2009 BFRL Project Description

Project Title: Assessment of ASCE 41 First Generation Performance-Based Seismic Design Methods for New Buildings in High-Seismic Regions – Phases I - III

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

Objective: To benchmark current Performance-Based Seismic Design (PBSD) methodologies by assessing ASCE 41[1] first generation PBSD procedures for new buildings in high-seismic regions and analyze unresolved inconsistencies in predicted seismic performance using those procedures.

Problem:

What is the problem? Prescriptive building code procedures, such as those found in ASCE 7[2], for new construction in high seismic regions often restrict design innovation, leading to inefficient structural designs and higher construction costs. ASCE 7 allows alternative "rational" design methods, such as performance-based seismic design (PBSD), to be used for new construction in lieu of its prescriptive provisions. However, ASCE 7 provides no substantial guidance on implementing the rational methods. The use of such methods (*e.g.*, PBSD) must be approved by the local authority having jurisdiction and typically requires substantial evidence that the design satisfies the required seismic performance. PBSD applied to *new* construction is premised philosophically on permitting non-prescriptive design, providing the engineer design freedom to bypass specific building code limitations to achieve enhanced seismic performance, if performance is validated by rigorous structural analysis. To implement PBSD in their design of new buildings, many practitioners attempt to adapt ASCE 41 analysis procedures, which have historically been used for evaluating the performance of *existing* buildings by assessing performance compliance with selected rehabilitation objectives – considered to be "first generation PBSD."

In addition to the actual analysis techniques, the ASCE 41 procedures require that building performance levels be established and quantified for use as benchmarks in the analyses. The IEBC[3] contains a table to correlate ASCE 41 performance levels with ASCE 7 Occupancy Categories. However, this chart has not been comprehensively validated. Recently, the ASCE 7

[1] *Seismic Rehabilitation of Existing Buildings*, ASCE/SEI 41-06, American Society of Civil Engineers, 2007
[2] *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-05, American Society of Civil Engineers, 2006.
[3] *International Existing Building Code*, IEBC, International Code Council, Washington, D.C., 2006.

Seismic Subcommittee rejected a proposal for ASCE 7-10 to adopt a similar chart, because of the lack of validation.

In June 2008, NEHRP sponsored a PBSD workshop for leading practitioners and researchers from around the U.S. to develop a comprehensive list of research needs to foster full development and implementation of PBSD, from which the Building Seismic Safety Council (BSSC) reported a prioritized list of key PBSD research and implementation needs[4]. In this listing of needed research efforts, *the highest priority need is to "benchmark" current PBSD methodologies*. Two conclusions from the workshop were that ASCE 41 procedures are currently perceived to be conservative and that a uniform level of confidence in the PBSD methods now used by various leading practitioners has not been achieved, primarily because no systematic effort has been undertaken to critically examine predicted performance.

Why is it hard to solve? Calibration of performance levels and earthquake hazard levels to qualitative and quantitative definitions that account for risk, economic loss, and operational interruption is difficult. Dynamic response of buildings to strong motion is complex and changes significantly as earthquake intensities (and accompanying nonlinear behavior) increase, thus increasing the difficulty of coupling performance level with earthquake hazard.

Development of PBSD guidelines and evaluation of predicted performance requires extensive computational expertise and time. Without an explicit, detailed research program, a comprehensive evaluation of existing and new techniques cannot be undertaken.

How is it solved today, and by whom? Today, practitioners and jurisdictional code officials are implementing building code clauses that permit advanced "rational" analysis and design techniques in lieu of prescriptive provisions. These rational methods often reference ASCE 41 for component and material strengths, and deformation capacities. As discussed previously, a uniform level of confidence has not been achieved with this method.

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[5] as well as two NEHRP Strategic Priorities[6]: 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.

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[4] *Research Required to Support Full Implementation of Performance-Based Seismic Design*, NIST GCR 09-917-2, National Institute of Standards and Technology, 2009.
[5] *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009-2013*, October 2008.
[6] *Ibid*.

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[7] – problem-focused research and technical resources development to improve seismic engineering practice (guidelines and manuals development).

BFRL also maintains a comprehensive FEA capability, as well as software packages common to commercial design firms. This competence is required in order to predict, with acceptable confidence, the performance of a structure under strong ground motions, and provide the continuum to provide appropriate standards for implementation in a commercial design firm.

Approach:

What is the new technical idea? The project will benchmark current PBSD methodologies by assessing ASCE 41 first generation procedures for new buildings in high-seismic regions and analyzing unresolved inconsistencies in predicted seismic performance using those procedures. BFRL engineers will design and analyze a number of structurally regular[8] buildings of varying numbers of stories. The designs will use recognized design procedures (i.e., ASCE 7-05) for new buildings in areas of high seismicity. The buildings designed in this manner will then be subjected to evaluation using the ASCE 41 procedures now being used by practitioners, using high-end nonlinear finite element analysis – see the Research Plan below.

Several key planned outcomes of this project are to: correlate deterministic performance objectives specified for existing buildings in ASCE 41 with objectives implied in ASCE 7; correlate ASCE 41 component-level performance criteria (*e.g.*, plastic hinges in moment frames) with the global performance of a building as a whole; quantify implied target building performance levels (*e.g.*, Immediate Occupancy, Life Safety, and Collapse Prevention), given the deterministic acceptance criteria of ASCE 41; and, correlate the results of the four ASCE 41 analysis methods with each other and with actual documented performance data.

An extramural peer review team consisting of leading practitioners and researchers who are already engaged in project peer reviews will be retained under task order arrangements with the NEHRP Consultants Joint Venture. The peer review team will also assist in scoping and refining reliability studies of analysis results, to correlate ASCE 41 Performance Levels with ASCE 7 Occupancy Categories.

The project has the added benefit of providing at its completion a series of peer-reviewed archetypal building designs that can be used by BFRL in future analytical research projects that support other aspects of PBSD.

Why can we succeed now? Commercial design firms are currently implementing first generation PBSD practices for new construction based on ASCE 41. Conducting this project now can accelerate PBSD knowledge transfer to the design community and provide the necessary resolutions to unresolved inconsistencies. This project can succeed because of the inherent

[7] *The Missing Piece: Improving Seismic Design and Construction Practices,* ATC 57, Applied Technology Council, 2003.
[8] Regular buildings are defined here as buildings whose seismic force-resisting systems (SFRS) do not contain any horizontal or vertical irregularities as defined in modern seismic code provisions (*e.g.*, ASCE 7-05).

capacity of the NEHRP Consultants Joint Venture to provide nationally prominent structural engineers who are already engaged in project peer reviews.

What is the research plan? A design space consisting of five building system types will be utilized, similar to that used in FEMA P695[9] (ATC-63 Project). Over a period of time, BFRL will assess the design space, which is shown in Table 1. The project will be divided into five phases with each phase representing one seismic force-resisting system (SFRS) type, as listed in Table 1. To provide adequate detail and results, each phase will result in a single published outcome covering design, analysis, analytical results, comparison to reference performance, and any inconsistencies with the four methods. Expected completion dates of the five phases are given in Table 1.

Each SFRS type will have several designs for varying heights, to capture the effects of higher response modes, P-Delta influence, and degree of concentrated inelastic regions. Each SFRS will be designed in accordance with the provisions of ASCE 7-05.

Each SFRS will be modeled in detail, including material and geometric nonlinearities, in LS-DYNA, or an equivalent nonlinear finite element analysis program. The systems will be evaluated by each of the four methods developed in ASCE 41 to judge compliance with predefined seismic performance objectives. The seismic performance objectives will consist of the following four earthquake levels associated with the *Basic Safety Objective* (BSO): *Operational* – 50% probability of being exceeded in 50 years; *Immediate Occupancy* (IO) – 20% probability of being exceeded in 50 years; *Life Safety* (LS) – 10% probability of being exceeded in 50 years; and, *Collapse Prevention*(CP) – 2% probability of being exceeded in 50 years.

Forty earthquake records from the Pacific Earthquake Engineering Research (PEER) Strong Motion Database will be selected for the dynamic analyses – twenty far-field records (distance from site > 5 km) and twenty near-fault records (distance from site ≤ 5 km). Response histories will be selected for each earthquake intensity following rules and restrictions defined in FEMA P695, with specific consideration given to source magnitude and peak ground acceleration and velocity. Response histories will be normalized to be compatible with the BSO. Scaling of records for evaluation at the CP limit state may follow the methodology used in FEMA P695. Scaling of records for lower performance limit states (*i.e.*, LS, IO) will be similar to that used in FEMA P695 but with some modification to represent variation in records at these limit states.

In support of the work at NIST, an extramural peer review team will be engaged through the NEHRP Consultants Joint Venture. External project funding specifically engages the peer review panel for Phase 1 through 3 only. The specialists selected will provide the requisite expertise in seismic hazard analysis, ground motion scaling for varying return periods, nonlinear dynamic analysis modeling, and structural behavior and design of steel building structures.

Further detailed project tasks will be outlined upon consultation with review panel members, and the Project Description will be updated at that time.

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[9] 90% Draft: *Quantification of Building Seismic Performance Factors,* FEMA P695, Federal Emergency Management Agency, 2008.

Table 1 Project design space.

Phase	Construction Material	SFRS Type	Stories	Expected Completion Date	SFRS Notes
I	Steel	Special Moment Frame	4, 8[3], 16, 32[1]	1/30/10	• Two 8-story frames will be designed: (1) lighter columns with doubler plates and (2) heavier columns with no doubler plates • All SMRFs will use non-composite RBS Beams except the 32-story
II		Special Concentrically Braced Frame[2]	4, 8[3], 16	04/30/10	• Chevron bracing will be used for the 4- and 8-story frame • Two 8-story frames will be designed: (1) using conventional braces and (2) using Buckling-Restrained Braces • Two-story X bracing will be used for the 16 story frame
III		Special Eccentrically Braced Frame[2]	4, 8[3], 16	09/30/10	• Two 8-story frames will be designed: (1) using short links and (2) using long links
IV	Reinforced Concrete	Special Moment Frame	4, 8, 16, 32[1]	03/30/11	TBD
V		Special Structural Wall[2]	4, 8, 16	08/30/11	TBD

Notes:
1. Will be considered as a part of a dual system
2. Height Limitation = 240 ft. (code requirements apply)
3. See Frame Notes

Standards and Codes: The project will be formulated to facilitate incorporating its products into future editions of ASCE 41 and ASCE 7, and if applicable, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, which will be the basis for future model building code advances.