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Applicability of Nonlinear Multiple-Degree-of-Freedom Modeling for Design

Supporting Documentation

NEHRP Consultants Joint Venture

A Partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering

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NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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Prepared for
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Gaithersburg, Maryland

By
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Consortium of Universities for Research in Earthquake Engineering

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Gary Locke, Secretary

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Preface - Supporting Documentation

The NEHRP Consultants Joint Venture is a partnership between the Applied Technology Council (ATC) and the Consortium of Universities for Research in Earthquake Engineering (CUREE). In 2007, the National Institute of Standards and Technology (NIST) awarded the NEHRP Consultants Joint Venture a National Earthquake Hazards Reduction Program (NEHRP) "Earthquake Structural and Engineering Research" task order contract (SB1341-07-CQ-0019) to conduct a variety of tasks. In 2008, NIST initiated Task Order 68241 entitled "Improved Nonlinear Static Seismic Analysis Procedures – Multiple-Degree-of-Freedom Modeling." The purpose of this project was to conduct further studies on multiple-degree-of-freedom effects as outlined in the Federal Emergency Management Agency (FEMA) report, FEMA 440, *Improvement of Nonlinear Static Seismic Analysis Procedures* (FEMA, 2005).

The FEMA 440 Report concluded that current nonlinear static analysis procedures, which are based on single-degree-of-freedom (SDOF) models, are limited in their ability to capture the complex behavior of structures that experience multiple-degree-of-freedom (MDOF) response, and that improved nonlinear analysis techniques to more reliably address MDOF effects were needed. In response to this need, work on this project included a detailed review of recent research on nonlinear MDOF modeling and the conduct of focused analytical studies to fill gaps in available information. The objective of this work was to improve nonlinear MDOF modeling for structural design practice by providing guidance on: (1) the minimum level of MDOF model sophistication necessary to make performance-based engineering decisions; (2) selection of appropriate nonlinear analysis methods; and (3) possible new analytical approaches. Summary findings, conclusions, and recommendations from this work are contained in the main volume report, *Applicability of Nonlinear Multiple-Degree-of-Freedom Modeling for Design*. This volume, *Supporting Documentation*, contains appendices that provide detailed reporting on the focused analytical studies, ancillary studies, and literature review activities that formed the basis of the findings.

The NEHRP Consultants Joint Venture is indebted to the leadership of Mike Valley, Project Director, and to the members of the Project Technical Committee, consisting of Mark Aschheim, Craig Comartin, William Holmes, Helmut Krawinkler, and Mark Sinclair, for their significant contributions in the development of this report and the resulting recommendations. Focused analytical studies were led by Mark Aschheim and Helmut Krawinkler and conducted by Michalis Fragiadakis, Dimitrios Lignos, Chris Putman, and Dimitrios Vamvatsikos. Technical review and comment at key developmental stages on the project were provided by the Project Review Panel consisting of Michael Constantinou, Jerry Hajjar, Joe Maffei, Jack Moehle, Farzad Naeim, and Michael Willford. The names and affiliations of all who contributed to this project are included in the list of Project Participants at the end of this report.

NEHRP Consultants Joint Venture also gratefully acknowledges Jack Hayes (Director, NEHRP) and Kevin Wong (NIST Technical Monitor) for their input and guidance in the preparation of this report and Ayse Hortacsu and Peter N. Mork for ATC report production services.

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