703, A06, MF-A01).

NCEER-88-0014 "Parameter Identification and Implementation of a Kinematic Plasticity Model for Frictional Soils," by J.H. Prevost and D.V. Griffiths, to be published.

NCEER-88-0015 "Two- and Three- Dimensional Dynamic Finite Element Analyses of the Long Valley Dam," by D.V. Griffiths and J.H. Prevost, 6/17/88, (PB89-144711, A04, MF-A01).

NCEER-88-0016 "Damage Assessment of Reinforced Concrete Structures in Eastern United States," by A.M. Reinhorn, M.J. Seidel, S.K. Kunnath and Y.J. Park, 6/15/88, (PB89-122220, A04, MF-A01). This report is only available through NTIS (see address given above).

NCEER-88-0017 "Dynamic Compliance of Vertically Loaded Strip Foundations in Multilayered Viscoelastic Soils," by S. Ahmad and A.S.M. Israil, 6/17/88, (PB89-102891, A04, MF-A01).

NCEER-88-0018 "An Experimental Study of Seismic Structural Response With Added Viscoelastic Dampers," by R.C. Lin, Z. Liang, T.T. Soong and R.H. Zhang, 6/30/88, (PB89-122212, A05, MF-A01). This report is available only through NTIS (see address given above).

NCEER-88-0019 "Experimental Investigation of Primary - Secondary System Interaction," by G.D. Manolis, G. Juhn and A.M. Reinhorn, 5/27/88, (PB89-122204, A04, MF-A01).

NCEER-88-0020 "A Response Spectrum Approach For Analysis of Nonclassically Damped Structures," by J.N. Yang, S. Sarkani and F.X. Long, 4/22/88, (PB89-102909, A04, MF-A01).

NCEER-88-0021 "Seismic Interaction of Structures and Soils: Stochastic Approach," by A.S. Veletsos and A.M. Prasad, 7/21/88, (PB89-122196, A04, MF-A01). This report is only available through NTIS (see address given above).

NCEER-88-0022 "Identification of the Serviceability Limit State and Detection of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 6/15/88, (PB89-122188, A05, MF-A01). This report is available only through NTIS (see address given above).

NCEER-88-0023 "Multi-Hazard Risk Analysis: Case of a Simple Offshore Structure," by B.K. Bhartia and E.H. Vanmarcke, 7/21/88, (PB89-145213, A05, MF-A01).

NCEER-88-0024 "Automated Seismic Design of Reinforced Concrete Buildings," by Y.S. Chung, C. Meyer and M. Shinozuka, 7/5/88, (PB89-122170, A06, MF-A01). This report is available only through NTIS (see address given above).

NCEER-88-0025 "Experimental Study of Active Control of MDOF Structures Under Seismic Excitations," by L.L. Chung, R.C. Lin, T.T. Soong and A.M. Reinhorn, 7/10/88, (PB89-122600, A04, MF-A01).

NCEER-88-0026 "Earthquake Simulation Tests of a Low-Rise Metal Structure," by J.S. Hwang, K.C. Chang, G.C. Lee and R.L. Ketter, 8/1/88, (PB89-102917, A04, MF-A01).

NCEER-88-0027 "Systems Study of Urban Response and Reconstruction Due to Catastrophic Earthquakes," by F. Kozin and H.K. Zhou, 9/22/88, (PB90-162348, A04, MF-A01).

NCEER-88-0028 "Seismic Fragility Analysis of Plane Frame Structures," by H.H-M. Hwang and Y.K. Low, 7/31/88, (PB89-131445, A06, MF-A01).

NCEER-88-0029 "Response Analysis of Stochastic Structures," by A. Kardara, C. Bucher and M. Shinozuka, 9/22/88, (PB89-174429, A04, MF-A01).

NCEER-88-0030 "Nonnormal Accelerations Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 9/19/88, (PB89-131437, A04, MF-A01).

NCEER-88-0031 "Design Approaches for Soil-Structure Interaction," by A.S. Veletsos, A.M. Prasad and Y. Tang, 12/30/88, (PB89-174437, A03, MF-A01). This report is available only through NTIS (see address given above).

NCEER-88-0032 "A Re-evaluation of Design Spectra for Seismic Damage Control," by C.J. Turkstra and A.G. Tallin, 11/7/88, (PB89-145221, A05, MF-A01).

NCEER-88-0033 "The Behavior and Design of Noncontact Lap Splices Subjected to Repeated Inelastic Tensile Loading," by V.E. Sagan, P. Gergely and R.N. White, 12/8/88, (PB89-163737, A08, MF-A01).

NCEER-88-0034 "Seismic Response of Pile Foundations," by S.M. Mamoon, P.K. Banerjee and S. Ahmad, 11/1/88, (PB89-145239, A04, MF-A01).

NCEER-88-0035 "Modeling of R/C Building Structures With Flexible Floor Diaphragms (IDARC2)," by A.M. Reinhorn, S.K. Kunnath and N. Panahshahi, 9/7/88, (PB89-207153, A07, MF-A01).

NCEER-88-0036 "Solution of the Dam-Reservoir Interaction Problem Using a Combination of FEM, BEM with Particular Integrals, Modal Analysis, and Substructuring," by C-S. Tsai, G.C. Lee and R.L. Ketter, 12/31/88, (PB89-207146, A04, MF-A01).

NCEER-88-0037 "Optimal Placement of Actuators for Structural Control," by F.Y. Cheng and C.P. Pantelides, 8/15/88, (PB89-162846, A05, MF-A01).

NCEER-88-0038 "Teflon Bearings in Aseismic Base Isolation: Experimental Studies and Mathematical Modeling," by A. Mokha, M.C. Constantinou and A.M. Reinhorn, 12/5/88, (PB89-218457, A10, MF-A01). This report is available only through NTIS (see address given above).

NCEER-88-0039 "Seismic Behavior of Flat Slab High-Rise Buildings in the New York City Area," by P. Weidlinger and M. Ettouney, 10/15/88, (PB90-145681, A04, MF-A01).

NCEER-88-0040 "Evaluation of the Earthquake Resistance of Existing Buildings in New York City," by P. Weidlinger and M. Ettouney, 10/15/88, to be published.

NCEER-88-0041 "Small-Scale Modeling Techniques for Reinforced Concrete Structures Subjected to Seismic Loads," by W. Kim, A. El-Attar and R.N. White, 11/22/88, (PB89-189625, A05, MF-A01).

NCEER-88-0042 "Modeling Strong Ground Motion from Multiple Event Earthquakes," by G.W. Ellis and A.S. Cakmak, 10/15/88, (PB89-174445, A03, MF-A01).

NCEER-88-0043 "Nonstationary Models of Seismic Ground Acceleration," by M. Grigoriu, S.E. Ruiz and E. Rosenblueth, 7/15/88, (PB89-189617, A04, MF-A01).

NCEER-88-0044 "SARCF User's Guide: Seismic Analysis of Reinforced Concrete Frames," by Y.S. Chung, C. Meyer and M. Shinozuka, 11/9/88, (PB89-174452, A08, MF-A01).

NCEER-88-0045 "First Expert Panel Meeting on Disaster Research and Planning," edited by J. Pantelic and J. Stoyle, 9/15/88, (PB89-174460, A05, MF-A01).

NCEER-88-0046 "Preliminary Studies of the Effect of Degrading Infill Walls on the Nonlinear Seismic Response of Steel Frames," by C.Z. Chrysostomou, P. Gergely and J.F. Abel, 12/19/88, (PB89-208383, A05, MF-A01).

NCEER-88-0047 "Reinforced Concrete Frame Component Testing Facility - Design, Construction, Instrumentation and Operation," by S.P. Pessiki, C. Conley, T. Bond, P. Gergely and R.N. White, 12/16/88, (PB89-174478, A04, MF-A01).

NCEER-89-0001 "Effects of Protective Cushion and Soil Compliancy on the Response of Equipment Within a Seismically Excited Building," by J.A. HoLung, 2/16/89, (PB89-207179, A04, MF-A01).

NCEER-89-0002 "Statistical Evaluation of Response Modification Factors for Reinforced Concrete Structures," by H.H-M. Hwang and J-W. Jaw, 2/17/89, (PB89-207187, A05, MF-A01).

NCEER-89-0003 "Hysteretic Columns Under Random Excitation," by G-Q. Cai and Y.K. Lin, 1/9/89, (PB89-196513, A03, MF-A01).

NCEER-89-0004 "Experimental Study of `Elephant Foot Bulge' Instability of Thin-Walled Metal Tanks," by Z-H. Jia and R.L. Ketter, 2/22/89, (PB89-207195, A03, MF-A01).

NCEER-89-0005 "Experiment on Performance of Buried Pipelines Across San Andreas Fault," by J. Isenberg, E. Richardson and T.D. O'Rourke, 3/10/89, (PB89-218440, A04, MF-A01). This report is available only through NTIS (see address given above).

NCEER-89-0006 "A Knowledge-Based Approach to Structural Design of Earthquake-Resistant Buildings," by M. Subramani, P. Gergely, C.H. Conley, J.F. Abel and A.H. Zaghw, 1/15/89, (PB89-218465, A06, MF-A01).

NCEER-89-0007 "Liquefaction Hazards and Their Effects on Buried Pipelines," by T.D. O'Rourke and P.A. Lane, 2/1/89, (PB89-218481, A09, MF-A01).

NCEER-89-0008 "Fundamentals of System Identification in Structural Dynamics," by H. Imai, C-B. Yun, O. Maruyama and M. Shinozuka, 1/26/89, (PB89-207211, A04, MF-A01).

NCEER-89-0009 "Effects of the 1985 Michoacan Earthquake on Water Systems and Other Buried Lifelines in Mexico," by A.G. Ayala and M.J. O'Rourke, 3/8/89, (PB89-207229, A06, MF-A01).

NCEER-89-R010 "NCEER Bibliography of Earthquake Education Materials," by K.E.K. Ross, Second Revision, 9/1/89, (PB90-125352, A05, MF-A01). This report is replaced by NCEER-92-0018.

NCEER-89-0011 "Inelastic Three-Dimensional Response Analysis of Reinforced Concrete Building Structures (IDARC-3D), Part I - Modeling," by S.K. Kunnath and A.M. Reinhorn, 4/17/89, (PB90-114612, A07, MF-A01). This report is available only through NTIS (see address given above).

NCEER-89-0012 "Recommended Modifications to ATC-14," by C.D. Poland and J.O. Malley, 4/12/89, (PB90-108648, A15, MF-A01).

NCEER-89-0013 "Repair and Strengthening of Beam-to-Column Connections Subjected to Earthquake Loading," by M. Corazao and A.J. Durrani, 2/28/89, (PB90-109885, A06, MF-A01).

NCEER-89-0014 "Program EXKAL2 for Identification of Structural Dynamic Systems," by O. Maruyama, C-B. Yun, M. Hoshiya and M. Shinozuka, 5/19/89, (PB90-109877, A09, MF-A01).

NCEER-89-0015 "Response of Frames With Bolted Semi-Rigid Connections, Part I - Experimental Study and Analytical Predictions," by P.J. DiCorso, A.M. Reinhorn, J.R. Dickerson, J.B. Radziminski and W.L. Harper, 6/1/89, to be published.

NCEER-89-0016 "ARMA Monte Carlo Simulation in Probabilistic Structural Analysis," by P.D. Spanos and M.P. Mignolet, 7/10/89, (PB90-109893, A03, MF-A01).

NCEER-89-P017 "Preliminary Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 6/23/89, (PB90-108606, A03, MF-A01).

NCEER-89-0017 "Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 12/31/89, (PB90-207895, A012, MF-A02). This report is available only through NTIS (see address given above).

NCEER-89-0018 "Multidimensional Models of Hysteretic Material Behavior for Vibration Analysis of Shape Memory Energy Absorbing Devices, by E.J. Graesser and F.A. Cozzarelli, 6/7/89, (PB90-164146, A04, MF-A01).

NCEER-89-0019 "Nonlinear Dynamic Analysis of Three-Dimensional Base Isolated Structures (3D-BASIS)," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 8/3/89, (PB90-161936, A06, MF-A01). This report has been replaced by NCEER-93-0011.

NCEER-89-0020 "Structural Control Considering Time-Rate of Control Forces and Control Rate Constraints," by F.Y. Cheng and C.P. Pantelides, 8/3/89, (PB90-120445, A04, MF-A01).

NCEER-89-0021 "Subsurface Conditions of Memphis and Shelby County," by K.W. Ng, T-S. Chang and H-H.M. Hwang, 7/26/89, (PB90-120437, A03, MF-A01).

NCEER-89-0022 "Seismic Wave Propagation Effects on Straight Jointed Buried Pipelines," by K. Elhmadi and M.J. O'Rourke, 8/24/89, (PB90-162322, A10, MF-A02).

NCEER-89-0023 "Workshop on Serviceability Analysis of Water Delivery Systems," edited by M. Grigoriu, 3/6/89, (PB90-127424, A03, MF-A01).

NCEER-89-0024 "Shaking Table Study of a 1/5 Scale Steel Frame Composed of Tapered Members," by K.C. Chang, J.S. Hwang and G.C. Lee, 9/18/89, (PB90-160169, A04, MF-A01).

NCEER-89-0025 "DYNA1D: A Computer Program for Nonlinear Seismic Site Response Analysis - Technical Documentation," by Jean H. Prevost, 9/14/89, (PB90-161944, A07, MF-A01). This report is available only through NTIS (see address given above).

NCEER-89-0026 "1:4 Scale Model Studies of Active Tendon Systems and Active Mass Dampers for Aseismic Protection," by A.M. Reinhorn, T.T. Soong, R.C. Lin, Y.P. Yang, Y. Fukao, H. Abe and M. Nakai, 9/15/89, (PB90-173246, A10, MF-A02). This report is available only through NTIS (see address given above).

NCEER-89-0027 "Scattering of Waves by Inclusions in a Nonhomogeneous Elastic Half Space Solved by Boundary Element Methods," by P.K. Hadley, A. Askar and A.S. Cakmak, 6/15/89, (PB90-145699, A07, MF-A01).

NCEER-89-0028 "Statistical Evaluation of Deflection Amplification Factors for Reinforced Concrete Structures," by H.H.M. Hwang, J-W. Jaw and A.L. Ch'ng, 8/31/89, (PB90-164633, A05, MF-A01).

NCEER-89-0029 "Bedrock Accelerations in Memphis Area Due to Large New Madrid Earthquakes," by H.H.M. Hwang, C.H.S. Chen and G. Yu, 11/7/89, (PB90-162330, A04, MF-A01).

NCEER-89-0030 "Seismic Behavior and Response Sensitivity of Secondary Structural Systems," by Y.Q. Chen and T.T. Soong, 10/23/89, (PB90-164658, A08, MF-A01).

NCEER-89-0031 "Random Vibration and Reliability Analysis of Primary-Secondary Structural Systems," by Y. Ibrahim, M. Grigoriu and T.T. Soong, 11/10/89, (PB90-161951, A04, MF-A01).

NCEER-89-0032 "Proceedings from the Second U.S. - Japan Workshop on Liquefaction, Large Ground Deformation and Their Effects on Lifelines, September 26-29, 1989," Edited by T.D. O'Rourke and M. Hamada, 12/1/89, (PB90-209388, A22, MF-A03).

NCEER-89-0033 "Deterministic Model for Seismic Damage Evaluation of Reinforced Concrete Structures," by J.M. Bracci, A.M. Reinhorn, J.B. Mander and S.K. Kunnath, 9/27/89, (PB91-108803, A06, MF-A01).

NCEER-89-0034 "On the Relation Between Local and Global Damage Indices," by E. DiPasquale and A.S. Cakmak, 8/15/89, (PB90-173865, A05, MF-A01).

NCEER-89-0035 "Cyclic Undrained Behavior of Nonplastic and Low Plasticity Silts," by A.J. Walker and H.E. Stewart, 7/26/89, (PB90-183518, A10, MF-A01).

NCEER-89-0036 "Liquefaction Potential of Surficial Deposits in the City of Buffalo, New York," by M. Budhu, R. Giese and L. Baumgrass, 1/17/89, (PB90-208455, A04, MF-A01).

NCEER-89-0037 "A Deterministic Assessment of Effects of Ground Motion Incoherence," by A.S. Veletsos and Y. Tang, 7/15/89, (PB90-164294, A03, MF-A01).

NCEER-89-0038 "Workshop on Ground Motion Parameters for Seismic Hazard Mapping," July 17-18, 1989, edited by R.V. Whitman, 12/1/89, (PB90-173923, A04, MF-A01).

NCEER-89-0039 "Seismic Effects on Elevated Transit Lines of the New York City Transit Authority," by C.J. Costantino, C.A. Miller and E. Heymsfield, 12/26/89, (PB90-207887, A06, MF-A01).

NCEER-89-0040 "Centrifugal Modeling of Dynamic Soil-Structure Interaction," by K. Weissman, Supervised by J.H. Prevost, 5/10/89, (PB90-207879, A07, MF-A01).

NCEER-89-0041 "Linearized Identification of Buildings With Cores for Seismic Vulnerability Assessment," by I-K. Ho and A.E. Aktan, 11/1/89, (PB90-251943, A07, MF-A01).

NCEER-90-0001 "Geotechnical and Lifeline Aspects of the October 17, 1989 Loma Prieta Earthquake in San Francisco," by T.D. O'Rourke, H.E. Stewart, F.T. Blackburn and T.S. Dickerman, 1/90, (PB90-208596, A05, MF-A01).

NCEER-90-0002 "Nonnormal Secondary Response Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 2/28/90, (PB90-251976, A07, MF-A01).

NCEER-90-0003 "Earthquake Education Materials for Grades K-12," by K.E.K. Ross, 4/16/90, (PB91-251984, A05, MF-A05). This report has been replaced by NCEER-92-0018.

NCEER-90-0004 "Catalog of Strong Motion Stations in Eastern North America," by R.W. Busby, 4/3/90, (PB90-251984, A05, MF-A01).

NCEER-90-0005 "NCEER Strong-Motion Data Base: A User Manual for the GeoBase Release (Version 1.0 for the Sun3)," by P. Friberg and K. Jacob, 3/31/90 (PB90-258062, A04, MF-A01).

NCEER-90-0006 "Seismic Hazard Along a Crude Oil Pipeline in the Event of an 1811-1812 Type New Madrid Earthquake," by H.H.M. Hwang and C-H.S. Chen, 4/16/90, (PB90-258054, A04, MF-A01).

NCEER-90-0007 "Site-Specific Response Spectra for Memphis Sheahan Pumping Station," by H.H.M. Hwang and C.S. Lee, 5/15/90, (PB91-108811, A05, MF-A01).

NCEER-90-0008 "Pilot Study on Seismic Vulnerability of Crude Oil Transmission Systems," by T. Ariman, R. Dobry, M. Grigoriu, F. Kozin, M. O'Rourke, T. O'Rourke and M. Shinozuka, 5/25/90, (PB91-108837, A06, MF-A01).

NCEER-90-0009 "A Program to Generate Site Dependent Time Histories: EQGEN," by G.W. Ellis, M. Srinivasan and A.S. Cakmak, 1/30/90, (PB91-108829, A04, MF-A01).

NCEER-90-0010 "Active Isolation for Seismic Protection of Operating Rooms," by M.E. Talbott, Supervised by M. Shinozuka, 6/8/9, (PB91-110205, A05, MF-A01).

NCEER-90-0011 "Program LINEARID for Identification of Linear Structural Dynamic Systems," by C-B. Yun and M. Shinozuka, 6/25/90, (PB91-110312, A08, MF-A01).

NCEER-90-0012 "Two-Dimensional Two-Phase Elasto-Plastic Seismic Response of Earth Dams," by A.N. Yiagos, Supervised by J.H. Prevost, 6/20/90, (PB91-110197, A13, MF-A02).

NCEER-90-0013 "Secondary Systems in Base-Isolated Structures: Experimental Investigation, Stochastic Response and Stochastic Sensitivity," by G.D. Manolis, G. Juhn, M.C. Constantinou and A.M. Reinhorn, 7/1/90, (PB91-110320, A08, MF-A01).

NCEER-90-0014 "Seismic Behavior of Lightly-Reinforced Concrete Column and Beam-Column Joint Details," by S.P. Pessiki, C.H. Conley, P. Gergely and R.N. White, 8/22/90, (PB91-108795, A11, MF-A02).

NCEER-90-0015 "Two Hybrid Control Systems for Building Structures Under Strong Earthquakes," by J.N. Yang and A. Danielians, 6/29/90, (PB91-125393, A04, MF-A01).

NCEER-90-0016 "Instantaneous Optimal Control with Acceleration and Velocity Feedback," by J.N. Yang and Z. Li, 6/29/90, (PB91-125401, A03, MF-A01).

NCEER-90-0017 "Reconnaissance Report on the Northern Iran Earthquake of June 21, 1990," by M. Mehrain, 10/4/90, (PB91-125377, A03, MF-A01).

NCEER-90-0018 "Evaluation of Liquefaction Potential in Memphis and Shelby County," by T.S. Chang, P.S. Tang, C.S. Lee and H. Hwang, 8/10/90, (PB91-125427, A09, MF-A01).

NCEER-90-0019 "Experimental and Analytical Study of a Combined Sliding Disc Bearing and Helical Steel Spring Isolation System," by M.C. Constantinou, A.S. Mokha and A.M. Reinhorn, 10/4/90, (PB91-125385, A06, MF-A01). This report is available only through NTIS (see address given above).

NCEER-90-0020 "Experimental Study and Analytical Prediction of Earthquake Response of a Sliding Isolation System with a Spherical Surface," by A.S. Mokha, M.C. Constantinou and A.M. Reinhorn, 10/11/90, (PB91-125419, A05, MF-A01).

NCEER-90-0021 "Dynamic Interaction Factors for Floating Pile Groups," by G. Gazetas, K. Fan, A. Kaynia and E. Kausel, 9/10/90, (PB91-170381, A05, MF-A01).

NCEER-90-0022 "Evaluation of Seismic Damage Indices for Reinforced Concrete Structures," by S. Rodriguez-Gomez and A.S. Cakmak, 9/30/90, PB91-171322, A06, MF-A01).

NCEER-90-0023 "Study of Site Response at a Selected Memphis Site," by H. Desai, S. Ahmad, E.S. Gazetas and M.R. Oh, 10/11/90, (PB91-196857, A03, MF-A01).

NCEER-90-0024 "A User's Guide to Strongmo: Version 1.0 of NCEER's Strong-Motion Data Access Tool for PCs and Terminals," by P.A. Friberg and C.A.T. Susch, 11/15/90, (PB91-171272, A03, MF-A01).

NCEER-90-0025 "A Three-Dimensional Analytical Study of Spatial Variability of Seismic Ground Motions," by L-L. Hong and A.H.-S. Ang, 10/30/90, (PB91-170399, A09, MF-A01).

NCEER-90-0026 "MUMOID User's Guide - A Program for the Identification of Modal Parameters," by S. Rodriguez-Gomez and E. DiPasquale, 9/30/90, (PB91-171298, A04, MF-A01).

NCEER-90-0027 "SARCF-II User's Guide - Seismic Analysis of Reinforced Concrete Frames," by S. Rodriguez-Gomez, Y.S. Chung and C. Meyer, 9/30/90, (PB91-171280, A05, MF-A01).

NCEER-90-0028 "Viscous Dampers: Testing, Modeling and Application in Vibration and Seismic Isolation," by N. Makris and M.C. Constantinou, 12/20/90 (PB91-190561, A06, MF-A01).

NCEER-90-0029 "Soil Effects on Earthquake Ground Motions in the Memphis Area," by H. Hwang, C.S. Lee, K.W. Ng and T.S. Chang, 8/2/90, (PB91-190751, A05, MF-A01).

NCEER-91-0001 "Proceedings from the Third Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures for Soil Liquefaction, December 17-19, 1990," edited by T.D. O'Rourke and M. Hamada, 2/1/91, (PB91-179259, A99, MF-A04).

NCEER-91-0002 "Physical Space Solutions of Non-Proportionally Damped Systems," by M. Tong, Z. Liang and G.C. Lee, 1/15/91, (PB91-179242, A04, MF-A01).

NCEER-91-0003 "Seismic Response of Single Piles and Pile Groups," by K. Fan and G. Gazetas, 1/10/91, (PB92-174994, A04, MF-A01).

NCEER-91-0004 "Damping of Structures: Part 1 - Theory of Complex Damping," by Z. Liang and G. Lee, 10/10/91, (PB92-197235, A12, MF-A03).

NCEER-91-0005 "3D-BASIS - Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures: Part II," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 2/28/91, (PB91-190553, A07, MF-A01). This report has been replaced by NCEER-93-0011.

NCEER-91-0006 "A Multidimensional Hysteretic Model for Plasticity Deforming Metals in Energy Absorbing Devices," by E.J. Graesser and F.A. Cozzarelli, 4/9/91, (PB92-108364, A04, MF-A01).

NCEER-91-0007 "A Framework for Customizable Knowledge-Based Expert Systems with an Application to a KBES for Evaluating the Seismic Resistance of Existing Buildings," by E.G. Ibarra-Anaya and S.J. Fenves, 4/9/91, (PB91-210930, A08, MF-A01).

NCEER-91-0008 "Nonlinear Analysis of Steel Frames with Semi-Rigid Connections Using the Capacity Spectrum Method," by G.G. Deierlein, S-H. Hsieh, Y-J. Shen and J.F. Abel, 7/2/91, (PB92-113828, A05, MF-A01).

NCEER-91-0009 "Earthquake Education Materials for Grades K-12," by K.E.K. Ross, 4/30/91, (PB91-212142, A06, MF-A01). This report has been replaced by NCEER-92-0018.

NCEER-91-0010 "Phase Wave Velocities and Displacement Phase Differences in a Harmonically Oscillating Pile," by N. Makris and G. Gazetas, 7/8/91, (PB92-108356, A04, MF-A01).

NCEER-91-0011 "Dynamic Characteristics of a Full-Size Five-Story Steel Structure and a 2/5 Scale Model," by K.C. Chang, G.C. Yao, G.C. Lee, D.S. Hao and Y.C. Yeh," 7/2/91, (PB93-116648, A06, MF-A02).

NCEER-91-0012 "Seismic Response of a 2/5 Scale Steel Structure with Added Viscoelastic Dampers," by K.C. Chang, T.T. Soong, S-T. Oh and M.L. Lai, 5/17/91, (PB92-110816, A05, MF-A01).

NCEER-91-0013 "Earthquake Response of Retaining Walls; Full-Scale Testing and Computational Modeling," by S. Alampalli and A-W.M. Elgamal, 6/20/91, to be published.

NCEER-91-0014 "3D-BASIS-M: Nonlinear Dynamic Analysis of Multiple Building Base Isolated Structures," by P.C. Tsopelas, S. Nagarajaiah, M.C. Constantinou and A.M. Reinhorn, 5/28/91, (PB92-113885, A09, MF-A02).

NCEER-91-0015 "Evaluation of SEAOC Design Requirements for Sliding Isolated Structures," by D. Theodossiou and M.C. Constantinou, 6/10/91, (PB92-114602, A11, MF-A03).

NCEER-91-0016 "Closed-Loop Modal Testing of a 27-Story Reinforced Concrete Flat Plate-Core Building," by H.R. Somaprasad, T. Toksoy, H. Yoshiyuki and A.E. Aktan, 7/15/91, (PB92-129980, A07, MF-A02).

NCEER-91-0017 "Shake Table Test of a 1/6 Scale Two-Story Lightly Reinforced Concrete Building," by A.G. El-Attar, R.N. White and P. Gergely, 2/28/91, (PB92-222447, A06, MF-A02).

NCEER-91-0018 "Shake Table Test of a 1/8 Scale Three-Story Lightly Reinforced Concrete Building," by A.G. El-Attar, R.N. White and P. Gergely, 2/28/91, (PB93-116630, A08, MF-A02).

NCEER-91-0019 "Transfer Functions for Rigid Rectangular Foundations," by A.S. Veletsos, A.M. Prasad and W.H. Wu, 7/31/91, to be published.

NCEER-91-0020 "Hybrid Control of Seismic-Excited Nonlinear and Inelastic Structural Systems," by J.N. Yang, Z. Li and A. Danielians, 8/1/91, (PB92-143171, A06, MF-A02).

NCEER-91-0021 "The NCEER-91 Earthquake Catalog: Improved Intensity-Based Magnitudes and Recurrence Relations for U.S. Earthquakes East of New Madrid," by L. Seeber and J.G. Armbruster, 8/28/91, (PB92-176742, A06, MF-A02).

NCEER-91-0022 "Proceedings from the Implementation of Earthquake Planning and Education in Schools: The Need for Change - The Roles of the Changemakers," by K.E.K. Ross and F. Winslow, 7/23/91, (PB92-129998, A12, MF-A03).

NCEER-91-0023 "A Study of Reliability-Based Criteria for Seismic Design of Reinforced Concrete Frame Buildings," by H.H.M. Hwang and H-M. Hsu, 8/10/91, (PB92-140235, A09, MF-A02).

NCEER-91-0024 "Experimental Verification of a Number of Structural System Identification Algorithms," by R.G. Ghanem, H. Gavin and M. Shinozuka, 9/18/91, (PB92-176577, A18, MF-A04).

NCEER-91-0025 "Probabilistic Evaluation of Liquefaction Potential," by H.H.M. Hwang and C.S. Lee," 11/25/91, (PB92-143429, A05, MF-A01).

NCEER-91-0026 "Instantaneous Optimal Control for Linear, Nonlinear and Hysteretic Structures - Stable Controllers," by J.N. Yang and Z. Li, 11/15/91, (PB92-163807, A04, MF-A01).

NCEER-91-0027 "Experimental and Theoretical Study of a Sliding Isolation System for Bridges," by M.C. Constantinou, A. Kartoum, A.M. Reinhorn and P. Bradford, 11/15/91, (PB92-176973, A10, MF-A03).

NCEER-92-0001 "Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes, Volume 1: Japanese Case Studies," Edited by M. Hamada and T. O'Rourke, 2/17/92, (PB92-197243, A18, MF-A04).

NCEER-92-0002 "Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes, Volume 2: United States Case Studies," Edited by T. O'Rourke and M. Hamada, 2/17/92, (PB92-197250, A20, MF-A04).

NCEER-92-0003 "Issues in Earthquake Education," Edited by K. Ross, 2/3/92, (PB92-222389, A07, MF-A02).

NCEER-92-0004 "Proceedings from the First U.S. - Japan Workshop on Earthquake Protective Systems for Bridges," Edited by I.G. Buckle, 2/4/92, (PB94-142239, A99, MF-A06).

NCEER-92-0005 "Seismic Ground Motion from a Haskell-Type Source in a Multiple-Layered Half-Space," A.P. Theoharis, G. Deodatis and M. Shinozuka, 1/2/92, to be published.

NCEER-92-0006 "Proceedings from the Site Effects Workshop," Edited by R. Whitman, 2/29/92, (PB92-197201, A04, MF-A01).

NCEER-92-0007 "Engineering Evaluation of Permanent Ground Deformations Due to Seismically-Induced Liquefaction," by M.H. Baziar, R. Dobry and A-W.M. Elgamal, 3/24/92, (PB92-222421, A13, MF-A03).

NCEER-92-0008 "A Procedure for the Seismic Evaluation of Buildings in the Central and Eastern United States," by C.D. Poland and J.O. Malley, 4/2/92, (PB92-222439, A20, MF-A04).

NCEER-92-0009 "Experimental and Analytical Study of a Hybrid Isolation System Using Friction Controllable Sliding Bearings," by M.Q. Feng, S. Fujii and M. Shinozuka, 5/15/92, (PB93-150282, A06, MF-A02).

NCEER-92-0010 "Seismic Resistance of Slab-Column Connections in Existing Non-Ductile Flat-Plate Buildings," by A.J. Durrani and Y. Du, 5/18/92, (PB93-116812, A06, MF-A02).

NCEER-92-0011 "The Hysteretic and Dynamic Behavior of Brick Masonry Walls Upgraded by Ferrocement Coatings Under Cyclic Loading and Strong Simulated Ground Motion," by H. Lee and S.P. Prawel, 5/11/92, to be published.

NCEER-92-0012 "Study of Wire Rope Systems for Seismic Protection of Equipment in Buildings," by G.F. Demetriades, M.C. Constantinou and A.M. Reinhorn, 5/20/92, (PB93-116655, A08, MF-A02).

NCEER-92-0013 "Shape Memory Structural Dampers: Material Properties, Design and Seismic Testing," by P.R. Witting and F.A. Cozzarelli, 5/26/92, (PB93-116663, A05, MF-A01).

NCEER-92-0014 "Longitudinal Permanent Ground Deformation Effects on Buried Continuous Pipelines," by M.J. O'Rourke, and C. Nordberg, 6/15/92, (PB93-116671, A08, MF-A02).

NCEER-92-0015 "A Simulation Method for Stationary Gaussian Random Functions Based on the Sampling Theorem," by M. Grigoriu and S. Balopoulou, 6/11/92, (PB93-127496, A05, MF-A01).

NCEER-92-0016 "Gravity-Load-Designed Reinforced Concrete Buildings: Seismic Evaluation of Existing Construction and Detailing Strategies for Improved Seismic Resistance," by G.W. Hoffmann, S.K. Kunnath, A.M. Reinhorn and J.B. Mander, 7/15/92, (PB94-142007, A08, MF-A02).

NCEER-92-0017 "Observations on Water System and Pipeline Performance in the Limón Area of Costa Rica Due to the April 22, 1991 Earthquake," by M. O'Rourke and D. Ballantyne, 6/30/92, (PB93-126811, A06, MF-A02).

NCEER-92-0018 "Fourth Edition of Earthquake Education Materials for Grades K-12," Edited by K.E.K. Ross, 8/10/92, (PB93-114023, A07, MF-A02).

NCEER-92-0019 "Proceedings from the Fourth Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures for Soil Liquefaction," Edited by M. Hamada and T.D. O'Rourke, 8/12/92, (PB93-163939, A99, MF-E11).

NCEER-92-0020 "Active Bracing System: A Full Scale Implementation of Active Control," by A.M. Reinhorn, T.T. Soong, R.C. Lin, M.A. Riley, Y.P. Wang, S. Aizawa and M. Higashino, 8/14/92, (PB93-127512, A06, MF-A02).

NCEER-92-0021 "Empirical Analysis of Horizontal Ground Displacement Generated by Liquefaction-Induced Lateral Spreads," by S.F. Bartlett and T.L. Youd, 8/17/92, (PB93-188241, A06, MF-A02).

NCEER-92-0022 "IDARC Version 3.0: Inelastic Damage Analysis of Reinforced Concrete Structures," by S.K. Kunnath, A.M. Reinhorn and R.F. Lobo, 8/31/92, (PB93-227502, A07, MF-A02).

NCEER-92-0023 "A Semi-Empirical Analysis of Strong-Motion Peaks in Terms of Seismic Source, Propagation Path and Local Site Conditions, by M. Kamiyama, M.J. O'Rourke and R. Flores-Berrones, 9/9/92, (PB93-150266, A08, MF-A02).

NCEER-92-0024 "Seismic Behavior of Reinforced Concrete Frame Structures with Nonductile Details, Part I: Summary of Experimental Findings of Full Scale Beam-Column Joint Tests," by A. Beres, R.N. White and P. Gergely, 9/30/92, (PB93-227783, A05, MF-A01).

NCEER-92-0025 "Experimental Results of Repaired and Retrofitted Beam-Column Joint Tests in Lightly Reinforced Concrete Frame Buildings," by A. Beres, S. El-Borgi, R.N. White and P. Gergely, 10/29/92, (PB93-227791, A05, MF-A01).

NCEER-92-0026 "A Generalization of Optimal Control Theory: Linear and Nonlinear Structures," by J.N. Yang, Z. Li and S. Vongchavalitkul, 11/2/92, (PB93-188621, A05, MF-A01).

NCEER-92-0027 "Seismic Resistance of Reinforced Concrete Frame Structures Designed Only for Gravity Loads: Part I - Design and Properties of a One-Third Scale Model Structure," by J.M. Bracci, A.M. Reinhorn and J.B. Mander, 12/1/92, (PB94-104502, A08, MF-A02).

NCEER-92-0028 "Seismic Resistance of Reinforced Concrete Frame Structures Designed Only for Gravity Loads: Part II - Experimental Performance of Subassemblages," by L.E. Aycardi, J.B. Mander and A.M. Reinhorn, 12/1/92, (PB94-104510, A08, MF-A02).

NCEER-92-0029 "Seismic Resistance of Reinforced Concrete Frame Structures Designed Only for Gravity Loads: Part III - Experimental Performance and Analytical Study of a Structural Model," by J.M. Bracci, A.M. Reinhorn and J.B. Mander, 12/1/92, (PB93-227528, A09, MF-A01).

NCEER-92-0030 "Evaluation of Seismic Retrofit of Reinforced Concrete Frame Structures: Part I - Experimental Performance of Retrofitted Subassemblages," by D. Choudhuri, J.B. Mander and A.M. Reinhorn, 12/8/92, (PB93-198307, A07, MF-A02).

NCEER-92-0031 "Evaluation of Seismic Retrofit of Reinforced Concrete Frame Structures: Part II - Experimental Performance and Analytical Study of a Retrofitted Structural Model," by J.M. Bracci, A.M. Reinhorn and J.B. Mander, 12/8/92, (PB93-198315, A09, MF-A03).

NCEER-92-0032 "Experimental and Analytical Investigation of Seismic Response of Structures with Supplemental Fluid Viscous Dampers," by M.C. Constantinou and M.D. Symans, 12/21/92, (PB93-191435, A10, MF-A03). This report is available only through NTIS (see address given above).

NCEER-92-0033 "Reconnaissance Report on the Cairo, Egypt Earthquake of October 12, 1992," by M. Khater, 12/23/92, (PB93-188621, A03, MF-A01).

NCEER-92-0034 "Low-Level Dynamic Characteristics of Four Tall Flat-Plate Buildings in New York City," by H. Gavin, S. Yuan, J. Grossman, E. Pekelis and K. Jacob, 12/28/92, (PB93-188217, A07, MF-A02).

NCEER-93-0001 "An Experimental Study on the Seismic Performance of Brick-Infilled Steel Frames With and Without Retrofit," by J.B. Mander, B. Nair, K. Wojtkowski and J. Ma, 1/29/93, (PB93-227510, A07, MF-A02).

NCEER-93-0002 "Social Accounting for Disaster Preparedness and Recovery Planning," by S. Cole, E. Pantoja and V. Razak, 2/22/93, (PB94-142114, A12, MF-A03).

NCEER-93-0003 "Assessment of 1991 NEHRP Provisions for Nonstructural Components and Recommended Revisions," by T.T. Soong, G. Chen, Z. Wu, R-H. Zhang and M. Grigoriu, 3/1/93, (PB93-188639, A06, MF-A02).

NCEER-93-0004 "Evaluation of Static and Response Spectrum Analysis Procedures of SEAOC/UBC for Seismic Isolated Structures," by C.W. Winters and M.C. Constantinou, 3/23/93, (PB93-198299, A10, MF-A03).

NCEER-93-0005 "Earthquakes in the Northeast - Are We Ignoring the Hazard? A Workshop on Earthquake Science and Safety for Educators," edited by K.E.K. Ross, 4/2/93, (PB94-103066, A09, MF-A02).

NCEER-93-0006 "Inelastic Response of Reinforced Concrete Structures with Viscoelastic Braces," by R.F. Lobo, J.M. Bracci, K.L. Shen, A.M. Reinhorn and T.T. Soong, 4/5/93, (PB93-227486, A05, MF-A02).

NCEER-93-0007 "Seismic Testing of Installation Methods for Computers and Data Processing Equipment," by K. Kosar, T.T. Soong, K.L. Shen, J.A. HoLung and Y.K. Lin, 4/12/93, (PB93-198299, A07, MF-A02).

NCEER-93-0008 "Retrofit of Reinforced Concrete Frames Using Added Dampers," by A. Reinhorn, M. Constantinou and C. Li, to be published.

NCEER-93-0009 "Seismic Behavior and Design Guidelines for Steel Frame Structures with Added Viscoelastic Dampers," by K.C. Chang, M.L. Lai, T.T. Soong, D.S. Hao and Y.C. Yeh, 5/1/93, (PB94-141959, A07, MF-A02).

NCEER-93-0010 "Seismic Performance of Shear-Critical Reinforced Concrete Bridge Piers," by J.B. Mander, S.M. Waheed, M.T.A. Chaudhary and S.S. Chen, 5/12/93, (PB93-227494, A08, MF-A02).

NCEER-93-0011 "3D-BASIS-TABS: Computer Program for Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures," by S. Nagarajaiah, C. Li, A.M. Reinhorn and M.C. Constantinou, 8/2/93, (PB94-141819, A09, MF-A02).

NCEER-93-0012 "Effects of Hydrocarbon Spills from an Oil Pipeline Break on Ground Water," by O.J. Helweg and H.H.M. Hwang, 8/3/93, (PB94-141942, A06, MF-A02).

NCEER-93-0013 "Simplified Procedures for Seismic Design of Nonstructural Components and Assessment of Current Code Provisions," by M.P. Singh, L.E. Suarez, E.E. Matheu and G.O. Maldonado, 8/4/93, (PB94-141827, A09, MF-A02).

NCEER-93-0014 "An Energy Approach to Seismic Analysis and Design of Secondary Systems," by G. Chen and T.T. Soong, 8/6/93, (PB94-142767, A11, MF-A03).

NCEER-93-0015 "Proceedings from School Sites: Becoming Prepared for Earthquakes - Commemorating the Third Anniversary of the Loma Prieta Earthquake," Edited by F.E. Winslow and K.E.K. Ross, 8/16/93, (PB94-154275, A16, MF-A02).

NCEER-93-0016 "Reconnaissance Report of Damage to Historic Monuments in Cairo, Egypt Following the October 12, 1992 Dahshur Earthquake," by D. Sykora, D. Look, G. Croci, E. Karaesmen and E. Karaesmen, 8/19/93, (PB94-142221, A08, MF-A02).

NCEER-93-0017 "The Island of Guam Earthquake of August 8, 1993," by S.W. Swan and S.K. Harris, 9/30/93, (PB94-141843, A04, MF-A01).

NCEER-93-0018 "Engineering Aspects of the October 12, 1992 Egyptian Earthquake," by A.W. Elgamal, M. Amer, K. Adalier and A. Abul-Fadl, 10/7/93, (PB94-141983, A05, MF-A01).

NCEER-93-0019 "Development of an Earthquake Motion Simulator and its Application in Dynamic Centrifuge Testing," by I. Krstelj, Supervised by J.H. Prevost, 10/23/93, (PB94-181773, A-10, MF-A03).

NCEER-93-0020 "NCEER-Taisei Corporation Research Program on Sliding Seismic Isolation Systems for Bridges: Experimental and Analytical Study of a Friction Pendulum System (FPS)," by M.C. Constantinou, P. Tsopelas, Y-S. Kim and S. Okamoto, 11/1/93, (PB94-142775, A08, MF-A02).

NCEER-93-0021 "Finite Element Modeling of Elastomeric Seismic Isolation Bearings," by L.J. Billings, Supervised by R. Shepherd, 11/8/93, to be published.

NCEER-93-0022 "Seismic Vulnerability of Equipment in Critical Facilities: Life-Safety and Operational Consequences," by K. Porter, G.S. Johnson, M.M. Zadeh, C. Scawthorn and S. Eder, 11/24/93, (PB94-181765, A16, MF-A03).

NCEER-93-0023 "Hokkaido Nansei-oki, Japan Earthquake of July 12, 1993, by P.I. Yanev and C.R. Scawthorn, 12/23/93, (PB94-181500, A07, MF-A01).

NCEER-94-0001 "An Evaluation of Seismic Serviceability of Water Supply Networks with Application to the San Francisco Auxiliary Water Supply System," by I. Markov, Supervised by M. Grigoriu and T. O'Rourke, 1/21/94, (PB94-204013, A07, MF-A02).

NCEER-94-0002 "NCEER-Taisei Corporation Research Program on Sliding Seismic Isolation Systems for Bridges: Experimental and Analytical Study of Systems Consisting of Sliding Bearings, Rubber Restoring Force Devices and Fluid Dampers," Volumes I and II, by P. Tsopelas, S. Okamoto, M.C. Constantinou, D. Ozaki and S. Fujii, 2/4/94, (PB94-181740, A09, MF-A02 and PB94-181757, A12, MF-A03).

NCEER-94-0003 "A Markov Model for Local and Global Damage Indices in Seismic Analysis," by S. Rahman and M. Grigoriu, 2/18/94, (PB94-206000, A12, MF-A03).

NCEER-94-0004 "Proceedings from the NCEER Workshop on Seismic Response of Masonry Infills," edited by D.P. Abrams, 3/1/94, (PB94-180783, A07, MF-A02).

NCEER-94-0005 "The Northridge, California Earthquake of January 17, 1994: General Reconnaissance Report," edited by J.D. Goltz, 3/11/94, (PB94-193943, A10, MF-A03).

NCEER-94-0006 "Seismic Energy Based Fatigue Damage Analysis of Bridge Columns: Part I - Evaluation of Seismic Capacity," by G.A. Chang and J.B. Mander, 3/14/94, (PB94-219185, A11, MF-A03).

NCEER-94-0007 "Seismic Isolation of Multi-Story Frame Structures Using Spherical Sliding Isolation Systems," by T.M. Al-Hussaini, V.A. Zayas and M.C. Constantinou, 3/17/94, (PB94-193745, A09, MF-A02).

NCEER-94-0008 "The Northridge, California Earthquake of January 17, 1994: Performance of Highway Bridges," edited by I.G. Buckle, 3/24/94, (PB94-193851, A06, MF-A02).

NCEER-94-0009 "Proceedings of the Third U.S.-Japan Workshop on Earthquake Protective Systems for Bridges," edited by I.G. Buckle and I. Friedland, 3/31/94, (PB94-195815, A99, MF-A06).

NCEER-94-0010 "3D-BASIS-ME: Computer Program for Nonlinear Dynamic Analysis of Seismically Isolated Single and Multiple Structures and Liquid Storage Tanks," by P.C. Tsopelas, M.C. Constantinou and A.M. Reinhorn, 4/12/94, (PB94-204922, A09, MF-A02).

NCEER-94-0011 "The Northridge, California Earthquake of January 17, 1994: Performance of Gas Transmission Pipelines," by T.D. O'Rourke and M.C. Palmer, 5/16/94, (PB94-204989, A05, MF-A01).

NCEER-94-0012 "Feasibility Study of Replacement Procedures and Earthquake Performance Related to Gas Transmission Pipelines," by T.D. O'Rourke and M.C. Palmer, 5/25/94, (PB94-206638, A09, MF-A02).

NCEER-94-0013 "Seismic Energy Based Fatigue Damage Analysis of Bridge Columns: Part II - Evaluation of Seismic Demand," by G.A. Chang and J.B. Mander, 6/1/94, (PB95-18106, A08, MF-A02).

NCEER-94-0014 "NCEER-Taisei Corporation Research Program on Sliding Seismic Isolation Systems for Bridges: Experimental and Analytical Study of a System Consisting of Sliding Bearings and Fluid Restoring Force/Damping Devices," by P. Tsopelas and M.C. Constantinou, 6/13/94, (PB94-219144, A10, MF-A03).

NCEER-94-0015 "Generation of Hazard-Consistent Fragility Curves for Seismic Loss Estimation Studies," by H. Hwang and J-R. Huo, 6/14/94, (PB95-181996, A09, MF-A02).

NCEER-94-0016 "Seismic Study of Building Frames with Added Energy-Absorbing Devices," by W.S. Pong, C.S. Tsai and G.C. Lee, 6/20/94, (PB94-219136, A10, A03).

NCEER-94-0017 "Sliding Mode Control for Seismic-Excited Linear and Nonlinear Civil Engineering Structures," by J. Yang, J. Wu, A. Agrawal and Z. Li, 6/21/94, (PB95-138483, A06, MF-A02).

NCEER-94-0018 "3D-BASIS-TABS Version 2.0: Computer Program for Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures," by A.M. Reinhorn, S. Nagarajaiah, M.C. Constantinou, P. Tsopelas and R. Li, 6/22/94, (PB95-182176, A08, MF-A02).

NCEER-94-0019 "Proceedings of the International Workshop on Civil Infrastructure Systems: Application of Intelligent Systems and Advanced Materials on Bridge Systems," Edited by G.C. Lee and K.C. Chang, 7/18/94, (PB95-252474, A20, MF-A04).

NCEER-94-0020 "Study of Seismic Isolation Systems for Computer Floors," by V. Lambrou and M.C. Constantinou, 7/19/94, (PB95-138533, A10, MF-A03).

NCEER-94-0021 "Proceedings of the U.S.-Italian Workshop on Guidelines for Seismic Evaluation and Rehabilitation of Unreinforced Masonry Buildings," Edited by D.P. Abrams and G.M. Calvi, 7/20/94, (PB95-138749, A13, MF-A03).

NCEER-94-0022 "NCEER-Taisei Corporation Research Program on Sliding Seismic Isolation Systems for Bridges: Experimental and Analytical Study of a System Consisting of Lubricated PTFE Sliding Bearings and Mild Steel Dampers," by P. Tsopelas and M.C. Constantinou, 7/22/94, (PB95-182184, A08, MF-A02).

NCEER-94-0023 “Development of Reliability-Based Design Criteria for Buildings Under Seismic Load,” by Y.K. Wen, H. Hwang and M. Shinozuka, 8/1/94, (PB95-211934, A08, MF-A02).

NCEER-94-0024 “Experimental Verification of Acceleration Feedback Control Strategies for an Active Tendon System,” by S.J. Dyke, B.F. Spencer, Jr., P. Quast, M.K. Sain, D.C. Kaspari, Jr. and T.T. Soong, 8/29/94, (PB95-212320, A05, MF-A01).

NCEER-94-0025 “Seismic Retrofitting Manual for Highway Bridges,” Edited by I.G. Buckle and I.F. Friedland, published by the Federal Highway Administration (PB95-212676, A15, MF-A03).

NCEER-94-0026 “Proceedings from the Fifth U.S.-Japan Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction,” Edited by T.D. O’Rourke and M. Hamada, 11/7/94, (PB95-220802, A99, MF-E08).

NCEER-95-0001 "Experimental and Analytical Investigation of Seismic Retrofit of Structures with Supplemental Damping: Part 1 - Fluid Viscous Damping Devices," by A.M. Reinhorn, C. Li and M.C. Constantinou, 1/3/95, (PB95-266599, A09, MF-A02).

NCEER-95-0002 "Experimental and Analytical Study of Low-Cycle Fatigue Behavior of Semi-Rigid Top-And-Seat Angle Connections," by G. Pekcan, J.B. Mander and S.S. Chen, 1/5/95, (PB95-220042, A07, MF-A02).

NCEER-95-0003 "NCEER-ATC Joint Study on Fragility of Buildings," by T. Anagnos, C. Rojahn and A.S. Kiremidjian, 1/20/95, (PB95-220026, A06, MF-A02).

NCEER-95-0004 "Nonlinear Control Algorithms for Peak Response Reduction," by Z. Wu, T.T. Soong, V. Gattulli and R.C. Lin, 2/16/95, (PB95-220349, A05, MF-A01).

NCEER-95-0005 "Pipeline Replacement Feasibility Study: A Methodology for Minimizing Seismic and Corrosion Risks to Underground Natural Gas Pipelines," by R.T. Eguchi, H.A. Seligson and D.G. Honegger, 3/2/95, (PB95-252326, A06, MF-A02).

NCEER-95-0006 "Evaluation of Seismic Performance of an 11-Story Frame Building During the 1994 Northridge Earthquake," by F. Naeim, R. DiSulio, K. Benuska, A. Reinhorn and C. Li, to be published.

NCEER-95-0007 "Prioritization of Bridges for Seismic Retrofitting," by N. Basöz and A.S. Kiremidjian, 4/24/95, (PB95-252300, A08, MF-A02).

NCEER-95-0008 "Method for Developing Motion Damage Relationships for Reinforced Concrete Frames," by A. Singhal and A.S. Kiremidjian, 5/11/95, (PB95-266607, A06, MF-A02).

NCEER-95-0009 "Experimental and Analytical Investigation of Seismic Retrofit of Structures with Supplemental Damping: Part II - Friction Devices," by C. Li and A.M. Reinhorn, 7/6/95, (PB96-128087, A11, MF-A03).

NCEER-95-0010 "Experimental Performance and Analytical Study of a Non-Ductile Reinforced Concrete Frame Structure Retrofitted with Elastomeric Spring Dampers," by G. Pekcan, J.B. Mander and S.S. Chen, 7/14/95, (PB96-137161, A08, MF-A02).

NCEER-95-0011 "Development and Experimental Study of Semi-Active Fluid Damping Devices for Seismic Protection of Structures," by M.D. Symans and M.C. Constantinou, 8/3/95, (PB96-136940, A23, MF-A04).

NCEER-95-0012 "Real-Time Structural Parameter Modification (RSPM): Development of Innervated Structures," by Z. Liang, M. Tong and G.C. Lee, 4/11/95, (PB96-137153, A06, MF-A01).

NCEER-95-0013 "Experimental and Analytical Investigation of Seismic Retrofit of Structures with Supplemental Damping: Part III - Viscous Damping Walls," by A.M. Reinhorn and C. Li, 10/1/95, (PB96-176409, A11, MF-A03).

NCEER-95-0014 "Seismic Fragility Analysis of Equipment and Structures in a Memphis Electric Substation," by J-R. Huo and H.H.M. Hwang, 8/10/95, (PB96-128087, A09, MF-A02).

NCEER-95-0015 "The Hanshin-Awaji Earthquake of January 17, 1995: Performance of Lifelines," Edited by M. Shinozuka, 11/3/95, (PB96-176383, A15, MF-A03).

NCEER-95-0016 "Highway Culvert Performance During Earthquakes," by T.L. Youd and C.J. Beckman, available as NCEER-96-0015.

NCEER-95-0017 "The Hanshin-Awaji Earthquake of January 17, 1995: Performance of Highway Bridges," Edited by I.G. Buckle, 12/1/95, to be published.

NCEER-95-0018 "Modeling of Masonry Infill Panels for Structural Analysis," by A.M. Reinhorn, A. Madan, R.E. Valles, Y. Reichmann and J.B. Mander, 12/8/95, (PB97-110886, MF-A01, A06).

NCEER-95-0019 "Optimal Polynomial Control for Linear and Nonlinear Structures," by A.K. Agrawal and J.N. Yang, 12/11/95, (PB96-168737, A07, MF-A02).

NCEER-95-0020 "Retrofit of Non-Ductile Reinforced Concrete Frames Using Friction Dampers," by R.S. Rao, P. Gergely and R.N. White, 12/22/95, (PB97-133508, A10, MF-A02).

NCEER-95-0021 "Parametric Results for Seismic Response of Pile-Supported Bridge Bents," by G. Mylonakis, A. Nikolaou and G. Gazetas, 12/22/95, (PB97-100242, A12, MF-A03).

NCEER-95-0022 "Kinematic Bending Moments in Seismically Stressed Piles," by A. Nikolaou, G. Mylonakis and G. Gazetas, 12/23/95, (PB97-113914, MF-A03, A13).

NCEER-96-0001 "Dynamic Response of Unreinforced Masonry Buildings with Flexible Diaphragms," by A.C. Costley and D.P. Abrams," 10/10/96, (PB97-133573, MF-A03, A15).

NCEER-96-0002 "State of the Art Review: Foundations and Retaining Structures," by I. Po Lam, to be published.

NCEER-96-0003 "Ductility of Rectangular Reinforced Concrete Bridge Columns with Moderate Confinement," by N. Wehbe, M. Saiidi, D. Sanders and B. Douglas, 11/7/96, (PB97-133557, A06, MF-A02).

NCEER-96-0004 "Proceedings of the Long-Span Bridge Seismic Research Workshop," edited by I.G. Buckle and I.M. Friedland, to be published.

NCEER-96-0005 "Establish Representative Pier Types for Comprehensive Study: Eastern United States," by J. Kulicki and Z. Prucz, 5/28/96, (PB98-119217, A07, MF-A02).

NCEER-96-0006 "Establish Representative Pier Types for Comprehensive Study: Western United States," by R. Imbsen, R.A. Schamber and T.A. Osterkamp, 5/28/96, (PB98-118607, A07, MF-A02).

NCEER-96-0007 "Nonlinear Control Techniques for Dynamical Systems with Uncertain Parameters," by R.G. Ghanem and M.I. Bujakov, 5/27/96, (PB97-100259, A17, MF-A03).

NCEER-96-0008 "Seismic Evaluation of a 30-Year Old Non-Ductile Highway Bridge Pier and Its Retrofit," by J.B. Mander, B. Mahmoodzadegan, S. Bhadra and S.S. Chen, 5/31/96, (PB97-110902, MF-A03, A10).

NCEER-96-0009 "Seismic Performance of a Model Reinforced Concrete Bridge Pier Before and After Retrofit," by J.B. Mander, J.H. Kim and C.A. Ligozio, 5/31/96, (PB97-110910, MF-A02, A10).

NCEER-96-0010 "IDARC2D Version 4.0: A Computer Program for the Inelastic Damage Analysis of Buildings," by R.E. Valles, A.M. Reinhorn, S.K. Kunnath, C. Li and A. Madan, 6/3/96, (PB97-100234, A17, MF-A03).

NCEER-96-0011 "Estimation of the Economic Impact of Multiple Lifeline Disruption: Memphis Light, Gas and Water Division Case Study," by S.E. Chang, H.A. Seligson and R.T. Eguchi, 8/16/96, (PB97-133490, A11, MF-A03).

NCEER-96-0012 "Proceedings from the Sixth Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction, Edited by M. Hamada and T. O'Rourke, 9/11/96, (PB97-133581, A99, MF-A06).

NCEER-96-0013 "Chemical Hazards, Mitigation and Preparedness in Areas of High Seismic Risk: A Methodology for Estimating the Risk of Post-Earthquake Hazardous Materials Release," by H.A. Seligson, R.T. Eguchi, K.J. Tierney and K. Richmond, 11/7/96, (PB97-133565, MF-A02, A08).

NCEER-96-0014 "Response of Steel Bridge Bearings to Reversed Cyclic Loading," by J.B. Mander, D-K. Kim, S.S. Chen and G.J. Premus, 11/13/96, (PB97-140735, A12, MF-A03).

NCEER-96-0015 "Highway Culvert Performance During Past Earthquakes," by T.L. Youd and C.J. Beckman, 11/25/96, (PB97-133532, A06, MF-A01).

NCEER-97-0001 "Evaluation, Prevention and Mitigation of Pounding Effects in Building Structures," by R.E. Valles and A.M. Reinhorn, 2/20/97, (PB97-159552, A14, MF-A03).

NCEER-97-0002 "Seismic Design Criteria for Bridges and Other Highway Structures," by C. Rojahn, R. Mayes, D.G. Anderson, J. Clark, J.H. Hom, R.V. Nutt and M.J. O'Rourke, 4/30/97, (PB97-194658, A06, MF-A03).

NCEER-97-0003 “Proceedings of the U.S.-Italian Workshop on Seismic Evaluation and Retrofit,” Edited by D.P. Abrams and G.M. Calvi, 3/19/97, (PB97-194666, A13, MF-A03).

NCEER-97-0004 "Investigation of Seismic Response of Buildings with Linear and Nonlinear Fluid Viscous Dampers," by A.A. Seleemah and M.C. Constantinou, 5/21/97, (PB98-109002, A15, MF-A03).

NCEER-97-0005 "Proceedings of the Workshop on Earthquake Engineering Frontiers in Transportation Facilities," edited by G.C. Lee and I.M. Friedland, 8/29/97, (PB98-128911, A25, MR-A04).

NCEER-97-0006 "Cumulative Seismic Damage of Reinforced Concrete Bridge Piers," by S.K. Kunnath, A. El-Bahy, A. Taylor and W. Stone, 9/2/97, (PB98-108814, A11, MF-A03).

NCEER-97-0007 "Structural Details to Accommodate Seismic Movements of Highway Bridges and Retaining Walls," by R.A. Imbsen, R.A. Schamber, E. Thorkildsen, A. Kartoum, B.T. Martin, T.N. Rosser and J.M. Kulicki, 9/3/97, (PB98-108996, A09, MF-A02).

NCEER-97-0008 "A Method for Earthquake Motion-Damage Relationships with Application to Reinforced Concrete Frames," by A. Singhal and A.S. Kiremidjian, 9/10/97, (PB98-108988, A13, MF-A03).

NCEER-97-0009 "Seismic Analysis and Design of Bridge Abutments Considering Sliding and Rotation," by K. Fishman and R. Richards, Jr., 9/15/97, (PB98-108897, A06, MF-A02).

NCEER-97-0010 "Proceedings of the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities," edited by I.M. Friedland, M.S. Power and R.L. Mayes, 9/22/97, (PB98-128903, A21, MF-A04).

NCEER-97-0011 "Seismic Analysis for Design or Retrofit of Gravity Bridge Abutments," by K.L. Fishman, R. Richards, Jr. and R.C. Divito, 10/2/97, (PB98-128937, A08, MF-A02).

NCEER-97-0012 "Evaluation of Simplified Methods of Analysis for Yielding Structures," by P. Tsopelas, M.C. Constantinou, C.A. Kircher and A.S. Whittaker, 10/31/97, (PB98-128929, A10, MF-A03).

NCEER-97-0013 "Seismic Design of Bridge Columns Based on Control and Repairability of Damage," by C-T. Cheng and J.B. Mander, 12/8/97, (PB98-144249, A11, MF-A03).

NCEER-97-0014 "Seismic Resistance of Bridge Piers Based on Damage Avoidance Design," by J.B. Mander and C-T. Cheng, 12/10/97, (PB98-144223, A09, MF-A02).

NCEER-97-0015 “Seismic Response of Nominally Symmetric Systems with Strength Uncertainty,” by S. Balopoulou and M. Grigoriu, 12/23/97, (PB98-153422, A11, MF-A03).

NCEER-97-0016 “Evaluation of Seismic Retrofit Methods for Reinforced Concrete Bridge Columns,” by T.J. Wipf, F.W. Klaiber and F.M. Russo, 12/28/97, (PB98-144215, A12, MF-A03).

NCEER-97-0017 “Seismic Fragility of Existing Conventional Reinforced Concrete Highway Bridges,” by C.L. Mullen and A.S. Cakmak, 12/30/97, (PB98-153406, A08, MF-A02).

NCEER-97-0018 “Loss Asssessment of Memphis Buildings,” edited by D.P. Abrams and M. Shinozuka, 12/31/97, (PB98-144231, A13, MF-A03).

NCEER-97-0019 “Seismic Evaluation of Frames with Infill Walls Using Quasi-static Experiments,” by K.M. Mosalam, R.N. White and P. Gergely, 12/31/97, (PB98-153455, A07, MF-A02).

NCEER-97-0020 “Seismic Evaluation of Frames with Infill Walls Using Pseudo-dynamic Experiments,” by K.M. Mosalam, R.N. White and P. Gergely, 12/31/97, (PB98-153430, A07, MF-A02).

NCEER-97-0021 “Computational Strategies for Frames with Infill Walls: Discrete and Smeared Crack Analyses and Seismic Fragility,” by K.M. Mosalam, R.N. White and P. Gergely, 12/31/97, (PB98-153414, A10, MF-A02).

NCEER-97-0022 "Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils," edited by T.L. Youd and I.M. Idriss, 12/31/97, (PB98-155617, A15, MF-A03).

MCEER-98-0001 "Extraction of Nonlinear Hysteretic Properties of Seismically Isolated Bridges from Quick-Release Field Tests," by Q. Chen, B.M. Douglas, E.M. Maragakis and I.G. Buckle, 5/26/98, (PB99-118838, A06, MF-A01).

MCEER-98-0002 "Methodologies for Evaluating the Importance of Highway Bridges," by A. Thomas, S. Eshenaur and J. Kulicki, 5/29/98, (PB99-118846, A10, MF-A02).

MCEER-98-0003 "Capacity Design of Bridge Piers and the Analysis of Overstrength," by J.B. Mander, A. Dutta and P. Goel, 6/1/98, (PB99-118853, A09, MF-A02).

MCEER-98-0004 "Evaluation of Bridge Damage Data from the Loma Prieta and Northridge, California Earthquakes," by N. Basoz and A. Kiremidjian, 6/2/98, (PB99-118861, A15, MF-A03).

MCEER-98-0005 "Screening Guide for Rapid Assessment of Liquefaction Hazard at Highway Bridge Sites," by T. L. Youd, 6/16/98, (PB99-118879, A06, not available on microfiche).

MCEER-98-0006 "Structural Steel and Steel/Concrete Interface Details for Bridges," by P. Ritchie, N. Kauhl and J. Kulicki, 7/13/98, (PB99-118945, A06, MF-A01).

MCEER-98-0007 "Capacity Design and Fatigue Analysis of Confined Concrete Columns," by A. Dutta and J.B. Mander, 7/14/98, (PB99-118960, A14, MF-A03).

MCEER-98-0008 "Proceedings of the Workshop on Performance Criteria for Telecommunication Services Under Earthquake Conditions," edited by A.J. Schiff, 7/15/98, (PB99-118952, A08, MF-A02).

MCEER-98-0009 "Fatigue Analysis of Unconfined Concrete Columns," by J.B. Mander, A. Dutta and J.H. Kim, 9/12/98, (PB99-123655, A10, MF-A02).

MCEER-98-0010 "Centrifuge Modeling of Cyclic Lateral Response of Pile-Cap Systems and Seat-Type Abutments in Dry Sands," by A.D. Gadre and R. Dobry, 10/2/98, (PB99-123606, A13, MF-A03).

MCEER-98-0011 "IDARC-BRIDGE: A Computational Platform for Seismic Damage Assessment of Bridge Structures," by A.M. Reinhorn, V. Simeonov, G. Mylonakis and Y. Reichman, 10/2/98, (PB99-162919, A15, MF-A03).

MCEER-98-0012 "Experimental Investigation of the Dynamic Response of Two Bridges Before and After Retrofitting with Elastomeric Bearings," by D.A. Wendichansky, S.S. Chen and J.B. Mander, 10/2/98, (PB99-162927, A15, MF-A03).

MCEER-98-0013 "Design Procedures for Hinge Restrainers and Hinge Sear Width for Multiple-Frame Bridges," by R. Des Roches and G.L. Fenves, 11/3/98, (PB99-140477, A13, MF-A03).

MCEER-98-0014 "Response Modification Factors for Seismically Isolated Bridges," by M.C. Constantinou and J.K. Quarshie, 11/3/98, (PB99-140485, A14, MF-A03).

MCEER-98-0015 "Proceedings of the U.S.-Italy Workshop on Seismic Protective Systems for Bridges," edited by I.M. Friedland and M.C. Constantinou, 11/3/98, (PB2000-101711, A22, MF-A04).

MCEER-98-0016 "Appropriate Seismic Reliability for Critical Equipment Systems: Recommendations Based on Regional Analysis of Financial and Life Loss," by K. Porter, C. Scawthorn, C. Taylor and N. Blais, 11/10/98, (PB99-157265, A08, MF-A02).

MCEER-98-0017 "Proceedings of the U.S. Japan Joint Seminar on Civil Infrastructure Systems Research," edited by M. Shinozuka and A. Rose, 11/12/98, (PB99-156713, A16, MF-A03).

MCEER-98-0018 "Modeling of Pile Footings and Drilled Shafts for Seismic Design," by I. PoLam, M. Kapuskar and D. Chaudhuri, 12/21/98, (PB99-157257, A09, MF-A02).

MCEER-99-0001 "Seismic Evaluation of a Masonry Infilled Reinforced Concrete Frame by Pseudodynamic Testing," by S.G. Buonopane and R.N. White, 2/16/99, (PB99-162851, A09, MF-A02).

MCEER-99-0002 "Response History Analysis of Structures with Seismic Isolation and Energy Dissipation Systems: Verification Examples for Program SAP2000," by J. Scheller and M.C. Constantinou, 2/22/99, (PB99-162869, A08, MF-A02).

MCEER-99-0003 "Experimental Study on the Seismic Design and Retrofit of Bridge Columns Including Axial Load Effects," by A. Dutta, T. Kokorina and J.B. Mander, 2/22/99, (PB99-162877, A09, MF-A02).

MCEER-99-0004 "Experimental Study of Bridge Elastomeric and Other Isolation and Energy Dissipation Systems with Emphasis on Uplift Prevention and High Velocity Near-source Seismic Excitation," by A. Kasalanati and M. C. Constantinou, 2/26/99, (PB99-162885, A12, MF-A03).

MCEER-99-0005 "Truss Modeling of Reinforced Concrete Shear-flexure Behavior," by J.H. Kim and J.B. Mander, 3/8/99, (PB99-163693, A12, MF-A03).

MCEER-99-0006 "Experimental Investigation and Computational Modeling of Seismic Response of a 1:4 Scale Model Steel Structure with a Load Balancing Supplemental Damping System," by G. Pekcan, J.B. Mander and S.S. Chen, 4/2/99, (PB99-162893, A11, MF-A03).

MCEER-99-0007 "Effect of Vertical Ground Motions on the Structural Response of Highway Bridges," by M.R. Button, C.J. Cronin and R.L. Mayes, 4/10/99, (PB2000-101411, A10, MF-A03).

MCEER-99-0008 "Seismic Reliability Assessment of Critical Facilities: A Handbook, Supporting Documentation, and Model Code Provisions," by G.S. Johnson, R.E. Sheppard, M.D. Quilici, S.J. Eder and C.R. Scawthorn, 4/12/99, (PB2000-101701, A18, MF-A04).

MCEER-99-0009 "Impact Assessment of Selected MCEER Highway Project Research on the Seismic Design of Highway Structures," by C. Rojahn, R. Mayes, D.G. Anderson, J.H. Clark, D'Appolonia Engineering, S. Gloyd and R.V. Nutt, 4/14/99, (PB99-162901, A10, MF-A02).

MCEER-99-0010 "Site Factors and Site Categories in Seismic Codes," by R. Dobry, R. Ramos and M.S. Power, 7/19/99, (PB2000-101705, A08, MF-A02).

MCEER-99-0011 "Restrainer Design Procedures for Multi-Span Simply-Supported Bridges," by M.J. Randall, M. Saiidi, E. Maragakis and T. Isakovic, 7/20/99, (PB2000-101702, A10, MF-A02).

MCEER-99-0012 "Property Modification Factors for Seismic Isolation Bearings," by M.C. Constantinou, P. Tsopelas, A. Kasalanati and E. Wolff, 7/20/99, (PB2000-103387, A11, MF-A03).

MCEER-99-0013 "Critical Seismic Issues for Existing Steel Bridges," by P. Ritchie, N. Kauhl and J. Kulicki, 7/20/99, (PB2000-101697, A09, MF-A02).

MCEER-99-0014 "Nonstructural Damage Database," by A. Kao, T.T. Soong and A. Vender, 7/24/99, (PB2000-101407, A06, MF-A01).

MCEER-99-0015 "Guide to Remedial Measures for Liquefaction Mitigation at Existing Highway Bridge Sites," by H.G. Cooke and J. K. Mitchell, 7/26/99, (PB2000-101703, A11, MF-A03).

MCEER-99-0016 "Proceedings of the MCEER Workshop on Ground Motion Methodologies for the Eastern United States," edited by N. Abrahamson and A. Becker, 8/11/99, (PB2000-103385, A07, MF-A02).

MCEER-99-0017 "Quindío, Colombia Earthquake of January 25, 1999: Reconnaissance Report," by A.P. Asfura and P.J. Flores, 10/4/99, (PB2000-106893, A06, MF-A01).

MCEER-99-0018 "Hysteretic Models for Cyclic Behavior of Deteriorating Inelastic Structures," by M.V. Sivaselvan and A.M. Reinhorn, 11/5/99, (PB2000-103386, A08, MF-A02).

MCEER-99-0019 "Proceedings of the 7th U.S.- Japan Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction," edited by T.D. O'Rourke, J.P. Bardet and M. Hamada, 11/19/99, (PB2000-103354, A99, MF-A06).

MCEER-99-0020 "Development of Measurement Capability for Micro-Vibration Evaluations with Application to Chip Fabrication Facilities," by G.C. Lee, Z. Liang, J.W. Song, J.D. Shen and W.C. Liu, 12/1/99, (PB2000-105993, A08, MF-A02).

MCEER-99-0021 "Design and Retrofit Methodology for Building Structures with Supplemental Energy Dissipating Systems," by G. Pekcan, J.B. Mander and S.S. Chen, 12/31/99, (PB2000-105994, A11, MF-A03).

MCEER-00-0001 "The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report," edited by C. Scawthorn; with major contributions by M. Bruneau, R. Eguchi, T. Holzer, G. Johnson, J. Mander, J. Mitchell, W. Mitchell, A. Papageorgiou, C. Scaethorn, and G. Webb, 3/23/00, (PB2000-106200, A11, MF-A03).

MCEER-00-0002 "Proceedings of the MCEER Workshop for Seismic Hazard Mitigation of Health Care Facilities," edited by G.C. Lee, M. Ettouney, M. Grigoriu, J. Hauer and J. Nigg, 3/29/00, (PB2000-106892, A08, MF-A02).

MCEER-00-0003 "The Chi-Chi, Taiwan Earthquake of September 21, 1999: Reconnaissance Report," edited by G.C. Lee and C.H. Loh, with major contributions by G.C. Lee, M. Bruneau, I.G. Buckle, S.E. Chang, P.J. Flores, T.D. O'Rourke, M. Shinozuka, T.T. Soong, C-H. Loh, K-C. Chang, Z-J. Chen, J-S. Hwang, M-L. Lin, G-Y. Liu, K-C. Tsai, G.C. Yao and C-L. Yen, 4/30/00, (PB2001-100980, A10, MF-A02).

MCEER-00-0004 "Seismic Retrofit of End-Sway Frames of Steel Deck-Truss Bridges with a Supplemental Tendon System: Experimental and Analytical Investigation," by G. Pekcan, J.B. Mander and S.S. Chen, 7/1/00, (PB2001-100982, A10, MF-A02).

MCEER-00-0005 "Sliding Fragility of Unrestrained Equipment in Critical Facilities," by W.H. Chong and T.T. Soong, 7/5/00, (PB2001-100983, A08, MF-A02).

MCEER-00-0006 "Seismic Response of Reinforced Concrete Bridge Pier Walls in the Weak Direction," by N. Abo-Shadi, M. Saiidi and D. Sanders, 7/17/00, (PB2001-100981, A17, MF-A03).

MCEER-00-0007 "Low-Cycle Fatigue Behavior of Longitudinal Reinforcement in Reinforced Concrete Bridge Columns," by J. Brown and S.K. Kunnath, 7/23/00, (PB2001-104392, A08, MF-A02).

MCEER-00-0008 "Soil Structure Interaction of Bridges for Seismic Analysis," I. PoLam and H. Law, 9/25/00, (PB2001-105397, A08, MF-A02).

MCEER-00-0009 "Proceedings of the First MCEER Workshop on Mitigation of Earthquake Disaster by Advanced Technologies (MEDAT-1), edited by M. Shinozuka, D.J. Inman and T.D. O'Rourke, 11/10/00, (PB2001-105399, A14, MF-A03).

MCEER-00-0010 "Development and Evaluation of Simplified Procedures for Analysis and Design of Buildings with Passive Energy Dissipation Systems, Revision 01," by O.M. Ramirez, M.C. Constantinou, C.A. Kircher, A.S. Whittaker, M.W. Johnson, J.D. Gomez and C. Chrysostomou, 11/16/01, (PB2001-105523, A23, MF-A04).

MCEER-00-0011 "Dynamic Soil-Foundation-Structure Interaction Analyses of Large Caissons," by C-Y. Chang, C-M. Mok, Z-L. Wang, R. Settgast, F. Waggoner, M.A. Ketchum, H.M. Gonnermann and C-C. Chin, 12/30/00, (PB2001-104373, A07, MF-A02).

MCEER-00-0012 "Experimental Evaluation of Seismic Performance of Bridge Restrainers," by A.G. Vlassis, E.M. Maragakis and M. Saiid Saiidi, 12/30/00, (PB2001-104354, A09, MF-A02).

MCEER-00-0013 "Effect of Spatial Variation of Ground Motion on Highway Structures," by M. Shinozuka, V. Saxena and G. Deodatis, 12/31/00, (PB2001-108755, A13, MF-A03).

MCEER-00-0014 "A Risk-Based Methodology for Assessing the Seismic Performance of Highway Systems," by S.D. Werner, C.E. Taylor, J.E. Moore, II, J.S. Walton and S. Cho, 12/31/00, (PB2001-108756, A14, MF-A03).

MCEER-01-0001 "Experimental Investigation of P-Delta Effects to Collapse During Earthquakes," by D. Vian and M. Bruneau, 6/25/01, (PB2002-100534, A17, MF-A03).

MCEER-01-0002 "Proceedings of the Second MCEER Workshop on Mitigation of Earthquake Disaster by Advanced Technologies (MEDAT-2)," edited by M. Bruneau and D.J. Inman, 7/23/01, (PB2002-100434, A16, MF-A03).

MCEER-01-0003 "Sensitivity Analysis of Dynamic Systems Subjected to Seismic Loads," by C. Roth and M. Grigoriu, 9/18/01, (PB2003-100884, A12, MF-A03).

MCEER-01-0004 "Overcoming Obstacles to Implementing Earthquake Hazard Mitigation Policies: Stage 1 Report," by D.J. Alesch and W.J. Petak, 12/17/01, (PB2002-107949, A07, MF-A02).

MCEER-01-0005 "Updating Real-Time Earthquake Loss Estimates: Methods, Problems and Insights," by C.E. Taylor, S.E. Chang and R.T. Eguchi, 12/17/01, (PB2002-107948, A05, MF-A01).

MCEER-01-0006 "Experimental Investigation and Retrofit of Steel Pile Foundations and Pile Bents Under Cyclic Lateral Loadings," by A. Shama, J. Mander, B. Blabac and S. Chen, 12/31/01, (PB2002-107950, A13, MF-A03).

MCEER-02-0001 "Assessment of Performance of Bolu Viaduct in the 1999 Duzce Earthquake in Turkey" by P.C. Roussis, M.C. Constantinou, M. Erdik, E. Durukal and M. Dicleli, 5/8/02, (PB2003-100883, A08, MF-A02).

MCEER-02-0002 "Seismic Behavior of Rail Counterweight Systems of Elevators in Buildings," by M.P. Singh, Rildova and L.E. Suarez, 5/27/02. (PB2003-100882, A11, MF-A03).

MCEER-02-0003 "Development of Analysis and Design Procedures for Spread Footings," by G. Mylonakis, G. Gazetas, S. Nikolaou and A. Chauncey, 10/02/02, (PB2004-101636, A13, MF-A03, CD-A13).

MCEER-02-0004 "Bare-Earth Algorithms for Use with SAR and LIDAR Digital Elevation Models," by C.K. Huyck, R.T. Eguchi and B. Houshmand, 10/16/02, (PB2004-101637, A07, CD-A07).

MCEER-02-0005 "Review of Energy Dissipation of Compression Members in Concentrically Braced Frames," by K.Lee and M. Bruneau, 10/18/02, (PB2004-101638, A10, CD-A10).

MCEER-03-0001 "Experimental Investigation of Light-Gauge Steel Plate Shear Walls for the Seismic Retrofit of Buildings" by J. Berman and M. Bruneau, 5/2/03, (PB2004-101622, A10, MF-A03, CD-A10).

MCEER-03-0002 "Statistical Analysis of Fragility Curves," by M. Shinozuka, M.Q. Feng, H. Kim, T. Uzawa and T. Ueda, 6/16/03, (PB2004-101849, A09, CD-A09).

MCEER-03-0003 "Proceedings of the Eighth U.S.-Japan Workshop on Earthquake Resistant Design f Lifeline Facilities and Countermeasures Against Liquefaction," edited by M. Hamada, J.P. Bardet and T.D. O'Rourke, 6/30/03, (PB2004-104386, A99, CD-A99).

MCEER-03-0004 "Proceedings of the PRC-US Workshop on Seismic Analysis and Design of Special Bridges," edited by L.C. Fan and G.C. Lee, 7/15/03, (PB2004-104387, A14, CD-A14).

MCEER-03-0005 "Urban Disaster Recovery: A Framework and Simulation Model," by S.B. Miles and S.E. Chang, 7/25/03, (PB2004-104388, A07, CD-A07).

MCEER-03-0006 "Behavior of Underground Piping Joints Due to Static and Dynamic Loading," by R.D. Meis, M. Maragakis and R. Siddharthan, 11/17/03, (PB2005-102194, A13, MF-A03, CD-A00).

MCEER-04-0001 "Experimental Study of Seismic Isolation Systems with Emphasis on Secondary System Response and Verification of Accuracy of Dynamic Response History Analysis Methods," by E. Wolff and M. Constantinou, 1/16/04 (PB2005-102195, A99, MF-E08, CD-A00).

MCEER-04-0002 "Tension, Compression and Cyclic Testing of Engineered Cementitious Composite Materials," by K. Kesner and S.L. Billington, 3/1/04, (PB2005-102196, A08, CD-A08).

MCEER-04-0003 "Cyclic Testing of Braces Laterally Restrained by Steel Studs to Enhance Performance During Earthquakes," by O.C. Celik, J.W. Berman and M. Bruneau, 3/16/04, (PB2005-102197, A13, MF-A03, CD-A00).

MCEER-04-0004 "Methodologies for Post Earthquake Building Damage Detection Using SAR and Optical Remote Sensing: Application to the August 17, 1999 Marmara, Turkey Earthquake," by C.K. Huyck, B.J. Adams, S. Cho, R.T. Eguchi, B. Mansouri and B. Houshmand, 6/15/04, (PB2005-104888, A10, CD-A00).

MCEER-04-0005 "Nonlinear Structural Analysis Towards Collapse Simulation: A Dynamical Systems Approach," by M.V. Sivaselvan and A.M. Reinhorn, 6/16/04, (PB2005-104889, A11, MF-A03, CD-A00).

MCEER-04-0006 "Proceedings of the Second PRC-US Workshop on Seismic Analysis and Design of Special Bridges," edited by G.C. Lee and L.C. Fan, 6/25/04, (PB2005-104890, A16, CD-A00).

MCEER-04-0007 "Seismic Vulnerability Evaluation of Axially Loaded Steel Built-up Laced Members," by K. Lee and M. Bruneau, 6/30/04, (PB2005-104891, A16, CD-A00).

MCEER-04-0008 "Evaluation of Accuracy of Simplified Methods of Analysis and Design of Buildings with Damping Systems for Near-Fault and for Soft-Soil Seismic Motions," by E.A. Pavlou and M.C. Constantinou, 8/16/04, (PB2005-104892, A08, MF-A02, CD-A00).

MCEER-04-0009 "Assessment of Geotechnical Issues in Acute Care Facilities in California," by M. Lew, T.D. O'Rourke, R. Dobry and M. Koch, 9/15/04, (PB2005-104893, A08, CD-A00).

MCEER-04-0010 "Scissor-Jack-Damper Energy Dissipation System," by A.N. Sigaher-Boyle and M.C. Constantinou, 12/1/04 (PB2005-108221).

MCEER-04-0011 "Seismic Retrofit of Bridge Steel Truss Piers Using a Controlled Rocking Approach," by M. Pollino and M. Bruneau, 12/20/04 (PB2006-105795).

MCEER-05-0001 "Experimental and Analytical Studies of Structures Seismically Isolated with an Uplift-Restraint Isolation System," by P.C. Roussis and M.C. Constantinou, 1/10/05 (PB2005-108222).

MCEER-05-0002 "A Versatile Experimentation Model for Study of Structures Near Collapse Applied to Seismic Evaluation of Irregular Structures," by D. Kusumastuti, A.M. Reinhorn and A. Rutenberg, 3/31/05 (PB2006-101523).

MCEER-05-0003 "Proceedings of the Third PRC-US Workshop on Seismic Analysis and Design of Special Bridges," edited by L.C. Fan and G.C. Lee, 4/20/05, (PB2006-105796).

MCEER-05-0004 "Approaches for the Seismic Retrofit of Braced Steel Bridge Piers and Proof-of-Concept Testing of an Eccentrically Braced Frame with Tubular Link," by J.W. Berman and M. Bruneau, 4/21/05 (PB2006-101524).

MCEER-05-0005 "Simulation of Strong Ground Motions for Seismic Fragility Evaluation of Nonstructural Components in Hospitals," by A. Wanitkorkul and A. Filiatrault, 5/26/05 (PB2006-500027).

MCEER-05-0006 "Seismic Safety in California Hospitals: Assessing an Attempt to Accelerate the Replacement or Seismic Retrofit of Older Hospital Facilities," by D.J. Alesch, L.A. Arendt and W.J. Petak, 6/6/05 (PB2006-105794).

MCEER-05-0007 "Development of Seismic Strengthening and Retrofit Strategies for Critical Facilities Using Engineered Cementitious Composite Materials," by K. Kesner and S.L. Billington, 8/29/05 (PB2006-111701).

MCEER-05-0008 "Experimental and Analytical Studies of Base Isolation Systems for Seismic Protection of Power Transformers," by N. Murota, M.Q. Feng and G-Y. Liu, 9/30/05 (PB2006-111702).

MCEER-05-0009 "3D-BASIS-ME-MB: Computer Program for Nonlinear Dynamic Analysis of Seismically Isolated Structures," by P.C. Tsopelas, P.C. Roussis, M.C. Constantinou, R. Buchanan and A.M. Reinhorn, 10/3/05 (PB2006-111703).

MCEER-05-0010 "Steel Plate Shear Walls for Seismic Design and Retrofit of Building Structures," by D. Vian and M. Bruneau, 12/15/05 (PB2006-111704).

MCEER-05-0011 "The Performance-Based Design Paradigm," by M.J. Astrella and A. Whittaker, 12/15/05 (PB2006-111705).

MCEER-06-0001 "Seismic Fragility of Suspended Ceiling Systems," H. Badillo-Almaraz, A.S. Whittaker, A.M. Reinhorn and G.P. Cimellaro, 2/4/06 (PB2006-111706).

MCEER-06-0002 "Multi-Dimensional Fragility of Structures," by G.P. Cimellaro, A.M. Reinhorn and M. Bruneau, 3/1/06 (PB2007-106974, A09, MF-A02, CD A00).

MCEER-06-0003 "Built-Up Shear Links as Energy Dissipators for Seismic Protection of Bridges," by P. Dusicka, A.M. Itani and I.G. Buckle, 3/15/06 (PB2006-111708).

MCEER-06-0004 "Analytical Investigation of the Structural Fuse Concept," by R.E. Vargas and M. Bruneau, 3/16/06 (PB2006-111709).

MCEER-06-0005 "Experimental Investigation of the Structural Fuse Concept," by R.E. Vargas and M. Bruneau, 3/17/06 (PB2006-111710).

MCEER-06-0006 "Further Development of Tubular Eccentrically Braced Frame Links for the Seismic Retrofit of Braced Steel Truss Bridge Piers," by J.W. Berman and M. Bruneau, 3/27/06 (PB2007-105147).

MCEER-06-0007 "REDARS Validation Report," by S. Cho, C.K. Huyck, S. Ghosh and R.T. Eguchi, 8/8/06 (PB2007-106983).

MCEER-06-0008 "Review of Current NDE Technologies for Post-Earthquake Assessment of Retrofitted Bridge Columns," by J.W. Song, Z. Liang and G.C. Lee, 8/21/06 (PB2007-106984).

MCEER-06-0009 "Liquefaction Remediation in Silty Soils Using Dynamic Compaction and Stone Columns," by S. Thevanayagam, G.R. Martin, R. Nashed, T. Shenthan, T. Kanagalingam and N. Ecemis, 8/28/06 (PB2007-106985).

MCEER-06-0010 "Conceptual Design and Experimental Investigation of Polymer Matrix Composite Infill Panels for Seismic Retrofitting," by W. Jung, M. Chiewanichakorn and A.J. Aref, 9/21/06 (PB2007-106986).

MCEER-06-0011 "A Study of the Coupled Horizontal-Vertical Behavior of Elastomeric and Lead-Rubber Seismic Isolation Bearings," by G.P. Warn and A.S. Whittaker, 9/22/06 (PB2007-108679).

MCEER-06-0012 "Proceedings of the Fourth PRC-US Workshop on Seismic Analysis and Design of Special Bridges: Advancing Bridge Technologies in Research, Design, Construction and Preservation," Edited by L.C. Fan, G.C. Lee and L. Ziang, 10/12/06 (PB2007-109042).

MCEER-06-0013 "Cyclic Response and Low Cycle Fatigue Characteristics of Plate Steels," by P. Dusicka, A.M. Itani and I.G. Buckle, 11/1/06 06 (PB2007-106987).

MCEER-06-0014 "Proceedings of the Second US-Taiwan Bridge Engineering Workshop," edited by W.P. Yen, J. Shen, J-Y. Chen and M. Wang, 11/15/06 (PB2008-500041).

MCEER-06-0015 "User Manual and Technical Documentation for the REDARS™ Import Wizard," by S. Cho, S. Ghosh, C.K. Huyck and S.D. Werner, 11/30/06 (PB2007-114766).

MCEER-06-0016 "Hazard Mitigation Strategy and Monitoring Technologies for Urban and Infrastructure Public Buildings: Proceedings of the China-US Workshops," edited by X.Y. Zhou, A.L. Zhang, G.C. Lee and M. Tong, 12/12/06 (PB2008-500018).

MCEER-07-0001 "Static and Kinetic Coefficients of Friction for Rigid Blocks," by C. Kafali, S. Fathali, M. Grigoriu and A.S. Whittaker, 3/20/07 (PB2007-114767).

MCEER-07-0002 "Hazard Mitigation Investment Decision Making: Organizational Response to Legislative Mandate," by L.A. Arendt, D.J. Alesch and W.J. Petak, 4/9/07 (PB2007-114768).

MCEER-07-0003 "Seismic Behavior of Bidirectional-Resistant Ductile End Diaphragms with Unbonded Braces in Straight or Skewed Steel Bridges," by O. Celik and M. Bruneau, 4/11/07 (PB2008-105141).

MCEER-07-0004 "Modeling Pile Behavior in Large Pile Groups Under Lateral Loading," by A.M. Dodds and G.R. Martin, 4/16/07(PB2008-105142).

MCEER-07-0005 "Experimental Investigation of Blast Performance of Seismically Resistant Concrete-Filled Steel Tube Bridge Piers," by S. Fujikura, M. Bruneau and D. Lopez-Garcia, 4/20/07 (PB2008-105143).

MCEER-07-0006 "Seismic Analysis of Conventional and Isolated Liquefied Natural Gas Tanks Using Mechanical Analogs," by I.P. Christovasilis and A.S. Whittaker, 5/1/07.

MCEER-07-0007 "Experimental Seismic Performance Evaluation of Isolation/Restraint Systems for Mechanical Equipment – Part 1: Heavy Equipment Study," by S. Fathali and A. Filiatrault, 6/6/07 (PB2008-105144).

MCEER-07-0008 "Seismic Vulnerability of Timber Bridges and Timber Substructures," by A.A. Sharma, J.B. Mander, I.M. Friedland and D.R. Allicock, 6/7/07 (PB2008-105145).

MCEER-07-0009 "Experimental and Analytical Study of the XY-Friction Pendulum (XY-FP) Bearing for Bridge Applications," by C.C. Marin-Artieda, A.S. Whittaker and M.C. Constantinou, 6/7/07 (PB2008-105191).

MCEER-07-0010 "Proceedings of the PRC-US Earthquake Engineering Forum for Young Researchers," Edited by G.C. Lee and X.Z. Qi, 6/8/07 (PB2008-500058).

MCEER-07-0011 "Design Recommendations for Perforated Steel Plate Shear Walls," by R. Purba and M. Bruneau, 6/18/07, (PB2008-105192).

MCEER-07-0012 "Performance of Seismic Isolation Hardware Under Service and Seismic Loading," by M.C. Constantinou, A.S. Whittaker, Y. Kalpakidis, D.M. Fenz and G.P. Warn, 8/27/07, (PB2008-105193).

MCEER-07-0013 "Experimental Evaluation of the Seismic Performance of Hospital Piping Subassemblies," by E.R. Goodwin, E. Maragakis and A.M. Itani, 9/4/07, (PB2008-105194).

MCEER-07-0014 "A Simulation Model of Urban Disaster Recovery and Resilience: Implementation for the 1994 Northridge Earthquake," by S. Miles and S.E. Chang, 9/7/07, (PB2008-106426).

MCEER-07-0015 "Statistical and Mechanistic Fragility Analysis of Concrete Bridges," by M. Shinozuka, S. Banerjee and S-H. Kim, 9/10/07, (PB2008-106427).

MCEER-07-0016 "Three-Dimensional Modeling of Inelastic Buckling in Frame Structures," by M. Schachter and AM. Reinhorn, 9/13/07, (PB2008-108125).

MCEER-07-0017 "Modeling of Seismic Wave Scattering on Pile Groups and Caissons," by I. Po Lam, H. Law and C.T. Yang, 9/17/07 (PB2008-108150).

MCEER-07-0018 "Bridge Foundations: Modeling Large Pile Groups and Caissons for Seismic Design," by I. Po Lam, H. Law and G.R. Martin (Coordinating Author), 12/1/07 (PB2008-111190).

MCEER-07-0019 "Principles and Performance of Roller Seismic Isolation Bearings for Highway Bridges," by G.C. Lee, Y.C. Ou, Z. Liang, T.C. Niu and J. Song, 12/10/07 (PB2009-110466).

MCEER-07-0020 "Centrifuge Modeling of Permeability and Pinning Reinforcement Effects on Pile Response to Lateral Spreading," by L.L Gonzalez-Lagos, T. Abdoun and R. Dobry, 12/10/07 (PB2008-111191).

MCEER-07-0021 "Damage to the Highway System from the Pisco, Perú Earthquake of August 15, 2007," by J.S. O'Connor, L. Mesa and M. Nykamp, 12/10/07, (PB2008-108126).

MCEER-07-0022 "Experimental Seismic Performance Evaluation of Isolation/Restraint Systems for Mechanical Equipment – Part 2: Light Equipment Study," by S. Fathali and A. Filiatrault, 12/13/07 (PB2008-111192).

MCEER-07-0023 "Fragility Considerations in Highway Bridge Design," by M. Shinozuka, S. Banerjee and S.H. Kim, 12/14/07 (PB2008-111193).

MCEER-07-0024 "Performance Estimates for Seismically Isolated Bridges," by G.P. Warn and A.S. Whittaker, 12/30/07 (PB2008-112230).

MCEER-08-0001 "Seismic Performance of Steel Girder Bridge Superstructures with Conventional Cross Frames," by L.P. Carden, A.M. Itani and I.G. Buckle, 1/7/08, (PB2008-112231).

MCEER-08-0002 "Seismic Performance of Steel Girder Bridge Superstructures with Ductile End Cross Frames with Seismic Isolators," by L.P. Carden, A.M. Itani and I.G. Buckle, 1/7/08 (PB2008-112232).

MCEER-08-0003 "Analytical and Experimental Investigation of a Controlled Rocking Approach for Seismic Protection of Bridge Steel Truss Piers," by M. Pollino and M. Bruneau, 1/21/08 (PB2008-112233).

MCEER-08-0004 "Linking Lifeline Infrastructure Performance and Community Disaster Resilience: Models and Multi-Stakeholder Processes," by S.E. Chang, C. Pasion, K. Tatebe and R. Ahmad, 3/3/08 (PB2008-112234).

MCEER-08-0005 "Modal Analysis of Generally Damped Linear Structures Subjected to Seismic Excitations," by J. Song, Y-L. Chu, Z. Liang and G.C. Lee, 3/4/08 (PB2009-102311).

MCEER-08-0006 "System Performance Under Multi-Hazard Environments," by C. Kafali and M. Grigoriu, 3/4/08 (PB2008-112235).

MCEER-08-0007 "Mechanical Behavior of Multi-Spherical Sliding Bearings," by D.M. Fenz and M.C. Constantinou, 3/6/08 (PB2008-112236).

MCEER-08-0008 "Post-Earthquake Restoration of the Los Angeles Water Supply System," by T.H.P. Tabucchi and R.A. Davidson, 3/7/08 (PB2008-112237).

MCEER-08-0009 "Fragility Analysis of Water Supply Systems," by A. Jacobson and M. Grigoriu, 3/10/08 (PB2009-105545).

MCEER-08-0010 "Experimental Investigation of Full-Scale Two-Story Steel Plate Shear Walls with Reduced Beam Section Connections," by B. Qu, M. Bruneau, C-H. Lin and K-C. Tsai, 3/17/08 (PB2009-106368).

MCEER-08-0011 "Seismic Evaluation and Rehabilitation of Critical Components of Electrical Power Systems," S. Ersoy, B. Feizi, A. Ashrafi and M. Ala Saadeghvaziri, 3/17/08 (PB2009-105546).

MCEER-08-0012 "Seismic Behavior and Design of Boundary Frame Members of Steel Plate Shear Walls," by B. Qu and M. Bruneau, 4/26/08 . (PB2009-106744).

MCEER-08-0013 "Development and Appraisal of a Numerical Cyclic Loading Protocol for Quantifying Building System Performance," by A. Filiatrault, A. Wanitkorkul and M. Constantinou, 4/27/08 (PB2009-107906).

MCEER-08-0014 "Structural and Nonstructural Earthquake Design: The Challenge of Integrating Specialty Areas in Designing Complex, Critical Facilities," by W.J. Petak and D.J. Alesch, 4/30/08 (PB2009-107907).

MCEER-08-0015 "Seismic Performance Evaluation of Water Systems," by Y. Wang and T.D. O'Rourke, 5/5/08 (PB2009-107908).

MCEER-08-0016 "Seismic Response Modeling of Water Supply Systems," by P. Shi and T.D. O'Rourke, 5/5/08 (PB2009-107910).

MCEER-08-0017 "Numerical and Experimental Studies of Self-Centering Post-Tensioned Steel Frames," by D. Wang and A. Filiatrault, 5/12/08 (PB2009-110479).

MCEER-08-0018 "Development, Implementation and Verification of Dynamic Analysis Models for Multi-Spherical Sliding Bearings," by D.M. Fenz and M.C. Constantinou, 8/15/08 (PB2009-107911).

MCEER-08-0019 "Performance Assessment of Conventional and Base Isolated Nuclear Power Plants for Earthquake Blast Loadings," by Y.N. Huang, A.S. Whittaker and N. Luco, 10/28/08 (PB2009-107912).

MCEER-08-0020 “Remote Sensing for Resilient Multi-Hazard Disaster Response – Volume I: Introduction to Damage Assessment Methodologies,” by B.J. Adams and R.T. Eguchi, 11/17/08 (PB2010-102695).

MCEER-08-0021 “Remote Sensing for Resilient Multi-Hazard Disaster Response – Volume II: Counting the Number of Collapsed Buildings Using an Object-Oriented Analysis: Case Study of the 2003 Bam Earthquake,” by L. Gusella, C.K. Huyck and B.J. Adams, 11/17/08 (PB2010-100925).

MCEER-08-0022 “Remote Sensing for Resilient Multi-Hazard Disaster Response – Volume III: Multi-Sensor Image Fusion Techniques for Robust Neighborhood-Scale Urban Damage Assessment,” by B.J. Adams and A. McMillan, 11/17/08 (PB2010-100926).

MCEER-08-0023 “Remote Sensing for Resilient Multi-Hazard Disaster Response – Volume IV: A Study of Multi-Temporal and Multi-Resolution SAR Imagery for Post-Katrina Flood Monitoring in New Orleans,” by A. McMillan, J.G. Morley, B.J. Adams and S. Chesworth, 11/17/08 (PB2010-100927).

MCEER-08-0024 “Remote Sensing for Resilient Multi-Hazard Disaster Response – Volume V: Integration of Remote Sensing Imagery and VIEWS^{TM} Field Data for Post-Hurricane Charley Building Damage Assessment,” by J.A. Womble, K. Mehta and B.J. Adams, 11/17/08 (PB2009-115532).

MCEER-08-0025 “Building Inventory Compilation for Disaster Management: Application of Remote Sensing and Statistical Modeling,” by P. Sarabandi, A.S. Kiremidjian, R.T. Eguchi and B. J. Adams, 11/20/08 (PB2009-110484).

MCEER-08-0026 “New Experimental Capabilities and Loading Protocols for Seismic Qualification and Fragility Assessment of Nonstructural Systems,” by R. Retamales, G. Mosqueda, A. Filiatrault and A. Reinhorn, 11/24/08 (PB2009-110485).

MCEER-08-0027 “Effects of Heating and Load History on the Behavior of Lead-Rubber Bearings,” by I.V. Kalpakidis and M.C. Constantinou, 12/1/08 (PB2009-115533).

MCEER-08-0028 “Experimental and Analytical Investigation of Blast Performance of Seismically Resistant Bridge Piers,” by S.Fujikura and M. Bruneau, 12/8/08 (PB2009-115534).

MCEER-08-0029 “Evolutionary Methodology for Aseismic Decision Support,” by Y. Hu and G. Dargush, 12/15/08.

MCEER-08-0030 “Development of a Steel Plate Shear Wall Bridge Pier System Conceived from a Multi-Hazard Perspective,” by D. Keller and M. Bruneau, 12/19/08 (PB2010-102696).

MCEER-09-0001 “Modal Analysis of Arbitrarily Damped Three-Dimensional Linear Structures Subjected to Seismic Excitations,” by Y.L. Chu, J. Song and G.C. Lee, 1/31/09 (PB2010-100922).

MCEER-09-0002 “Air-Blast Effects on Structural Shapes,” by G. Ballantyne, A.S. Whittaker, A.J. Aref and G.F. Dargush, 2/2/09 (PB2010-102697).

MCEER-09-0003 “Water Supply Performance During Earthquakes and Extreme Events,” by A.L. Bonneau and T.D. O’Rourke, 2/16/09 (PB2010-100923).

MCEER-09-0004 “Generalized Linear (Mixed) Models of Post-Earthquake Ignitions,” by R.A. Davidson, 7/20/09 (PB2010-102698).

MCEER-09-0005 “Seismic Testing of a Full-Scale Two-Story Light-Frame Wood Building: NEESWood Benchmark Test,” by I.P. Christovasilis, A. Filiatrault and A. Wanitkorkul, 7/22/09.

MCEER-09-0006 “IDARC2D Version 7.0: A Program for the Inelastic Damage Analysis of Structures,” by A.M. Reinhorn, H. Roh, M. Sivaselvan, S.K. Kunnath, R.E. Valles, A. Madan, C. Li, R. Lobo and Y.J. Park, 7/28/09 (PB2010-103199).

MCEER-09-0007 “Enhancements to Hospital Resiliency: Improving Emergency Planning for and Response to Hurricanes,” by D.B. Hess and L.A. Arendt, 7/30/09 (PB2010-100924).

MCEER-09-0008 "Assessment of Base-Isolated Nuclear Structures for Design and Beyond-Design Basis Earthquake Shaking," by Y.N. Huang, A.S. Whittaker, R.P. Kennedy and R.L. Mayes, 8/20/09 (PB2010-102699).

MCEER-09-0009 "Quantification of Disaster Resilience of Health Care Facilities," by G.P. Cimellaro, C. Fumo, A.M Reinhorn and M. Bruneau, 9/14/09.

MCEER-09-0010 "Performance-Based Assessment and Design of Squat Reinforced Concrete Shear Walls," by C.K. Gulec and A.S. Whittaker, 9/15/09 (PB2010-102700).

MCEER-09-0011 "Proceedings of the Fourth US-Taiwan Bridge Engineering Workshop," edited by W.P. Yen, J.J. Shen, T.M. Lee and R.B. Zheng, 10/27/09 (PB2010-500009).

MCEER-09-0012 "Proceedings of the Special International Workshop on Seismic Connection Details for Segmental Bridge Construction," edited by W. Phillip Yen and George C. Lee, 12/21/09.

MCEER-10-0001 "Direct Displacement Procedure for Performance-Based Seismic Design of Multistory Woodframe Structures," by W. Pang and D. Rosowsky, 4/26/10.

MCEER-10-0002 "Simplified Direct Displacement Design of Six-Story NEESWood Capstone Building and Pre-Test Seismic Performance Assessment," by W. Pang, D. Rosowsky, J. van de Lindt and S. Pei, 5/28/10.

MCEER-10-0003 "Integration of Seismic Protection Systems in Performance-Based Seismic Design of Woodframed Structures," by J.K. Shinde and M.D. Symans, 6/18/10.

MCEER-10-0004 "Modeling and Seismic Evaluation of Nonstructural Components: Testing Frame for Experimental Evaluation of Suspended Ceiling Systems," by A.M. Reinhorn, K.P. Ryu and G. Maddaloni, 6/30/10.

MCEER-10-0005 "Analytical Development and Experimental Validation of a Structural-Fuse Bridge Pier Concept," by S. El-Bahey and M. Bruneau, 10/1/10.

MCEER-10-0006 "A Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework," by C.S. Renschler, A.E. Frazier, L.A. Arendt, G.P. Cimellaro, A.M. Reinhorn and M. Bruneau, 10/8/10.

MCEER-10-0007 "Impact of Horizontal Boundary Elements Design on Seismic Behavior of Steel Plate Shear Walls," by R. Purba and M. Bruneau, 11/14/10.

MCEER-10-0008 "Seismic Testing of a Full-Scale Mid-Rise Building: The NEESWood Capstone Test," by S. Pei, J.W. van de Lindt, S.E. Pryor, H. Shimizu, H. Isoda and D.R. Rammer, 12/1/10.

MCEER-10-0009 "Modeling the Effects of Detonations of High Explosives to Inform Blast-Resistant Design," by P. Sherkar, A.S. Whittaker and A.J. Aref, 12/1/10.

MCEER-10-0010 "L'Aquila Earthquake of April 6, 2009 in Italy: Rebuilding a Resilient City to Multiple Hazards," by G.P. Cimellaro, I.P. Christovasilis, A.M. Reinhorn, A. De Stefano and T. Kirova, 12/29/10.

MCEER-11-0001 "Numerical and Experimental Investigation of the Seismic Response of Light-Frame Wood Structures," by I.P. Christovasilis and A. Filiatrault, 8/8/11.

MCEER-11-0002 "Seismic Design and Analysis of Precast Segmental Concrete Bridge Model," by M. Anagnostopoulou, A. Filiatrault, and A. Aref, 9/15/11.

MCEER-11-0003 'Proceedings of the Workshop on Improving Earthquake Response of Substation Equipment," Edited by A.M. Reinhorn, 9/19/11.

MCEER

EARTHQUAKE ENGINEERING TO EXTREME EVENTS

University at Buffalo, The State University of New York
Red Jacket Quadrangle ▪ Buffalo, New York 14261
Phone: (716) 645-3391 ▪ Fax: (716) 645-3399
E-mail: *mceer@buffalo.edu* ▪ WWW Site *http://mceer.buffalo.edu*

University at Buffalo *The State University of New York*

ISSN 1520-295X