2009 BFRL Project Description

Project Title: Improved Structural Response Modification Factors for Seismic Design of New Buildings - Phase I

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BFRL Program: Measurement Science for Disaster-Resilient Structures and Communities: Earthquake Risk Mitigation R&D Program

Objective: To develop an advanced measurement science framework for developing improved structural response modification factors (R, C_d, Ω_o) for seismic design of new buildings.

Problem:

What is the problem? System response modification factors (R, C_d, Ω_o) for design of new buildings are fundamental to prescriptive seismic design provisions found in modern building codes (*e.g.*, ASCE 7[1]). They characterize the available ductility, damping, redundancy, and reserve strength for each seismic force-resisting system (SFRS). These factors were introduced ATC 3-06[2] in 1978 and initially implemented in *NEHRP Recommended Provisions*[3] in 1985. They were formulated by committee consensus coupled with calibration with building code parameters then in use in California.

In 1995, ATC 19[4] provided a critical review of system R factors, concluding that there is no mathematical basis for these response modification factors and that values currently assigned to R for different framing system will probably not result in uniform levels of risk for all buildings. The report further concluded that, to ensure consistent levels of damage, values for R should depend on the fundamental period of a building, the soil type on which it is founded, and the seismic zone in which it is located. The latter dependence is because the reserve strength in a framing system will probably be a function of the ratio of its gravity loads to its seismic loads and detailing requirements (which vary by zone).

More recently, the ATC-63 project produced FEMA P695[5], which outlines a methodology to quantify appropriate response factors for new SFRS's, with the ultimate goal of incorporation into ASCE 7. Methodological examples are illustrated for a few existing structural building systems. The results of this project indicated that the currently specified response factors for the

[1] *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-05, American Society of Civil Engineers, 2006.
[2] *Tentative Provisions for the Development of Seismic Regulations for Buildings*, ATC 3-06, Applied Technology Council, 1978.
[3] *NEHRP Recommend Provisions for Seismic Regulations for New Buildings and Other Structures*, Building Seismic Safety Council, 1985.
[4] *Structural Response Modification Factors*, ATC 19, Applied Technology Council, 1995.
[5] *Quantification of Building Seismic Performance Factors (90% Draft)* – FEMA P695, Federal Emergency Management Agency, April 2008.

tested systems are satisfactory in producing a system to achieve the intended seismic response at the collapse performance level. However, results indicate that the tested systems do not achieve a uniform level of risk at the intended performance level. FEMA P695 does not provide a methodology to determine the variation in modification factors as a function of period, ductility, seismic design category, or occupancy category.

Through the NEHRP Consultant Joint Venture, NIST recently funded ATC 76 – Tasks 1 and 4 to provide beta testing of the FEMA P695 methodology for several addition SFRS's. Results from this study indicate that certain systems with specific geometrical attributes achieve the intended performance, while others do not. Additionally, results were strongly associated with the analysis methodology used in design (i.e., equivalent lateral force and modal response spectrum). Similar to ATC 63 results, the test frames did not exhibit uniform levels of risk for the intended performance level.

These project results indicate that an improved response modification factor quantification methodology is needed that provides a uniform level of risk for all building systems. To adapt the methodology developed in FEMA P695 for this purpose, a systematic evaluation of the uncertainty and reliability of the method is needed, and a parametric study is needed to ascertain the requisite design parameters used to formulate improved response factors (*i.e.*, fundamental period, ductility, seismic design category, etc.). Such a study can move the current prescriptive procedures in building codes to be more closely aligned with more rigorous performance-based seismic design (PBSD).

Why is it hard to solve? Building seismic performance is strongly associated with the adopted response modification factors. They are used to determine the design forces targeted to the initiation of yielding so that a linear analysis can be used for design. As such, these factors link expected inelastic response to that at the elastic design level. Dynamic response of buildings to strong motion, as well as localized geotechnical conditions, is complex and changes significantly as earthquake intensities (and accompanying nonlinear behavior) increase, thus increasing the difficulty of coupling ultimate performance with first yield.

The methodology introduced in FEMA P695 introduces a means by which a uniform level of risk can be assigned and the response modification factors adjusted to achieve this risk. The reliability and uncertainties in this method must first be outlined so that a methodology can be developed to account for the various design parameters representing the vast design space of modern building structures. Development of improved response factors requires extensive computational expertise and time. Without an explicit, detailed research program, a comprehensive evaluation of improved factors cannot be accomplished.

How is it solved today, and by whom? This problem is not adequately solved today, as current design provisions use essentially the same response factors developed in ATC 3-06. Further, ATC 3-06 characterized only14 structural systems; ASCE 7-05 now lists 88 systems. Many of the additional systems in ASCE 7 were simply adopted by assumed equivalence to existing systems, with no scientific formulation to support the adopted values. All of the previously mentioned reports indicate that the currently provided response modification factors do not achieve uniform levels of risk for different building types. Thus it is likely that a vast

majority of the 88 systems currently specified in ASCE 7 will have similar non-uniform performance.

Why NIST? This project supports the BFRL mission of promoting U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of the U.S. building industry in ways that enhance economic security and improve the quality of life. It further supports the BFRL core competency in performance, reliability, and resilience of structures and communities under extreme loads and fulfills a national knowledge transfer role that is not well-supported by a fragmented U.S. construction industry.

Project results will be incorporated into modern building codes, standards, and reference documents. This project supports all three NEHRP Strategic Goals[6] as well as two NEHRP Strategic Priorities[7]: development of advanced earthquake risk mitigation technologies and practices, and development of Performance-Based Seismic Engineering tools and provisions. NIST is required by statute (P.L. 108-360) to support NEHRP activities.

In providing applied research and knowledge transfer activity to foster the transfer of research results into building codes, standards, and guidelines, the project fulfills one of the NIST functions that are outlined in ATC-57[8] – problem-focused research and technical resources development to improve seismic engineering practice (guidelines and manuals development).

Approach:

What is the new technical idea? The project will be performed by the NEHRP Consultants Joint Venture and managed by NIST BFRL. The Joint Venture will perform the work as a task order under the Indefinite Delivery, Indefinite Quantity contract that was awarded by NIST in 2007. Several key new technological advances can now be combined to enable comprehensive research to be performed in developing improved response modification factors.

Existing model building code provisions (*e.g.*, ASCE 7) define the structural response modification factors in terms of single designated values for each of the 88 currently listed SFRS's. As mentioned above, studies have shown this single-valued approach to be inaccurate, resulting in non-uniform risk. This study will focus analytical studies on defining these factors in variable terms in ways that will facilitate uniform risk in the prescriptive seismic design process. This will ultimately bring performance-based design approaches more directly into the prescriptive design process.

Why can we succeed now? The availability of more extensive ground motion data and significantly more capable numerical modeling procedures will enable more extensive parametric studies of structural response than has before been possible. Research results will provide the foundation for translating current state-of-the-art research to the much-needed state-of-the-practice that can be used by the practicing engineers. The methodology presented in FEMA P695 has the potential to provide a methodology for improving the current modification factors based on a uniform level of risk.

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[6] *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009-2013*, October 2008.
[7] *Ibid*.
[8] *The Missing Piece: Improving Seismic Design and Construction Practices*, ATC 57, Applied Technology Council, 2003.

What is the research plan? This task order to the NEHRP Consultants Joint Venture will develop advanced analytical procedures for improving response modification factors to achieve a uniform level of risk – Phase I of an anticipate multi-phase effort to develop improved response modification factors (Phase II). The project will collect and disseminate existing analytical and experimental research results on response modification factors including FEMA P695; identify limitations in the existing information and needed analytical research to improve it; develop best-practices for modeling and testing improved response factors by synergizing results from the data collection with new analytical research; and develop guidelines so that improved response factors can be incorporated into modern standards, tools, and codes. It is anticipated that small analytical studies will be conducted to verify assumptions as well as outline limitations. Phase I will conclude with a public workshop to illustrate the proposed methodology, outline needed research, and gather industry and practitioner feedback, before release of a Phase I report.

A detailed Phase I research plan, including the names of all project participants, will be developed by the contractor during the task order proposal development. This project description will be revised at that time to reflect the additional detail that will be provided.

Standards and Codes: The expected project outcome is a set of practice guidelines and tools that can be used by researchers and code committees to improve current response modification factors so that a uniform level of risk is achieved across all building systems. The anticipated cooperation with FEMA, as well NIST's direct involvement in standard and code development, direct linkage to the private codes and standards agencies (primarily ASCE 7) is ensured.