1. SYSTEMS VISION/VALUE ADDED AND BROADER IMPACTS OF CENTER

1.1 Systems Vision

PEER Mission Statement

The PEER mission is to develop, validate, and disseminate performance-based seismic design technologies for buildings and infrastructure to meet the diverse economic and safety needs of owners and society.

The PEER mission is to develop and disseminate technologies to support performance-based earthquake engineering. The approach is aimed at improving decision-making about seismic risk by making the choice of performance goals and the tradeoffs that they entail apparent to facility owners and society at large. The approach has gained worldwide attention in the past ten years with the realization that urban earthquakes in developed countries – Loma Prieta, Northridge, and Kobe – impose substantial economic and societal risks above and beyond potential loss of life and injuries. By providing quantitative tools for characterizing and managing these risks, performance-based earthquake engineering serves to address diverse economic and safety needs.

There are three levels of decision-making that are served by enhanced technologies for performance-based earthquake engineering and that are focal points for PEER research. One level is that of owners or investors in individual facilities (i.e., a building, a bridge) who face decisions about risk management as influenced by the seismic integrity of a facility. PEER seeks to develop a rigorous PBEE methodology that will support informed decision-making about seismic design, retrofit, and financial management for individual facilities. A second level is that of owners, investors, or managers of a portfolio of buildings or facilities – a university or corporate campus, a highway transportation department, or a lifeline organization – for which decisions concern not only individual structures but also priorities among elements of that portfolio. PEER seeks to show how to use the rigorous PBEE methodology to support informed decision-making about setting priorities for seismic improvements within such systems by making clear tradeoffs among improved performance of elements of the system. A third level of decision-making is concerned with consideration of the societal impacts and regulatory choices relating to minimum performance standards for public and private facilities. PEER seeks to make technical contributions to development of performance-based codes and standards. The direct beneficiaries of more rigorous approaches to performance-based earthquake engineering are the owners, investors, and risk managers who face these decisions. All of us, of course, ultimately benefit from decisions about seismic risk that better address tradeoffs between costs of reducing risks and benefits of seismic improvements.

The clients for PEER advances in PBEE technologies are members of the engineering profession as broadly defined. Performance-based earthquake engineering is bringing about a change in the profession that alters both the role of earthquake engineers (broadening their involvement as consultants for management of earthquake risks) and the demands placed on the profession (changing the methods of risk evaluation, design, and engineering). PEER is working hand-in-hand with business and industry partners to understand how advances in PBEE affect engineering practice and the construction regulatory environment and to identify ways to lessen barriers to adoption and implementation of PBEE. In addition, PEER is very active in educating future generations of earthquake engineers and risk management professionals. As such, PEER seeks to make a major contribution to the development of the earthquake engineering profession.

Despite advances in recent years in the use of performance-based earthquake engineering, existing technologies and methods for PBEE fall short on a number of grounds. Methods for seismic design or evaluation that are currently in widespread use are much less scientific and direct than the rigorous approach that we are developing. Although response of structures to strong ground motions in most cases is expected to be nonlinear, earthquake hazard today is represented by design maps through relatively simplistic single-parameter quantities such as linear spectral response. Likewise, structural evaluation and design commonly use linear analysis adjusted by factors whose values are based on tradition, limited earthquake observations, and materials industry pressures. Furthermore, engineering design and assessment generally focus on structural parameters and fail to quantify socio-economic parameters such as cost, downtime, and casualties. The result of this indirect and empirical approach is that seismic performance outcomes, as demonstrated in recent earthquakes, are highly variable and often at odds with stakeholder expectations.

Seismic design in a technologically advanced society should be more scientifically based. It should provide information on expected seismic performance, measurable in terms that are meaningful to those who need to make decisions about performance of an individual facility or of a network or campus of facilities, or about society in a broad context. And it should provide options for selecting optimal seismic performance to meet the diverse needs of owners and society.

To meet this objective, we have visualized the implementation of performance-based earthquake engineering as a process involving distinct and logically related steps, illustrated in Figure 1.1. (The description that follows emphasizes application to an individual facility for illustrative purposes.) The first step in the process is definition of performance objectives. Characteristically, this step might be viewed as defining what performance is acceptable over the life of the facility, or, alternatively, what loss is acceptable. The second step in the process is development of a design taking into consideration the multiple performance objectives that may affect the facility. The third step is an engineering evaluation in which seismic response and engineering performance measures are determined for the seismic hazard environment. The fourth step is socio-economic evaluation in which the engineering performance is translated to socio-economic measures. The assessment of seismic performance in socio-economic terms enables feedback to the first step, informing decisions about what performance objectives should be selected.

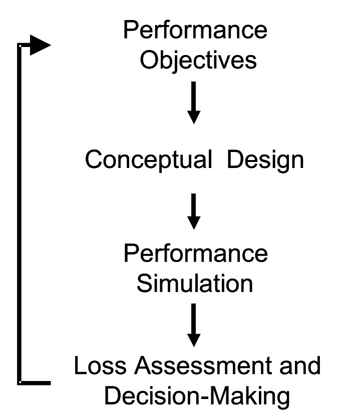

Figure 1.1 – Global Processes in the Implementation of Performance-Based Earthquake Engineering

A critical element of performance-based earthquake engineering is the need to integrate across disciplinary boundaries. The need for integration is illustrated qualitatively in Figure 1.2, which suggests the various phenomena or steps involved in a single analysis of a system for a single earthquake event. The steps are identified in the center of the diagram. These steps are organized around seismic hazard, performance simulation, and impact assessment on the left side. The right side of the figure identifies the traditional disciplinary contributions to the problem. The solution of the earthquake problem clearly is a multi-disciplinary endeavor.

The PEER programs in research, education, industry partnerships, and outreach are geared to producing the technology and human resources necessary to transition from current design methods to a performance-based design method. The primary goal is to produce and test through research the fundamental information and enabling technologies required for performance-based earthquake engineering. The Education Program promotes earthquake engineering awareness in the general public, and attracts and trains undergraduate and graduate students to conduct research and to implement research findings developed in the PEER program. The Business and Industry Partner Program involves earthquake professionals, relevant industry, and earthquake information users in PEER activities to ensure the utility of the research and to speed its implementation. The Outreach Program exposes the PEER activities and products to a broad audience including students, researchers, industry, and the general public.

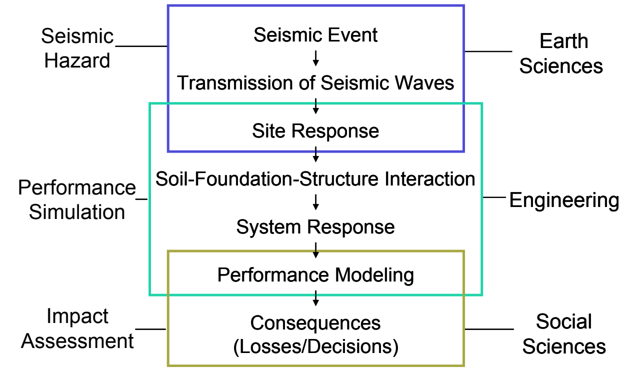

Figure 1.2 – Phenomena and steps involved in an analysis of a single system for a single seismic event

Ultimately, a PEER objective is to facilitate the development of practical guidelines and code provisions that will formalize performance-based earthquake engineering in practice, replacing some of the first-generation documents on this approach [e.g., FEMA 273, ATC 32, ATC 40, FEMA 354]. Because of the extensive research and technology transfer required, those developments will not be fully realized until toward Year 10 of the PEER program. However, the transition from current design and assessment approaches to performance-based approaches will occur continuously during the life of PEER. The process will be aided by the involvement of practicing earthquake professionals in our program, who will help guide and incorporate our research advances as they occur. The process will be further aided by high-level involvement of PEER key individuals in ongoing performance-based earthquake engineering development activities, especially the FEMA-funded ATC 58 project to develop performance-based seismic design guidelines. Thus, the PEER program will be of continual benefit to U.S. industry, the government, and the general public.

1.2 Value Added and Broader Impacts

PEER provides the opportunity for focused, long-term study to advance performance-based earthquake engineering. Although the basic concepts of performance-based earthquake engineering have existed previously, there has not previously been the opportunity to examine the performance metrics, the underpinning technologies, and the overall framework for implementation in professional practice. Examination of these broad issues requires a multi-disciplinary effort involving earth scientists, engineers, social scientists, and experts from other related disciplines. It also requires development of a framework that can link the different parts of the problem (seismic hazard, engineering demand analysis, performance assessment, and decision-making), consistently and systemically incorporating the uncertainties so that an overall statement on reliability can be made. Finally, it requires a longer-range vision so that the final methodology is not just an improvement in current methods but instead makes the major step in information and technology advancement necessary for realistic implementation of performance-based earthquake engineering. PEER is providing the focus, resources, vision, and professional and educational environment that make these things possible.

Participation in PEER has resulted in a genuine transformation in attitudes and outlook among PEER researchers who recognize and embrace the broader perspective that PEER promotes. The collaborative spirit and activities inspire creative thinking that one researcher or research group could not achieve in isolation. It is producing individual accomplishments in new areas and with outcomes that impact other research areas. The paragraphs that follow provide a sample of these accomplishments, with accomplishments from this last year marked with an asterisk* and ongoing projects marked with **.

1.2.1 Major accomplishments in knowledge advancement

- *A consistent framework for performance assessment* – PEER has established a performance assessment framework that improves understanding of the various elements of the earthquake performance problem and thereby fosters multi-disciplinary research. Importantly, the framework is bridging the gap between work done by engineers and social scientists in PEER as well as the gap between PEER researchers and earth scientists at the Southern California Earthquake Center (a Science and Technology Center). Another important outcome is the ability to develop performance metrics that are more relevant to decision-makers than are the measures widely used in engineering practice today. Within the new framework, losses are being expressed probabilistically in terms of casualties, dollars, and downtime. The framework forms a basis for decision-making for facilities, and will enable broad evaluation of the performance requirements for existing and innovative new technologies.
- *Geotechnical seismic site classification procedure* – A new geotechnical site classification procedure was developed to capture the pronounced effects of local ground conditions on earthquake shaking. The procedure results in a significant reduction in standard error when compared with a simpler "rock vs. soil" classification system. It is shown that sites previously grouped as "rock" should be subdivided as competent rock sites and weathered soft rock/shallow stiff soil sites. Soil depth also should be included in estimating seismic site response.*
- *Probabilistic assessment of soil liquefaction triggering* – Liquefaction is a phenomenon whereby soil deposits become a high-density liquid when subjected to earthquake shaking, potentially resulting in catastrophic foundation failures. Following a thorough examination of case histories including new field data from recent earthquakes, a new model for the likelihood liquefaction has been developed that greatly reduces predictive uncertainty.
- *Field test data and simulation of pier foundations* – In Northern California, drilled piers have been extensively used to provide the necessary resistance for dynamic uplift forces generated under seismic loading in multi-story structures. In a project co-funded by the UC Berkeley Office of Capital Projects, a set of dynamic axial tests was carried out on full-scale drilled piers. The tests have shown that the traditional approach significantly underestimated axial capacity of drilled piers; in this the test results translated directly into over $400,000 in savings. Most importantly, the methodology for dynamic testing of axial pier capacity, which was pioneered in this effort, is being incorporated by the consulting community into future projects.*

- *Analytical models of pile foundations* – PEER researchers have created and analyzed models of pile foundations in layered soils that will enable enhanced modeling of earthquake response of bridge construction. The models are being reviewed by Caltrans for incorporation in their new design guidelines. Potential cost-savings are significant, as foundation works are usually the most costly part of infrastructure development.*

- *Soil-foundation-structure interaction* – Using field performance data from seismically instrumented building sites, a new model for soil-foundation-structure interaction has been developed that removes a bias in previous models. The work led directly to revised building code provisions that were adopted as part of the Year 2000 NEHRP Provisions and Commentary.

- *Rocking response of rigid blocks* – Fundamental studies of the oscillatory response of rigid blocks is leading to new understanding of the behavior of building contents and equipment. It is found that existing procedures (which relate rocking response to the response of single-degree-of-freedom linear oscillators) are flawed. New rocking response spectra have emerged as a distinct, irreplaceable ground motion intensity measure that can be adopted by the profession as a valuable analysis and design tool.*

- *Regional damage from near-fault earthquakes* – In a joint study with researchers from Carnegie Mellon University and Mississippi State University, PEER researchers have completed an investigation of the spatial distribution of structural response over a large region when subjected to a strike-slip fault rupture. To accomplish this, nonlinear analytical models were positioned at 25,000 grid points on the surface of the approximately 10 km x 10 km region. Using a cluster of high-performance workstations, the OpenSees computational platform was used to demonstrate the directivity effects near the fault rupture zone. In additional to identifying important trends in building performance, the study introduces a new methodology, including visualization tools, for regional loss estimation and scenario planning.*

- *Procedures for estimating inelastic displacement response* – Studies of inelastic response to near-fault ground motions have shown that widely used displacement-estimation procedures require modification. The results of many projects were discussed in a PEER-organized international workshop (August 2001) whose aim partly was to influence directions of the FEMA-funded ATC-55 project on this subject. Proposed modifications being adopted by ATC 55 provide more accurate estimates of response and will have significant impact on design practice for assessment of existing hazardous buildings.*

- *Collapse models for reinforced concrete columns in existing buildings* – Experimental and analytical studies have led to improved models for shear strength and subsequent axial load collapse of reinforced concrete building columns typical of those used in older hazardous construction. These models are needed for seismic evaluation and rehabilitation of existing buildings. The proposed models and their impacts on engineering criteria have been adopted by the ASCE Standards Committee on Seismic Rehabilitation. The results also are widely implemented by PEER Business and Industry Partners.

- *Nisqually earthquake lessons* – In studying the 28 February 2001 Nisqually earthquake PEER researchers were able to expand understanding of socio-economic impacts of earthquakes. It was found that the effects on the economy are dominated by short-term business and other closures, rather than losses to the housing stock. Studies of decision-making by building owners and businesses about future attention to seismic issues provide important understanding of desired earthquake performance. Together these studies reinforce the importance of a robust PEER methodology for performance-based earthquake engineering that is able to address the varied types of earthquakes, varied impacts, and multiple sets of decision criteria that facility owners and others apply when making decisions about earthquake risks.*

- *Model of organizational decision processes related to mitigation investments* – Case-study research has led to development of a model of the heuristics and decision processes that many for-profit organizations rely on when making decisions about large investments to prevent losses. The results will be useful both to firms seeking to make the best possible decisions and to engineers seeking to communicate with firms about investments in earthquake mitigation.*

1.2.2 Major accomplishments in technology advancements

- *OpenSees* – The open source software framework OpenSees (Open System for Earthquake Engineering Simulation) has emerged as the most advanced and appropriate tool for seismic response simulation of structural and geotechnical systems. It enables probabilistic analysis of large and complex soil-foundation-structure systems based on state-of-the-art material and mechanical models for soils and structures, so that propagation of uncertainties can be represented in the performance assessment. This new level of understanding will form the basis for the next generation of performance-based seismic design practice that will result in safer and more economical civil structures. The flexible structure enables study of a broad range of problems; whereas the initial focus was on individual structures, a recent extension is simulating the regional distribution of damage using nonlinear response analyses of structures at 25,000 grid points in an epicentral region. Not counting the many PEER users, the OpenSees users group currently numbers over 240 individuals in the U.S. and international communities.*
- *Strong Motion Database* – The PEER Strong Motion Database has been expanded and improved, and now includes approximately 1,500 records from 143 events, which have been processed in a consistent manner. The database is web-enabled, allowing both researchers and practitioners to search and download records based on a broad variety of characteristics, including spectral quantities. In a recent expansion of the database, records from the recent Turkey and Taiwan events have been posted. This has significantly increased the number of large-magnitude records available from near-field stations. The database and search technology have found broad use in the research and practicing engineering communities.
- *Development of procedures for the rapid estimation of ground motions* – New methods are making it possible to automatically determine finite-source parameters of earthquakes such as the causative fault plane, length of fault, slip distribution, and rupture velocity. The approach makes use of regional broadband instrumentation to derive the source parameters; then, the source parameters are used to simulate near-fault ground motions for areas where there are no nearby recording instruments. This produces a much more detailed estimate of the distribution of ground motions, which is essential to characterizing the distributed shaking hazard to lifelines systems. This is an important contribution toward the objective

of near-real-time reporting of earthquake shaking hazard, and has been provided to ShakeMap V2.x software for wide use.*

- *Digital database of column performance* – PEER has developed an online database (*www.ce.washington.edu/~peera1*) that documents the performance of approximately 375 reinforced concrete columns during seismic tests. The database includes material and geometric properties, digital force-displacement histories, and performance (damage) indices. The database is being used widely in the US and abroad as a resource for performance model calibration.
- *Fragility models for reinforced concrete structures* – PEER has developed a comprehensive framework for developing probabilistic capacity and demand models for structural components and systems based on observational data. The framework uses Bayesian statistical techniques and properly accounts for all the prevailing uncertainties, including those arising from model imperfection, measurement errors, or statistical uncertainty due to small sample size. The technique can be applied to existing deterministic models to make them unbiased and to measure the associated uncertainty. The significance of this research is that it provides an objective framework for combining simplified models derived based on first principles with observational data to arrive at unbiased predictive models that are appropriate for performance-based design and loss estimation.
- *Probabilistically based engineering design and assessment methods* – PEER's performance-based design framework is leading to practical, probabilistically based design methods for engineers. One example is the load and resistance factor method adopted by FEMA for the evaluation of steel moment-resisting frames and by the draft ISO Standards for offshore structures. Yet another example is a new procedure to estimate yellow- and red-tag fragility curves for buildings (these tags are used to limit occupancy of damaged buildings following earthquakes; the procedure is built on the nonlinear static analysis used in practice and introduces the new fundamental concept that tagging should be based explicitly on the aftershock threat rather than on simply the damage state of the building. The procedure is undergoing testing on PG&E buildings by professional engineering firms this year. When implemented it will lead to more rational, risk-informed decisions to tag buildings after earthquakes.*

1.2.3 Major education and educational outreach accomplishments

- *Development of a PEER Student Community* – Over the past three years, our records show that students receiving PEER funding have earned over 60 BS degrees. We have found that once students are first introduced to the PEER Education Program, generally as interns, they will continue with involvement in other PEER programs. Many of our interns also participate in the Earthquake Engineering Scholars Course (EESC). Upon graduation, most EESC participants attend graduate school at one of our PEER Universities. One example of continued PEER involvement is Professor Tara Hutchinson, a new member of the PEER Education Committee. Before accepting a position as an Assistant Professor in UC Irvine's Department of Civil Engineering, she served as a member of the PEER Student Leadership Council while a graduate student at UC Davis.
- *Earthquake Engineering Scholars' Course* – Instituted in fall 1998 and continued annually thereafter, PEER's Earthquake Engineering Scholar's Course (EESC) has showcased the

graduate programs at PEER institutions and has each year introduced 30 handpicked undergraduate students to topics in the field of earthquake engineering including seismology, geotechnical earthquake engineering, structural dynamics, and public policy. The EESC is held during four weekend retreats at PEER core-university campuses, with each campus assigned one of the four topics. The EESC is intended for graduating seniors who have demonstrated a sincere interest in earthquake engineering or an earthquake-related field and who have achieved a high level of academic scholarship. Students value the unique opportunity to interact intellectually and socially with many faculty members and graduate students. The EESC has been successful in its objective to recruit new talent to the field of earthquake engineering as well as recruit students for each core university's graduate program. Most students who participated in the EESC over the past three years have gone on to pursue graduate study at a PEER institution.**

- *REU Earthquake Engineering Symposium for Young Researchers* – For the past three summers, PEER students have participated in the Earthquake Engineering Symposium for Young Researchers. This Tri-Center activity (with MAE and MCEER) provides students the opportunity to interact with their peers and see how earthquake engineering is perceived in other parts of the country. The undergraduate students who attend the Symposium present information about their ongoing research projects, and faculty who have attended the event have repeatedly remarked on the impressive caliber of the student presentations. Along with educational tours of earthquake-engineering sites of interest, the Symposium affords the Centers with a forum in which to ignite a formal discussion of Engineering Ethics among these young and enthusiastic students.**
- *Student Leadership Council* – Established in Year 3 of the PEER Center, the Student Leadership Council (SLC) and subsequent PEER Student Association (PSA) has formalized PEER's efforts to engage students in PEER's research, education programs, outreach, and management structure. Both undergraduate and graduate student representatives from each core and affiliated PEER campus serve as an active and valuable voice for all PEER students, providing feedback and input regarding PEER Education and Research programs. In Year 5 for the Third Annual PEER Student Day, the SLC organized a special meeting and poster session exclusively involving students and BIP members (no professors!), which gave PEER students a unique opportunity for one-on-one discussions with leading practitioners in earthquake engineering.**
- An example of PEER's outreach activities is a ***Learning with LEGO Program*** inspired by a campus initiative at UC Irvine, which in Year 5 brought over 500 K-12 students from socio-economically disadvantaged areas to the campus for an open house and shake-table demonstration in Spring 2002. The event was a competition among local elementary, middle, and high schools for the honor of having the best seismic designs. The LEGO structures were tested on one of PEER’s major earthquake simulators housed in the UCI Structural Engineering Test Hall. The event, which began in Year 3, is currently under the leadership of Tara Hutchinson, PEER Education Committee member from UC Irvine. The Education Committee is planning to expand this effort to other PEER campuses next year.**
- *Public Relations and Outreach Office* – Established in July of 2000, the Public Relations and Outreach Office has worked to improve the Center’s communication mechanisms and increase overall awareness of PEER. Accomplishments in the past year include the

launching of a reformatted and redesigned PEER newsletter, the PEER Annual meeting, and kicking-off a promotional campaign for the Ninth International Conference on Applications on Statistics and Probability in Civil Engineering, which PEER is co-sponsoring and organizing locally.**

- *Conference and Earthquake Information Display* – PEER has developed a conference exhibit displaying a content for a broadening audience. In 2001-2002, the exhibit was displayed at several events, including the Western States' Seismic Policy Council's (WSSPC) Annual Convention in Sacramento, the Earthquake Engineering Research Institute's Annual Meeting in Long Beach, the Structural Engineers Association of California's Annual Meeting in San Diego, and the Seventh National Conference on Earthquake Engineering (planned, July 2002), in Boston. The exhibit was also incorporated into earthquake information and preparedness displays, one at the California State Capitol in Sacramento, and another at UC Berkeley's annual open house Cal Day.**
- *Near-field earthquake effects* – PEER endeavors to increase knowledge and awareness of effects of near-field earthquakes on the built environment. In 1999, PEER organized and co-hosted an international Workshop on Effects of Near-Field Earthquake Shaking. More recently, and in cooperation with the United States Geological Survey, important near-field effects such as rupture directivity are being incorporated into an existing system (SHAKEMAP) for estimating ground motions in the first few minutes after an earthquake has occurred. This process provides important information on the likely distribution of strong shaking, even in areas that are sparsely instrumented, and will improve the effectiveness of emergency response.
- *PEER Annual Meeting* – Continuing a public meeting venue established in 2001, the 2002 PEER Annual meeting attracted over 250 representatives of industry, academia, and government. The theme for this year's meeting was "Advances in Performance-Based Earthquake Engineering" and the presentations of recent PEER research by leading practitioners included sessions with social science, structural, and geotechnical emphases. PEER Student Day was convened during Day One of the Annual Meeting, and afforded students and Business and Industry Partners the opportunity to present their research posters and results to one another.**
- *PEER-Sponsored Museum Exhibit on Earthquakes* – A multiyear project between PEER and the California Academy of Sciences to support the Academy's *Earthquakes!* exhibit continued during Year 5. The exhibit, which is visited by over 1 million people annually, focuses on earthquake preparedness and safety to help enable society and individuals live with and manage the risk of earthquakes. The Academy's facility in San Francisco is due to be closed for an extended period of time for seismic retrofitting in the near future, which has resulted in preliminary discussions with the Academy to migrate the exhibit to a graphical, user-driven CD-ROM application intended for a non-technical audience, which would demonstrate concepts of performance-based earthquake engineering.**